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Ground Water and Soil Contamination Remediation: Toward Compatible Science, Policy, and Public Perception

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Commission on Engineering and Technical Systems
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Preface

Since 1985, the Water Science and Technology Board has organized and hosted a colloquium series on emerging issues in water science and technology. These colloquia focus debate and attention on important issues identified by the board that might not otherwise receive adequate attention.

The board's fifth colloquium, held in Washington, D.C., on April 20-21, 1989, focused on how science influences policy and public perception where cleanup of ground water and soil contamination is concerned. It is not surprising that the public, press, and Congress are often unfamiliar with the scientific constraints involved in soil and ground water cleanup policy given the complex scientific questions underlying these issues. With this in mind, authors of the papers in this volume and other participants were invited not only for their technical knowledge concerning cleanup levels of contaminated soil and ground water, but also for their experience with public perception of such contamination issues and the statutes and laws that regulate how state and government agencies respond.

A steering committee of board members and others, working closely with WSTB staff, created and organized the colloquium program. Twelve papers were presented by recognized experts affiliated with federal and state regulatory agencies, environmental and public interest groups, private industry, consulting firms, universities, the U.S. Air Force, and law firms. The presenters (see Appendix A) included scientists and regulators involved in setting cleanup levels, as well as the affected parties.

Preparation of the papers was monitored carefully by the steering committee through the review of preliminary outlines and manuscripts in progress. For each scientifically oriented paper there is a corresponding paper that discusses policy and public perception. Following the presentation of each paper, there was a brief question-and-answer period so that the 68 attendees (see Appendix B) could participate in the debate.

The report has two major sections: an overview and the background papers by individual authors. The colloquium chairman, Richard A. Conway, and the steering committee prepared the overview based on review of the background papers and consideration of the presentations and discussion generated at the colloquium. The entire report has been reviewed by a group other than the authors, but only the overview has been subjected to the report review criteria established by the National Research Council's Report Review Committee. The issue papers have been reviewed for factual correctness.

The WSTB gratefully acknowledges the generous contributions of time and expertise of the colloquium participants. Special thanks are extended to those who made formal presentations.

Contents

Overview

The adage "pay me now, or pay me later" is painfully applicable to many aspects of our infrastructure and environment. Today, our nation seems acutely conscious of the links among human activities and the quality of our ground waters. Unfortunately, this has been so for less than two decades. Previously, many of our waste disposal and industrial practices were conducted with little recognition of their potential to cause contamination. The result is that a valuable resource may, in some cases, be unusable and even harmful to the health of current and future generations.

In the past decade, crises such as that at Love Canal heightened public and political attention to the problem of ground water contamination and resulted in massive governmental programs, such as Superfund, designed to undo the mistakes of our past. These cleanup and containment efforts are commonly referred to as *remediation* and encompass such technologies as "pump and treat," in situ biotechnologies, and others, including those that process soils. The national effort to remediate ground water and soil contamination is enormous, with federal expenditures through programs of the U.S. Environmental Protection Agency, Department of Energy, and Department of Defense running to/at several billion dollars per year.

There is an eerie sense among many professionals engaged in remediation that the process is far from effective--that there is enough disparity between results and costs to take stock. Further, it is the sense of the members of the National Research Council's (NRC) Water Science and Technology Board that many of the problems faced by remediation efforts can be attributed to incompatibilities among the relevant science, policy, and public perception components. The board believes that reducing these incompatibilities can improve the speed, effectiveness, and economy of remediation. In addition, the board wanted to encourage a frank discussion about whether or not certain technologies were feasible and whether a technology-based waiver in response to excessively conservative cleanup levels was a viable approach. Thus, it convened this special colloquium.

The colloquium was held in April 1989 and featured a set of invited papers organized to stimulate discussion on key aspects of the remediation process. The keynote paper, Chapter 1, points out that science, policy, and public perception in respect to ground water and soil contamination have long been out of synchrony. The author, Robert H. Harris, looks back to the early 1950s when the technical community appears to have been alone in beginning to recognize and advocate the solving of ground water contamination problems. Over the succeeding two decades, experts held several conferences and designed technical guide-lines to protect ground water. However, by Earth Day, April 22, 1970, when the public paused to take stock of its natural resources and found shocking evidence that air, water, and land pollution had reached monumental proportions, the pendulum swung the other way. Indeed the public became skeptical about whether its representatives and the technical community had the willingness and capability to define appropriate levels of environmental protection.

To set the stage for this colloquium, aimed at bringing science, policy, and public perception toward synchrony, Harris describes several case studies of the health effects of ground water contamination. (Harris et al., 1987; Clark et al., 1982; Zineski, 1980; Lagakos et al., 1986). He shows an association (versus causal) relationship between ground water contamination and health effects.

He also introduces the critical issues of the achievability and uniformity of remediation. Especially with dense nonaqueous-phase liquids, cleanup objectives may not be achievable at all, because of undefinable, undetectable flow patterns. Also, some flexibility in establishing soil cleanup levels seems appropriate as soil contamination is ubiquitous, and its impact depends on contaminant mobility, direct contact possibilities, and uses of any associated ground water resources. Two additional points are important: (1) the public demands more certainty in risk analysis than scientists can provide, and scientists need to be prepared to explain why they cannot yet fulfill this need; and (2) data gatherers should consider that the ultimate use of any study is to answer key questions of concern to society, not, for example, merely to conduct more and more analyses of contaminants at ultratrace levels.

SETTING GOALS FOR REMEDIATION OF CONTAMINATED GROUND WATER AND SOIL

Some technical options for the remediation of contaminated ground water and soil are described by Perry L. McCarty in Chapter 2. Adding to what is an already difficult problem is the complexity of the processes that govern contaminant fate and transport in the unsaturated soil from the ground surface down to the water table and the saturated zone. Imperfect understanding of these processes, the interrelations among them, and inadequate characterization of site-specific hydrogeologic conditions have led to incorrect application of existing technologies or erroneous assessment of remediation efforts. Abiotic and biotic processes dictate the transformation of contaminants and that in some cases the "natural assimilative capacity" of the subsurface environment might be sufficient to recover from a "temporary insult" to the system resulting from a contamination event (e.g., a chemical spill). McCarty provides an assessment of the requirements for success in the application of in situ bioremediation techniques.

The challenge for policymakers regarding setting goals for ground water and soil remediation is identified by Glen D. Anderson in Chapter 3 to be the development of the institutional framework, procedures, and guidance needed to make the most effective use of the science and to achieve the best attainable environmental results, given the limited financial resources available for analysis and remediation. Three interrelated policy issues must be addressed: decisionmaking criteria, the public role, and financing of cleanups.

Should we clean up the contaminated resource? Although many would not even ask this question, there may be situations where remediation is *not* desirable. Specific examples cited by Anderson include situations with some or all of the following characteristics: (1) the costs to society of cleanup far exceed the expected benefits of cleanup in terms of human health and welfare and ecological stability; (2) the contaminated resource is not used and is perceived to have a low potential to be used in the future; (3) there are inexpensive substitutes for the contaminated resource; (4) the resource will not be used after remediation because users will take permanent averting action; and (5) the contamination does not degrade water and/or soil quality to an unsafe or unhealthy level.

How much remediation should be undertaken? If a decision to proceed with remediation is made, three related decisions follow. First, a background analysis must determine the extent of contamination and remediation alternatives. Second, the remedy must be selected on the basis of a number of criteria, including those related to technical, environmental, and financial or economic factors. Finally, a decision must be made about when to stop remediation activities.

Once a contamination incident has occurred, the public is involved at three stages of the process. First, the public may provide information about resource use and the nature of the contamination that helps determine the extent of contamination. Second, the public is a "client" of the responsible agency during the decision phase regarding alternative water supplies. Third, the public may have a role in the remediation decisions.

The most important policy need is development of realistic criteria for making remediation decisions, especially for guiding decisions about whether to undertake remediation and when to stop it. Finally, to ensure that the remediation process can address cleanup effectively, better coordination is required between science and policy. This can be encouraged in a number of ways, including communication of uncertainty, supporting retrospective studies of the effectiveness of remediation, and improving information transfer about remedial options.

The determination of the responsibility for remediation is an important factor affecting the remediation process. Injunctive relief by state or local agencies is one way of forcing the responsible party to undertake environmental cleanup and is based on statutory and common law. In addition to injunctive relief, state or local agencies may have the "order authority" to force a responsible party to conduct or pay for remediation activities. An agency's ability to recover costs from responsible parties is much more limited than its authority to order remediation. A real dilemma for agencies is discovering that responsible parties lack the ability to pay. Insurance could be required, but often coverage is inadequate, unavailable, or unaffordable.

CHARACTERIZING SUBSURFACE CONTAMINATION

The adequacy of scientific tools to yield reliable information on the distribution and behavior of subsurface contaminants is addressed by Douglas M. Mackay in Chapter 4.

The available scientific and technical tools are "not always adequate to yield unambiguous information," and our failure to recognize these inadequacies has resulted in serious incompatibilities in public perceptions and expectations, as well as problems in regulatory policy and whether it sets achievable remediation goals. A "people problem" also exists; inexperienced and/or overworked regulators and engineers are dealing with an ever-increasing number of contaminated sites that have been poorly characterized and with technology that is advancing rapidly. The common public assumption is that "studying a problem to death" is an evasion, yet it may instead be an inevitable consequence of unsatisfactory scientific understanding. Understanding the constraints on technologies and uncertainty in knowledge requires a more flexible regulatory approach and the development of more realistic (and achievable) remediation goals.

The policy, regulatory, and procedural tools currently in use are introduced by Glenn Paulson in Chapter 5. The alphabet soup of federal laws (e.g., RCRA, SARA) relevant to soil and ground water cleanup can be quickly recited; their implications, however, cannot be quickly summarized. These laws and their implementing regulations constitute an elaborate scheme that, depending on which one is in focus, either embodies a set of complicated rules to effect behavior or establishes a set of quantitative goals for contaminant levels. The overall goal is either to correct what are now perceived to be the flaws of past practices or to prevent a recurrence of such problems in the future.

Preliminary site characterization and immediate cleanups are areas where obviously needed short-term remedial actions often are held hostage to other, less immediately threatening factors before remedial actions are taken. In Superfund, for example, there are strong incentives to perform "enforcement quality" site characterizations, which take far longer to make than does the "engineering-quality" information to guide short-term remedial actions. Concerns of other parties, such as neighbors and other units of government, can sometimes delay implementation of short-term remedies that might produce immediate and often dramatic reductions in public health or environmental risks.

The use of models is well established in several areas of pollution control. As a general rule, the models are conservative, that is, cautious and highly protective in establishing both possible exposures and consequences. Unless carried to an extreme, such an approach seems prudent when there are large uncertainties in either empirical knowledge or the operations of complex systems. However, models can take on a certain rigidity that can make them resistant to change; sometimes, too, their results seem overly credible even when fairly compelling evidence has accumulated showing their deficiencies.

Consent decrees and administrative orders are time-honored tools in the environmental field. If anything, they are becoming more common in dealing with soil and ground water contamination problems. In fact, we are seeing the pioneering of a new type of time horizon for these tools in a 5-year reevaluation of site conditions in the Superfund Amendments and Reauthorization Act (SARA), and a 30-year operating period for both the Resource Conservation and Recovery Act (RCRA) and Superfund sites.

What can be done? Paulson has several suggestions: First, a policy commitment to increase the research and development effort at federally supervised hazardous waste sites would be a major step forward. Second, an equal commitment to increasing the pool of trained people at all levels would help. Third, efforts are needed both to improve the understanding by all parties of the risks posed by ground water and soil contamination through two-way communication and to improve the public's confidence in the decisions of relevant regulatory bodies by good performance.

CURRENT PRACTICES IN SUBSURFACE REMEDIATION

The diversity in the types of wastes and the variety of disposal scenarios necessitates a broad range of technologies for cleanup of contaminated soils and aquifers. This challenge has been met by adapting "old" technologies developed for other purposes (e.g., oil recovery and wastewater treatment) and by developing innovative technologies. Larry W. Canter in Chapter 6 reviews these technologies and assesses the reasons for their failures or successes in a number of cases. It has been difficult to judge the success or failure of a given remediation effort because a broad range of criteria have been used for this purpose. No site can be returned to its pristine condition, and thus on the basis of this criterion, most cleanup efforts could not be judged as being completely successful. Canter proposes several actions that might lead to an increase in the likelihood of choosing, designing, and implementing effective remediation programs and discusses technical needs in improving remediation technologies.

In Chapter 7, Stephen R. Wassersug and Christopher J. Corbett provide an Environmental Protection Agency (EPA) perspective on progress in the remediation of contaminated ground water given the technical uncertainties, time constraints, and public and political demands. They describe how ground water is addressed by EPA's remedial program (both Superfund and RCRA). Ground water remediation costs at a site are many millions of dollars and the remediation may take 30 or more years to achieve. Remediations must be evaluated periodically and modified as necessary based on additional data and experience. The remedial process is illustrated by a case study involving the Tyson's Superfund Site in Montgomery County, Pennsylvania. This is a complex contamination problem that involves soil and bedrock contaminated with dense nonaqueous-phase liquid.

DECISIONMAKING REGARDING SUBSURFACE CONTAMINATION REMEDIATION

Limitations on how scientists can make decisions about ground water and soil remediation are described by William A. Wallace and David R. Lincoln in Chapter 8. They point out that the Superfund program is different technically from earlier environmental statutes in that it was assembled from existing technical disciplines and methods, including the traditional engineering construction approach of study-design-build. Standard practice reduces the technical uncertainty to manageable levels in the study phase of a project. The adoption of this paradigm at Superfund sites, however, has led to major investigation efforts to identify sources of contamination and characterize sites because of the high consequences of choosing an inappropriate remedial technology. Yet the scientists and engineers who participate in the tasks of assessment and remedy selection are finding that the available site assessment technologies often cannot deliver answers to the accuracy and precision demanded by the site remediation problem.

Until recently, the significance of the substantial uncertainties on the remedial decisions for these sites had not been recognized. The level of these uncertainties requires a new way to approach remediation. A very promising method, derived from geotechnical engineering for subsurface characterization, is the "observational method," which may be applied to manage uncertainty. The method does not reduce uncertainty but provides a framework in which remediation decisions are made with explicit recognition of and a plan for coping with uncertainty.

Rena I. Steinzor, in Chapter 9, discusses the various policy models that have been considered, accepted, and rejected by public policymakers over the last decade in decisions concerning ground water remediation projects. In the SARA debate, Congress considered four basic concepts: (1) ad hoc, case-by-case, (2) cleanup to "background," (3) strong, uniform, and specific national standards with waiver provisions to give necessary flexibility in the cleanup process, and (4) development of site-specific risk assessments to determine cleanup levels and remedies. Steinzor believes that a focus on the SARA reauthorization debate is both appropriate and necessary in framing the policy issues that should be considered in formulating a comprehensive ground water policy. The SARA debate is the most recent and by far the most meaningful occasion during which Congress, the EPA, the environmental community, and industry actively thought, wrote, and argued about these issues. The value of their mutual consideration of these problems far outweighs the limitations imposed by the fact that Superfund is in many ways a unique environmental program.

The basic premise of the paper is that Congress selected the approach of national standards with waivers, but that EPA is implementing a site-specific risk assessment approach. Steinzor believes that this controversy over EPA's implementation of Superfund's cleanup standards will persist in the years to come and that Congress will return to the issue in 1991, when the third reauthorization of the program will be necessary.

It is the thesis of this paper that SARA's *statutory* approach toward determining the nature and scope of ground water cleanup is the best model we have to impose on an admittedly complex and difficult problem. SARA's statutory provisions would apply very strong--even rigid--health-based cleanup standards to ground water remediation projects in the first instance. SARA would achieve necessary flexibility in the development of actual cleanup plans through the application of several specific "affirmative findings," or waivers, that allow those stringent, upfront standards to be set aside when necessary.

Steinzor argues that EPA's substitution of a hybrid risk assessment model for SARA's statutory model will have some long-term consequences that will make the formulation of good public policy in this area much more difficult, if not impossible. It is concluded that the hybrid model's failure to achieve protectiveness and permanency of cleanup is far more important in evaluating its overall desirability than is the supposedly more important factor of cost.

EMERGING TECHNOLOGY AND POLICY OPTIONS

In Chapter 10, Douglas C. Downey discusses the problems and potentials of new technologies for ground water and soil remediation. Although the perspective is scientific, there is no purely scientific approach to the application of new ground water and soil decontamination technologies. Public opinion and the regulatory climate greatly influence technology development. Concerns about liability have limited creativity and the application of new ideas. Existing policy and the public often demand more control over subsurface events than science and technology reasonably can be expected to provide.

Scientists must expand their vision and consider more than the immediate problem and project when planning remediation activities. They must stay informed of remediation attempts elsewhere, constantly review field and laboratory data and the relevant literature, and remain aware of pending laws and regulations. Poor information transfer has affected the use of existing technologies and is particularly detrimental to new technology development. Some type of comprehensive national information network would help meet this important need.

Also, practitioners must take care not to assume that success in the laboratory will transfer to success in field conditions. A laboratory setting offers relatively homogeneous media, quantified reactions, and a controlled environment. In the field, scientists face many uncertainties, including highly heterogeneous media, assumed reactions, and random variables. Although laboratory testing of soil and ground water decontamination methods is important for establishing the principles of treatment, field application will provide more realistic lessons. Certain methods work in laboratories but fail in the field. Every technology is a new technology when applied to a specific site. Pilot testing of new technologies is critical. Field tests should be conducted first on "best-case" sites, those with the fewest known complications and controversies. Field testing should include untreated controls and adequate sampling and analysis, just as in any scientific research.

In Chapter 11, Marcia E. Williams discusses the various frameworks within which remediation occurs and looks in particular at the disincentives that inhibit rapid, effective soil and ground water cleanups. Four cleanup frameworks exist: CERCLA/SARA (Superfund), RCRA, state cleanup programs, and voluntary cleanups. Williams notes changes in statutory structure that might improve the nation's ability to deal with soil and ground water contamination; such changes include removal of constraints on new mobile treatment units and constraints that inhibit voluntary cleanups. Current definitions and pretreatment requirements associated with land disposal can interfere with cleanup. One solution is to separate storage and disposal (landfills and waste piles) from treatment (land treatment).

In an assessment of changes in regulatory structure, some inconsistencies could be alleviated by requiring states to adopt all RCRA rules or requiring EPA to define more clearly the link between consistency and stringency. Ways to reduce time and money spent on cleanup, without loss of environmental protection, include requiring ground water or soil monitoring only for constituents that are in the waste or leachate and allowing reduced monitoring frequency in areas with slow-moving ground water. Problems related to the Land Disposal Restrictions Rule are examined, including technical constraints and disincentives for cleanup. A regulatory change in RCRA to differentiate between regulatory requirements for newly generated waste and cleanup wastes would remove the incentives that owners perceive to leave old wastes in place rather than remove or treat them. Also current research and development permitting can greatly slow or restrict important research initiatives. For example, under current definitions, in situ biotechnology applications are precluded from requiring research permits because they are not applicable to land disposal technologies.

There is a difference between regulation and policy, and it can be deceptively difficult to alter policy because of the attitudes of decisionmakers. According to Williams, examples of needed policy changes include allowing more flexible use of interim cleanup remedies; better early analysis of how site characterization data will be used in remediation decisions; increased capabilities to evaluate different levels of uncertainty associated with different cleanup options; and the assurance that state and federal agencies will not later reevaluate reasonable and expeditious voluntary cleanups under tougher standards.

Williams concludes that the disincentives affecting soil and ground water remediation are derived from a combination of statutory, regulatory, and policy factors, as well as from information shortages and public acceptability constraints. In each area, steps could be taken to improve policy incentives and to ensure that there is a balance between the pace and thoroughness of cleanups and environmental protection.

MAKING SCIENCE, POLICY, AND PUBLIC PERCEPTION COMPATIBLE

In Chapter 12, William J. Walsh summarizes steps that might be taken to help make science, policy, and public perception of subsurface remediation more compatible. Although the public supports the concept of ground water and soil remediation, the statutes that require cleanups have been enacted without an accurate understanding of the scientific limitations of such efforts. Conflicts between science and policy are generally conflicts in value judgments that reflect the lack of consensus on cleanup goals.

Thus, in the effort to enhance the compatibility of science, policy, and public perception, Walsh suggests that several issues must be understood:

- the distinction between science and policy;
- the source of policy;
- the scientific evidence needed to support a soil or ground water cleanup policy as a matter of law;
- the degree to which value judgments determine policy;
- the role of participants in the process, particularly the public; and
- the policy options and their scientific and policy limitations.

A policy includes the more detailed direction that an agency develops to guide its staff concerning how a statute is to be implemented. Science, however, is "accumulated and accepted knowledge that has been systemized and formulated with reference to the discovery of general truths . . ." and involves the "determination of what level of probability is needed to accept or reject a hypothesis." Soil and ground water remediation efforts have both scientific and policy components, but ultimately an agency must rely on policy to justify its decisions because few aspects of ground water science are scientifically certain.

However, there are several scientific realities that must be addressed by any ground water and soil cleanup policy: complete removal of contaminants from soil or ground water is physically impossible to achieve (NRC, 1983); ground water cleanups take a long time; and a few months of data collection are inadequate to characterize the hydrogeology of a site.

The critical issue in a soil or ground water remediation action is whether the residual concentration of chemicals remaining at the site is protective of human health and the environment. EPA makes a case-by-case determination of whether the residual concentration is acceptable. The agency's preference is to restore ground water to drinking water quality whenever practicable. EPA makes extreme worst-case assumptions in determining exposure to a contaminant. For example, it assumes that a drinking water well is located in the middle of the worst part of the ground water plume. This results in the risk appearing much higher than would normally be expected. Although EPA's application of its cleanup policy is not always consistent, it is not underprotective of public health (unless one considers that certain remediation funds would reduce more risk if applied to other environmental problems). To resolve this inconsistency, Walsh maintains that EPA needs to document and explain the protective nature of its cleanup decisions.

The public is becoming increasingly concerned about the dangers of adverse health effects and loss of property values associated with contaminated soil and ground water. Society is experiencing a growing fear of chemicals because of the potential for cancer and other diseases resulting from chemicals in a water supply. The public also is becoming more involved in environmental decisionmaking, and its voice is being heard throughout government and industry. EPA must communicate risk effectively and understandably during the public participation process.

Many parties can be involved in ground water and soil remediation policy, and Walsh's chapter 12 offers several recommendations to minimize conflict brought about by multiparty involvement. However, he states that nothing is simple about soil and ground water cleanup and as long as there are sharp value differences and an adversarial thrust to the nation's approach to environmental problems, many problems will continue to exist. He suggests that the adversarial nature of the process be lessened and that the public, press, and Congress be educated on the nature of the problem. Furthermore, many of EPA's policies discourage rather than encourage settlement. Thus Walsh recommends that EPA encourage innovative legal and technical solutions to ground water and soil remediation efforts.

It is difficult to make science, policy, and public perception compatible when remediation efforts involve multiple parties that perceive the problem differently. EPA must develop an effective working environment that encourages participation and communication among parties.

SUMMARY: SELECTED CRITICAL STEPS TOWARD MAKING SCIENCE, POLICY, AND PUBLIC PERCEPTION REGARDING SUBSURFACE CLEANUP MORE COMPATIBLE

Based on colloquium presentations, discussions, and assessments, and in an effort to distill constructive advice to increase the compatibility of science, policy, and public perception, the colloquium conveners suggest the following measures to EPA, other federal agencies, state agencies, and other parties involved in remediation efforts.

Remedial Decisions and Design Approval

- Systematic decisionmaking techniques that encompass multiple criteria including risk reduction, uncertainties, and resources in a trade-off matrix should be developed and agreed to by those concerned.
- Technical peer review and other evaluation should be applied to (1) all contaminant transport models; (2) all risk assessments, particularly the exposure assumptions; (3) the physical constants and cost estimates used in decisionmaking; and (4) any other purely scientific components in the cleanup process.
- Remediation efforts should be designed from the start as the experiments they are and not as efforts merely to "go through a required event." A phased or interim cleanup approach with extensive education built in should be used. Design by an observational method should be used with explicit recognition of uncertainty by designing for probable conditions,

identifying potential deviations, developing contingency plans, and continuously monitoring/modifying the remediation effort. This is a necessary shift in the remediation approach dictated by the high uncertainty involved, and it should be recognized and agreed to by all at the start.

- Good databases need to be developed to help us understand what types of situations lend themselves to particular technology/remediation strategies. This should help focus and limit preremediation studies and may reduce controversy.

Uncertainty Reduction, Policy, and Education

- To reduce scientific uncertainty as much as possible, funding should be increased for research programs to develop better subsurface characterization tools for fine structures of aquifers, for contaminant retardation and transformation, and for locating nonaqueous-phase liquids.
- Fuller use of affirmative findings (waivers) for national standards of cleanup and waivers that address staged cleanup, technical impracticality, and increase in environmental or health risk need to be explored. It is uncertain whether fuller use of waivers would decrease transaction costs and increase credibility, but this should be explored.
- The Environmental Protection Agency should retain an independent body to study and evaluate all of the post-SARA Remedial Investigations and Feasibility Studies to determine whether some elements of the process are inconsistent (e.g., the cost estimates made for remedial alternatives or the assessment of risks from the implementation of alternatives).
- As with National Priority List sites, potentially responsible parties should be encouraged to implement the Superfund process under EPA's supervision, with appropriate public involvement at the earliest possible time through settlement policies that encourage private cleanups.

Public Communication

- Communication needs to be improved between scientists, engineers, and the public to educate all parties about scientific uncertainties, societal costs, and public expectations for public health and ecological protection.
- Significant resources from federal and state agencies, academia, industry, and other participants in the regulatory

process need to be allocated to inform the public of the technical limitations of ground water cleanup, the policy alternatives available, and the trade-offs involved in soil and ground water cleanups.

- Federal and state agencies should obtain public input at the earliest possible point in the remedy-selection process; this requires training for regulators in the skills necessary to obtain meaningful public participation.
- The raising of false expectations among local residents must be avoided. A large number of sites, particularly industrial sites, will never be cleaned up to the point that the soil is edible and the leachate is drinkable. EPA drinking water standards and soil cleanup standards will not be achieved at many sites because the costs are likely to exceed the benefits to society. These facts should be clearly understood and communicated to the public.

Most regulatory decisions in this country are made in a highly adversarial climate, a situation that (1) usually consumes enormous amounts of resources; (2) is not a reliable way to obtain a clear technical understanding of a scientific problem; (3) may not characterize and treat uncertainty adequately; and (4) does not produce consistent solutions. Our national energies and resources are finite. EPA cannot endure the endless second-guessing accorded its soil and ground water policies; some closure must be given to the process.

It is not surprising that the public, press, and Congress are unfamiliar with the scientific constraints involved in soil and ground water cleanup policy, given the complex scientific questions underlying these issues. An essential component of any attempt to reduce the rhetoric is a serious effort to foster much better communication between all of the participants in the process.

The Environmental Protection Agency's present budget for and emphasis on public communication is small. Special attention must be given to developing effective public information and involvement programs. EPA must incorporate rewards for effective public communication and remedial training for poor communication into the system by which EPA judges the effectiveness of its personnel. The positive aspects of community relations must be instilled at every level of the agency.

The best defense for/against criticism from the public is not to throw money at the problem, but to (1) consider all available information, including public comments; (2) choose health-protec tive yet cost-effective remedies; (3) clearly present the technical and other bases for the decision; and (4) answer the public's questions.

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ISSUE PAPERS

1

Ground Water and Soil Remediation: Conflicts and Opportunities

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The time interval between initial waste disposal and appearance of polluted water in wells may be so great as to permit irreparable damage to underground supplies.

The results of ground water pollution may be very long lasting--sometimes to the extent of affecting future generations.

Some wastes are so potent that very small concentrations produce severe injury.

If corrective measures are deferred until proof of actual damage is at hand, so much pollution is likely to have taken place that restoration of purity will be difficult, costly, and slow, if possible at all.

American Water Works Association Task Force, 1952 and 1953

INTRODUCTION

If the above statements appeared today in a *Federal Register* notice of ground water protection regulations, they would pass as typical boilerplate. The fact that they were published nearly 40 years ago suggests that the relationships then among the technical community, the public, and the governing institutions may have been quite different from those that operate today. The post-World War II industrial and urban growth boom prompted the technical community to realize the need for measures to protect ground water resources, especially from municipal and industrial waste disposal practices.

Presentation at colloquium given by *Joseph V. Rodricks.*

Unfortunately, the public, either directly or through the actions of its governing institutions, seemed to rely on the unlimited capacity of Mother Earth to absorb the spoils of this industrial and population growth. This country was on a roll, and the short-term gains were evident to everyone. The long-term implications to the environment were in practically no one's political agenda.

Today, we have quite a different view of the earth's capacity to sustain unbridled cultural development and a very different political agenda. Before we explore together the current conflict between the public's expectations and our ability as scientists and engineers to meet them, let us review the historical developments that have brought us to where we are today.

THE DECADE OF ENLIGHTENMENT

As the statements by the American Water Works Association (AWWA) Task Force suggest, the decade following World War II found the technical community actively developing new approaches to waste disposal and realizing the threat waste disposal posed to our ground water resources. This was nowhere better exemplified than in the work of the California State Water Pollution Control Board and the Illinois Department of Public Health.

In 1952 the state of California, in an effort to protect ground water resources, issued guidelines governing the land disposal of municipal and industrial wastes (CDPW, 1952). It is clear from the following passage that the California regulatory community recognized the potential of landfilling practices to contaminate ground water:

> It is obvious that sites situated over "free ground water" would be unsuitable for the unrestricted disposal of industrial waste and suitable for the disposal of decomposable refuse only when the dump can be maintained at an elevation safely above the highest recorded or anticipated ground water level (CDPW, 1952).

California proposed a classification system that provided guidelines for the suitability of disposing of certain types of waste as a function of hydrogeological site conditions. One of the first uses of these guidelines was in the evaluation of potential landfill sites in Los Angeles County, eventually leading to the selection of sites believed to pose minimal risks of ground water contamination.

Parallel to California's pioneering efforts in the early 1950s, C. W. Klassen, chief sanitary engineer for the Illinois Department of Public Health, published guidelines in 1950 and 1951 (Klassen, 1950 and 1951) that were intended to prevent ground water contamination from sanitary landfills. Klassen's guidelines were similar to California's:

> Sanitary landfills should not be located on rock strata without studying the hazards involved. A minimum of 30 ft of clay till overburden should be kept between the rock strata and the fill unless studies indicate a lesser depth is satisfactory. Drift wells should not be nearer than 500 feet unless studies indicate that subsurface seepage will not occur.

These early 1950s guidelines were born out of the growing recognition within the technical community that ground water contamination was becoming an increasingly serious problem. The AWWA Task Force organized in the early 1950s reported on three separate occasions that industrial waste disposal practices were creating ground water contamination problems in nearly every state.

By 1961 the potential threat of ground water contamination was so pervasive that the U.S. Public Health Service convened a symposium on ground water contamination at its Cincinnati Taft Engineering Center (U.S. Department of Health, Education and Welfare, 1961). Although organizers of the conference expected that 50 or 60 people would attend, more than 300 convened for three days of discussions. The topics covered were wide ranging, including hydrogeological aspects, the types of contaminants in ground water, specific incidences of contamination, and advances in research.

What these events underscore is the extent to which the technical community understood the causes of ground water contamination and its potential seriousness. Unlike today, the technical community was far ahead of the public and its governmental representatives. The two decades following World War II found America preoccupied with industrial and urban growth, with few pauses to reflect upon the environmental impact and the other externalities of this growth. It was the technical community who seemed to understand the environmental damage that was in the making; the public could only lend a deaf ear.

THE POST-EARTH DAY ERA

Earth Day changed all of that. On April 22, 1970, the nation paused to take stock of its natural resources. What it found was shocking evidence that air, water, and land pollution had reached monumental proportions. The following decades witnessed a progressively widening gap between the public's and the technical community's perception of environmental risk.

Thus the pendulum has swung to the opposite extreme. The technical community is no longer leading public perception, it is following. The public is now skeptical of the intentions and abilities of its representatives and the technical community to define appropriate levels of environmental protection. There is hardly a community in this country in which environmental decisionmaking is not influenced profoundly by local or regional public interest groups.

It is this state of affairs that brings us to this symposium to question whether science and public policy are compatible and whether current decisions to remediate soil and ground water contamination are rational and economically efficient.

Perhaps the first question we should be asking ourselves is do the facts support the public's preoccupation with contaminated drinking water? Is there really a significant health risk posed by the part-per-billion (ppb) concentrations of synthetic organic chemicals that have become ubiquitous contaminants of both surface and ground water in this country? By health risk we mean cancer risk, because the public's fear of cancer invariably drives the technical and regulatory communities' decisions on remediation of contaminated soil and ground water.

At one extreme are scientists like Bruce Ames, who have come to believe that the public's fears are misplaced (Ames, 1985). Ames recently has written that "water pollution is irrelevant to the causes of human cancer" when compared "to the background level of carcinogens in nature" (Ames, 1986). Ames argues that naturally occurring carcinogens in our diet pose far greater risks of cancer than does drinking water.

At the other extreme are the recent actions of the U.S. Congress and the EPA. In the 1986 amendments to the Safe Drinking Water Act, Congress required the EPA to establish standards on 83 organic chemicals by 1989 and to promulgate standards for an additional 25 chemicals every year thereafter. To date, EPA has set numerical standards on eight carcinogens, in most cases at the analytical detection limit of 5 ppb or below.

What drives our current public policies in establishing standards for carcinogens in water is the assumption that carcinogens do not demonstrate a "threshold" effect (i.e., exposure to any amount of carcinogen represents some increased risk of cancer, however small). Although the results of animal bioassays have provided a scientific basis for setting numerical limits on carcinogens in drinking water, an impressive body of epidemiologic evidence has steadily grown in support of the public's fears and the actions of the regulatory agencies.

EPIDEMIOLOGIC STUDIES OF CHLORINATION

Epidemiologic studies provide some evidence of increased cancer risks from exposure to chlorinated drinking water. These risks have been attributed largely to the presence of trihalomethanes (THMs). THMs are organohalogen compounds introduced into drinking water by the reaction between naturally occurring and manmade organic substances in raw water and chlorine added for disinfection. Chloroform (trichloromethane) is the THM found most frequently in public drinking water supplies in the United States, although others have been detected, including bromodichloromethane, dibromochloromethane, bromoform, and dichloroiodomethane. All of the THMs have been found to cause cancer in animal studies. Both the laboratory and epidemiologic studies are relevant to ground water because low-molecular-weight halogenated compounds, including chloroform, are frequent ground water contaminants. Furthermore, the carcinogenic potency of the chlorination by-products, as well as the concentration range, is typical of many of the chemicals that contaminate ground water (e.g., low-molecular-weight chlorinated solvents). Therefore, the epidemiologic studies of chlorinated water, although more directly relevant to surface water, do provide important evidence supporting the public's concern for the same or similar chemicals in ground water.

The relationship between cancer mortality or morbidity and drinking water variables has been examined in more than twenty retrospective studies. While uncertainty still remains, owing to possible confounding factors (such as lack of exposure data for individuals, population migration, and other factors--including smoking, diet, occupation, and alcohol), the associated cancer risk for the gastrointestinal and urinary tracts appears to be higher for chlorinated water than it is for nonchlorinated water (Table 1.1).

Thirteen of the twenty retrospective epidemiologic studies available through 1977 were reviewed by the National Research Council (NRC) Epidemiology Subcommittee of the Safe Drinking Water Committee (NRC, 1980). Crump and Guess (1982) extended this review to include all of the case-control studies available through 1980. The NRC committee concluded, based primarily on a review of the ecologic studies, that "higher concentrations of THMs in drinking water may be associated with an increased frequency of cancer of the bladder." Crump and Guess concluded that the new case-control studies "strengthened the evidence for an association between rectal, colon and bladder cancer and drinking water quality provided by the earlier studies reviewed by the NAS Committee" (Crump and Guess, 1982). The cancer risk for these target organs among individuals exposed to chlorinated water was reported to be about 1.1 to 2.0 times higher than the cancer risks in individuals consuming nonchlorinated water.

Of recent note is the case-control study by Cantor et al. (1987), who developed exposure information from interviews of 2,805 bladder cancer victims and 5,258 controls. Bladder cancer risk in this study increased with total tap water consumption. Among men and women nonsmokers, the relative risk increased to 3.1 among those with ≥ 60 years of residence with a chlorinated surface water source. These results suggest that the proportion of bladder cancer attributable to ingestion of tap water from chlorinated surface supplies was 12 percent; among non-smokers the attributable risk was 27 percent.

EPIDEMIOLOGIC STUDIES OF CONTAMINATED GROUND WATER

Recent attention to adverse health effects associated with drinking water has focused on ground water, in large part because of the public concern raised at Love Canal. The concentrations of manmade contaminants generally are 10 to 1,000 times higher in contaminated ground water than they are in contaminated surface water, primarily because of the lower mixing and flow rates in aquifers compared to surface streams and rivers (CEQ, 1981). Therefore, any adverse health effects associated with contaminated drinking water may be more evident when contaminated ground water serves as the raw water supply.

TABLE 1.1 History of Epidemiological Studies on Carcinogenicity of Drinking Water

Year	Site	Study Result	Study Design
1976[1]	Bladder	+	Surface water v. ground water
	GI tract	+	
1977[2]	Bladder	+	Chlorinated v. nonchlorinated water
	Colon	+	
	Esophagus	+	
	Lung	+	
	Rectum	+	
	Stomach	+	
1977[3]	Bladder	+	Surface water v. ground water
	Colon	+	
	Rectum	+	
1977[4]	Bladder	+	Chlorinated v. nonchlorinated water
	Colon	+	
	Lung	+	
	Rectum	+	
1977[5]	Bladder	+	Surface water v. ground water
	Stomach	+	
1977[6]	Bladder	+	Surface water v. ground water
	Stomach	+	
1978[7]	Bladder	+	Trihalomethane concentration
	Lung	+	
	Stomach	-	
1978[8]	Bladder	+	Chloroform concentration
	Colon	+	
	Rectum	+	
1981[9]	Colon	-	Surface water v. ground water
	Rectum	+	
1981[10]	Colon	+	Total chlorine added
	Other sites	-	
1982[11]	Colon	+	Chlorinated v. nonchlorinated water
	Other sites	-	
1982[12]	Rectum	+	Chlorinated v. nonchlorinated water
	Other sites	-	
1982[13]	Breast	+	Surface water v. ground water
	Rectum	+	
	Other sites	-	

TABLE 1.1 Continued

Year	Site	Study Result	Study Design
1984[14]	Colon Rectum	- -	Trihalomethane concentration
1985[15]	Bladder	-	Chlorinated v. nonchlorinated water
1985[16]	Colon	+	Chlorinated v. nonchlorinated water
1986[17]	Bladder	+	Chlorinated v. chloraminated water
1987[18]	Bladder	+	Tap water intake
1987[19]	Colon	-	Trihalomethane concentration
1988[20]	Bladder	+	Chlorinated v. chloraminated water
1989[21]	Colon	+	Chlorinated v. nonchlorinated water

Since Love Canal, a number of incidents have been documented involving human exposure to contaminated drinking water from ground water sources. The case studies summarized below illustrate the potential causal relationship between exposure to chlorinated solvents in drinking water and adverse public health effects. Although these epidemiologic studies are not without methodologic flaws, improvement in the health of the exposed populations has been observed consistently after use of the contaminated water supplies was discontinued.

Hardeman County, Tennessee

From 1964 to 1972 pesticide production wastes were buried in shallow, unlined trenches at a dump site in Hardeman County, Tennessee. By 1977 local residents were complaining of taste and odor problems in their well water and were reporting an unusually high incidence of health symptoms. Ground water sampling conducted since 1978 confirmed that chlorinated solvents (including carbon tetrachloride, chloroform, methylene chloride, tetrachloroethylene, and other chlorinated solvents) had leached from the dump site contaminating nearby drinking water wells. Concentrations of these chemicals were in the thousands and tens of thousands of parts-per-billion range, similar to exposures found in the workplace (Harris et al., 1987).

Connecting the 18 affected homes to a clean municipal water system in 1979 resulted in the disappearance of acute symptoms, including nausea, diarrhea, abdominal cramping, skin and eye irritation, and upper respiratory infections. Persisting problems identified 2 years later by a neurologist included symptoms similar to carbon tetrachloride poisoning: enlarged livers, peripheral neuropathy, optic nerve atrophy, and significant eye problems.

The University of Cincinnati conducted a limited health survey in 1978 primarily to ascertain whether exposure to the contaminated water was associated with liver dysfunction (Clark et al., 1982). The survey included exposed individuals (i.e., those served by contaminated drinking water) and an unexposed control population. The initial hepatic profile testing revealed elevated concentrations of the serum enzymes, alkaline phosphatase and serum glutamic oxaloacetic transaminase (SGOT), in residents who used contaminated water. During follow-up examinations of these exposed individuals 2 months after well water use had ceased (January 1979), serum enzyme values were reduced significantly (Clark et al., 1982).

Gray, Maine

Between 1974 and 1977, 24 families in Gray, Maine, were exposed to dimethyl sulfide and halogenated hydrocarbons in private well water. Complaints of malodorous well water, rashes, and burning sensation of the eyes after showering or bathing led to the discovery that contaminants were leaching from a nearby chemical dump (Zineski, 1980).

Dimethyl sulfide was found in the homeowners' drinking water at the highest concentration, followed by 1,1,1-trichloroethane, trichloroethylene, freon, chloroform, and other chlorinated solvents. The concentrations of solvents were in the hundreds and thousands of parts per billion range, about one-tenth of the concentrations detected in the drinking water in Hardeman County, Tennessee.

An epidemiological investigation was undertaken to determine whether the 24 exposed families were experiencing an increased incidence of health problems. Questionnaires were mailed to these families and to 50 control families in Gray. A battery of laboratory tests also was offered to the exposed families and a smaller control group.

Through 1978 exposed individuals had a significantly higher incidence of headaches, rashes, loss of balance, numbness of the extremities, depression, nervousness, mood lability, difficulty concentrating, chest tightness, dyspnea, ocular burning after contact with water, and abdominal pains. The rate of occurrence of these symptoms, however, was not statistically different between the exposed and control populations following 1978. There was no significant difference in the reported occurrences of asthma or urinary tract infections between the exposed and control populations before or after exposure was ceased. No serious or consistent abnormalities were reported in laboratory tests (complete blood count, routine blood chemistry, and urinalysis tests). The occurrence of pregnancies was too low to draw any conclusions regarding miscarriage rates.

The epidemiologic study of Gray residents is limited by design constraints and by possible self-selection bias in the exposed population. The results suggest that acute symptoms coincided with exposure to chemicals. However, no evidence of persisting adverse effects in the exposed families was found.

Woburn, Massachusetts

Health problems were observed in Woburn, Massachusetts, in individuals exposed to drinking water containing solvents at concentrations of a few hundred ppb. Two municipal wells were contaminated with trichloroethylene at around 200 ppb and with 1,2-dichloroethylene, tetrachloroethylene, and chloroform at concentrations of less than 100 ppb. These wells were used periodically from 1964 through the 1970s. Some residents of Woburn were supplied with contaminated water to a much greater degree than were others.

In 1984 a team of Harvard University scientists conducted an epidemiologic study of the Woburn populations (Lagakos et al., 1986). During the 1970s, an increase in perinatal deaths (deaths within the last 3 months of pregnancy or the first 7 days after birth) was observed in families (4,403 pregnancies) receiving contaminated water. The relative risk of various types of birth defects also was compared for 3,814 births. The study groups were women who received less than 20 percent or more than 20 percent of their drinking water from contaminated wells. Relative risks were found to be elevated for eye and ear birth defects (relative risk = 3) and for birth defects generally considered associated with environmental exposures (including spina bifida, anencephaly, other CNS problems, and cleft palate; relative risk = 2.6). During the 3 years after use of the contaminated wells was discontinued, the relative risks of perinatal death and these birth defects among exposed mothers were comparable to those in other parts of the community.

The incidence of childhood leukemia was increased in Woburn, especially in the areas receiving almost all water from the contaminated wells. Childhood leukemia in Woburn continues to be studied. In exposed adults in Woburn, neurological damage, immunologic problems, and cardiac arrhythmias persisted for at least 5 years.

RESPONDING TO THE POLICY DILEMMAS

If one views the cumulative epidemiologic evidence objectively, it would be fair to conclude that the public is justified in its concern over contaminated ground water. Nonetheless, the risks associated with ground water contamination at some sites are very small. The political process by which Superfund sites were selected for the National Priorities List resulted in the inclusion of some sites that represent small risks and the exclusion of others that may represent significant risks. But the mounting evidence that the presence of certain synthetic organic compounds in drinking water may pose a significant public health risk justifies the regulatory intentions of the EPA under the major federal statutes that were meant to remediate soil and ground water contamination.

Despite the reasonable foundation upon which our regulatory apparatus rests, a host of policy dilemmas confront us, most of which will be discussed during this symposium. Three questions that are often posed are as follows:

- Can we achieve cleanup objectives quickly, as the public and Congress anticipate?
- In many cases, are cleanup objectives achievable at all, regardless of the time allotted?
- Should uniform standards be applied to soil remediation?

Risks as a Function of Time

Both Congress and the EPA have developed policies that encourage *rapid* cleanup at contaminated sites. The two EPA guidance documents (USEPA, 1986 and 1988) that discuss the application of risk assessment to the evaluation of remedial alternatives emphasize the importance of the time necessary to achieve remedial objectives. Present value costs are another important consideration. Absent from these discussions is the risk/time factor, information necessary to determine the aggregate risks associated with remedial objectives.

Without this information, an option that achieves the remedial objective in a shorter time but at a higher present value cost than an alternative that achieves the same objective in a longer time at a lower present value cost might be selected, even though the aggregate risks of the former might be greater than the latter.

Perhaps the issue can best be addressed through the use of a hypothetical example. Figure 1.1 illustrates two remedial options with the same objective but with different completion times. Option A achieves the remedial objective (e.g., a trichloroethene concentration of 5 ppb) sooner than does option B. If the present cost of A were less than that of B, EPA guidance clearly would suggest A as the remedial option of choice. However, the aggregate risks associated with option A (proportional to the area under the concentration/time curves) are considerably greater than those associated with option B. On the basis of aggregate risk, if the present value cost of B were less than that of A, then B might be the option of choice, even though it requires a longer time to accomplish the cleanup objective than does A.

At one site in New Jersey, the relationships between risk and cleanup time for the two options under consideration are similar. This is illustrated graphically in Figure 1.2. Option A achieves the cleanup objective in almost half the time of option B but at a much higher cost. If only cleanup times were considered, option A might appear twice as attractive (10 years to clean up versus 20 years). Yet on the basis of aggregate risk, the relative benefits of A would be considerably smaller (the ratio of the shaded area to the area under curve B).

The Achievability of Cleanup Objectives

At many sites with contaminated soil and ground water, the time necessary to achieve remedial objectives is highly unpredictable. In some cases there may be no known method for predicting when remedial objectives will be met, if at all. One case is extensive subsurface contamination with dense nonaqueous-phase liquids (DNAPLs). Many, if not most, waste

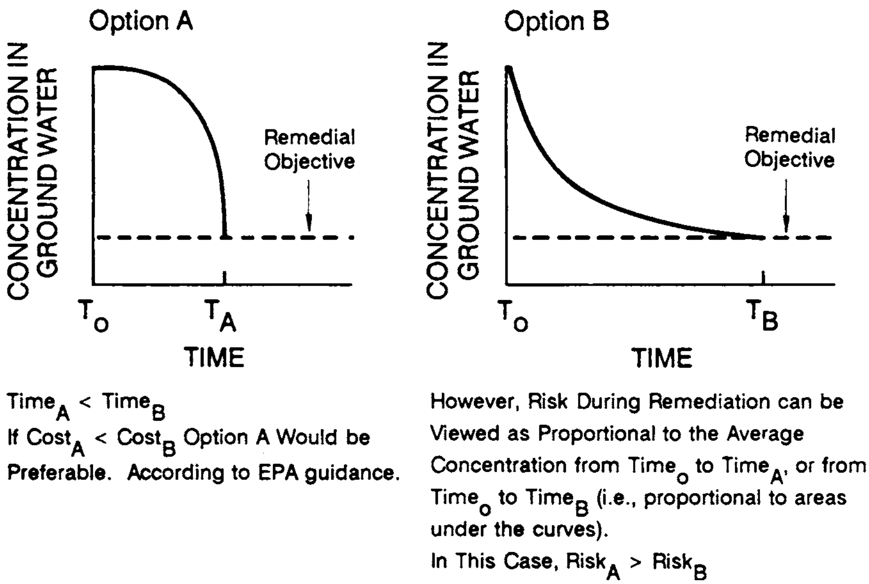

FIGURE 1.1 Aggregate risks for two remedial options that require different cleanup times and dissimilar remedies.

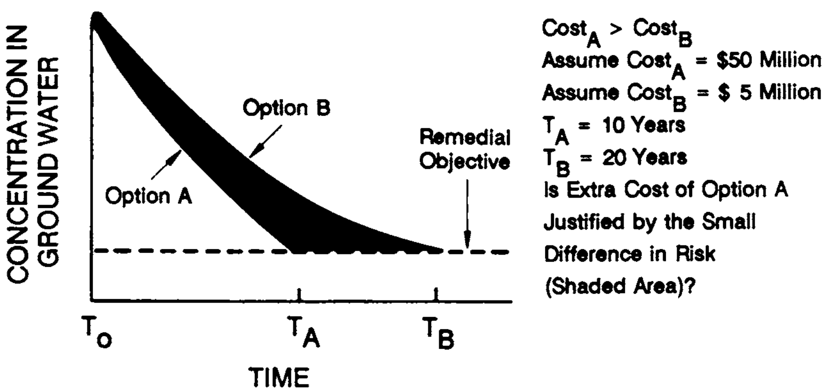

FIGURE 1.2 Aggregate risks for two remedial options that require different cleanup times and similar remedies.

contamination sites involve DNAPLs. State-of-the-art site investigation techniques are unable to identify all of the locations of DNAPLs in the subsurface and to develop remedial approaches with predictable cleanup times. DNAPLs can be contained through the construction of hydraulic or physical barriers, but true cleanup has yet to be demonstrated at any site. In such cases the public must be honestly apprised of the "perpetual care" that may be necessary, as well as of the uncertain time horizons for achieving "cleanup objectives," including the possibility that cleanup objectives may never be achieved.

Standards for Soil Remediation

To achieve cleanup at contaminated sites to a degree that obviates perpetual care means the cleanup of all source areas, including contaminated soil. In addition to the federal statutes, implementation of state statutes, such as New Jersey's Environmental Cleanup Responsibility Act (ECRA), is leading to the discovery that soil contamination is extensive, especially in industrialized areas. The increasing costs of excavation and removal for off-site landfilling or incineration have given rise to intense interest in in situ remediation methods, such as bioremediation, vacuum stripping, and soil washing.

Some states, including New Jersey and California, have developed guidelines for the cleanup of contaminated soil. In most cases these guidelines suggest cleanups to typical background concentrations of natural constituents, such as heavy metals. This approach places the burden of proof on the owner/operator to demonstrate that more permissive cleanup standards will adequately protect public health and the environment. The benefit of this approach is flexibility, since cleanup objectives can be developed on a case-by-case basis, considering site-specific conditions. These conditions include the impact of soil types on the mobility of contaminants, the suitability of ground water as a drinking water supply locally, existing or potential future uses of ground water resources, and the extent to which direct soil contact or fugitive emissions may pose on-site and off-site risks. To establish uniform standards for soil remediation would surely lead to economic inefficiencies in remediating contaminated sites.

CONCLUSION

As we debate tomorrow the important policy dilemmas that soil and ground water remediation pose, it would be helpful to reconsider the responsibility the technical community has in communicating honestly with the public, its representatives, and the regulatory community. We must attempt to communicate clearly the nature of the risks posed by soil and ground water contamination, the achievability and costs of remedial objectives, and the time necessary to achieve remedial objectives. Where risks are trivial, we must say so. Where reasonable cleanup objectives can be met cost-effectively, but over longer periods of time, we must be prepared to defend them.

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2

Scientific Limits to Remediation of Contaminated Soils and Ground Water

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The many problems recognized today with contaminated ground water were clearly outlined and identified during a symposium of leading experts called together by the Division of Water Supply and Wastewater Treatment of the U.S. Public Health Service nearly three decades ago.[1] Even then, the problems were well documented in the literature, and an urgent need for research to better understand the complexities involved was stressed. Nevertheless, a general awareness of the significance of contamination of the subsurface environment awaited another 15 years when news reached a more receptive public about toxic waste dumps at Love Canal and subsequently about the broad extent to which the nation's ground water supplies had become contaminated with hazardous organic chemicals. The public now wishes that these environmental abuses resulting from past neglect be cleaned up rapidly and permanently. A desire for zero contamination and zero risk frequently is voiced.

Consideration of the often-felt desire for a clean and risk-free subsurface environment raises important questions about our current and potential scientific and technical capability to achieve such a goal, the time frame over which remediation might be obtained, and the cost. The scientific knowledge of the many complex questions involved and the technology for restoring contaminated subsurface environments still are quite primitive, largely because of the short time frame over which subsurface contamination problems have been addressed seriously. To what extent might future research aid in our ability to achieve more economical and complete restoration, and to what degree should we push forth with our efforts for rapid cleanup? These are some of the issues addressed in this paper.

CHARACTERISTICS OF CONTAMINATED SUBSURFACE ENVIRONMENTS

Figure 2.1 illustrates a subsurface environment contaminated through leaking of solvent from a waste storage tank, one common way that contamination occurs. As the solvent is pulled downward by the force of gravity, residuals that are left behind contaminate the surface soil, the unsaturated (vadose) zone between the surface soil and the ground water table, and, finally, the aquifer containing the ground water as well. After the leakage is found and stopped, the contamination present may persist; may be spread further throughout the soil, the vadose zone, and the aquifer by physical forces; and may be transformed into other chemicals through chemical and biological processes. Often, a contaminating waste is a mixture of many chemicals, each of which may move and be transformed by different processes and to different extents. Thus the chemicals found in a contaminated ground water plume resulting from a surface spill may be greatly different in composition and relative amount than that of the spill itself. Indeed, through transformations, the chemicals in the contaminated ground water may not even have been present in the original spill. This is a common occurrence. The complexities of the subsurface environment, of the contaminants themselves, and of the processes governing the movement and fate of contaminants in the subsurface environment need to be well understood in order to develop a successful strategy for remediation and to adequately estimate the time frame involved.

Figure 2.1 illustrates a relatively homogeneous subsurface environment in which ground water flow direction and rate might be determined from relatively few observations of piezometric heads and data from pumping tests. Subsurface environments often are much more complex than this,[2] perhaps as illustrated in Figure 2.2. Layering of permeable (sands and gravels) and less permeable (silts, clays, and rock) strata are common and may contain discontinuities that could result from faults or large-scale stratigraphic features. Conductivity of water and contaminants through rocks and other such barriers may result from joints and fractures that are difficult to locate and to describe. The mixture of gravel, sand, silt, clay, and organic matter of which the subsurface environment consists can vary widely from location to location, as can the grain-size distribution and mineral composition within each broad class of subsurface strata. In addition, past construction of wells that are perhaps now abandoned and forgotten often can provide passage ways between separated aquifers.

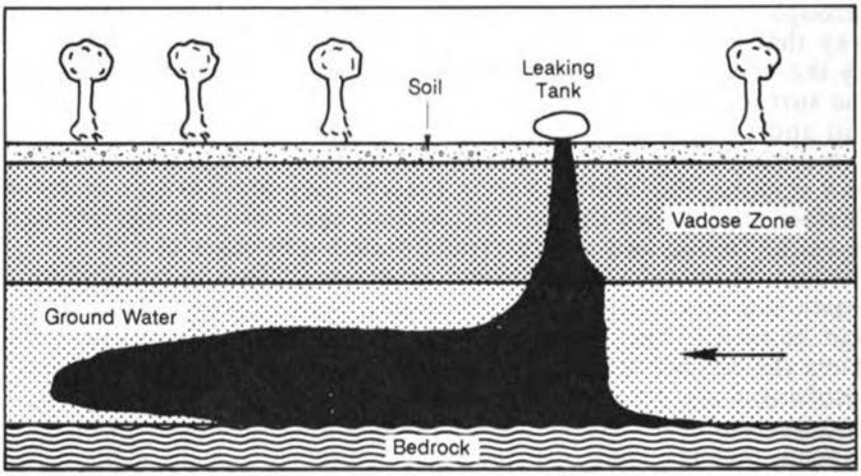

FIGURE 2.1 Contamination of a homogeneous subsurface system.

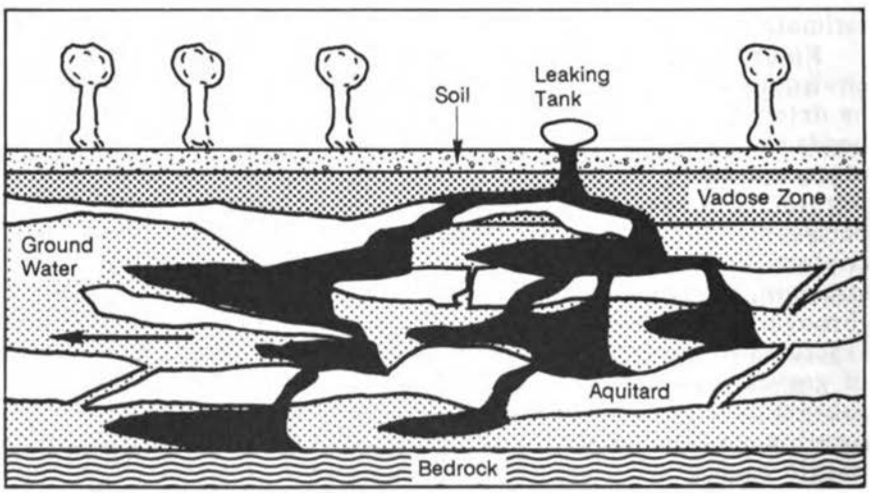

FIGURE 2.2 Contamination of a heterogeneous subsurface system.

Such complex systems are all too common, and when contaminated they provide some of the most challenging and difficult situations for restoration.

In addition to the physical characteristics of an aquifer, the chemical and microbiological characteristics also can be important as they can affect the chemical form of the contaminant and transformations that are likely to occur naturally or that might be enhanced or reduced as part of a remediation scheme. These aspects are discussed more fully below.

CONTAMINANT MOVEMENT AND FATE

Processes affecting the movement and fate of contaminants in the subsurface environment include advection, dispersion, sorption, volatilization, and transformation.[2] Advection is the process by which ground water and contaminants flow in response to gravitational, pressure, or density gradients. Dispersion is a mixing process that results both from fluid flow and molecular motion, resulting in the spreading and dilution of a contaminant within the system. Sorption is the partitioning of a contaminant between a gaseous or liquid phase and a solid phase, and it results in the retardation in the rate of movement of a contaminant with respect to that of the fluid in which it is contained. Volatilization results in a partitioning between liquid or solid and gaseous phases. Transformation causes change in one chemical species to another and may result from either chemical (abiotic) or biological (biotic) processes or from a combination of both. If a well supply becomes contaminated, estimates of the original source or sources of contamination, as well as projections of the future movement and fate of subsurface contaminants, require knowledge of these processes. Sound application of remediation schemes also requires knowledge of these processes and generally takes advantage of at least some of them for removal and/or in situ destruction of the contaminants. The role played by each of the multiple possible processes in movement and fate is a function of both the aquifer characteristics and the characteristics of the contaminants themselves.

Physical Characteristics

Sorption is a particularly important process that affects the rate of movement[2] and the time scale for removal of contaminants in either a liquid or gaseous phase. The degree of contaminant sorption is a function of its concentration in the fluid phase as well as of properties of the aquifer solids. Recent studies have indicated that the rate of partitioning between fluid and solid phases can be slow--on the order of weeks to months for at least some contaminants on some aquifer materials. This area is in need of greater study, for it can have a large impact on the time frame for restoration.

An additional complicating factor in estimating the movement of contaminants in the subsurface environment results with contaminants that are immiscible in water (e.g., oil or gasoline). Here, the oily phase can become trapped by capillary forces in the finer pore spaces of the aquifer so that the contaminants cannot be forced out by water moving through the system. The presence of such contaminants may be difficult to determine from monitoring of the water itself, but individual constituents can diffuse slowly out from the pore spaces to contaminate adjacent water over long periods of time. The density of some fluids, such as gasoline, is less than that of water, in which case they tend to float on the ground water table. However, capillary action causes a diffuse interface over which both water and the oil are present. The rising and lowering of the ground water table by recharge, discharge, or pumping can complicate these boundary conditions further. Heavier-than-water fluids, such as the solvent trichloroethene, tend to sink into ground water. However, solvent distribution at the boundary between the organic and aqueous phases can be equally complex. These complications need to be fully understood when making projections about time scales for aquifer remediation and the degree to which remediation might be effective.

Chemical and Biological Effects

Estimating of the potential for transformation of contaminants in the subsurface environment and the rate of such transformation requires knowledge of the chemical (pH, redox potential, etc.) and biological environment (type of microorganisms present and their transforming abilities under given environmental conditions). Transformations of many of the most common ground water contaminants of concern do occur, often producing other chemicals that are sometimes more hazardous than the original. Unfortunately, knowledge of what environmental parameters to measure and how to interpret them properly in order to predict the transforming potential in a given subsurface system currently is quite primitive. In addition, the important chemical and biological properties of an aquifer are so intertwined that they cannot be separated easily. Biological changes impart chemical changes, and chemical changes in turn affect the potential for given biological changes. Further, the addition of a contaminant to the subsurface environment changes both the biological and chemical characteristics to such an extent that they often dominate the characteristics that were present before contamination.

An example of the changes that can occur when a contaminant is introduced into the subsurface environment is illustrated in Figure 2.3. Acetone is a common solvent that is readily soluble in water, partitions little from water to aquifer solids, and is readily biodegraded under a wide range of environmental conditions by a broad range of microbial species. As the pure solvent, it is likely to be toxic to most microorganisms with which it comes in contact. But as it comes in contact with and dissolves in water--and thereby is advected away from the original point of contamination--it is likely to become sufficiently dilute so that it may be consumed by aquifer microorganisms. Here, it would be partially oxidized to carbon dioxide and water for energy and partially synthesized to produce new bacterial cells, thus increasing the population of the degrading population. The rate and extent of such reactions are functions of the concentrations of nitrogen and phosphorous species present that may be used for cell synthesis, as well as other characteristics such as temperature and pH. Transformations initially may be aerobic oxidations if dissolved oxygen is present in the ground water to serve as an electron acceptor. However, as the oxygen sources are depleted, the chemical environment becomes more reducing, and other microorganisms then may come into play. If nitrate is present, it could serve as the electron acceptor to a second group of bacteria, which would then flourish until the nitrates are depleted and ultimately converted into nitrogen gas. Then the environment would become more reducing and perhaps suitable for sulfate-reducing bacteria, if present, that could use the sulfate as an electron acceptor, converting it to sulfide, while oxidizing the acetone further. This results in a significant change in the chemical environment, and in the quality of the water. Sulfides are odorous, form complexes and precipitates with heavy metals that may be required for biological growth, and can bring about the chemical transformation of some halogenated organic species. When sulfates are depleted, and if there is sufficient acetone still remaining, a methane-producing a consortium of bacteria may come into action and convert the remaining acetone

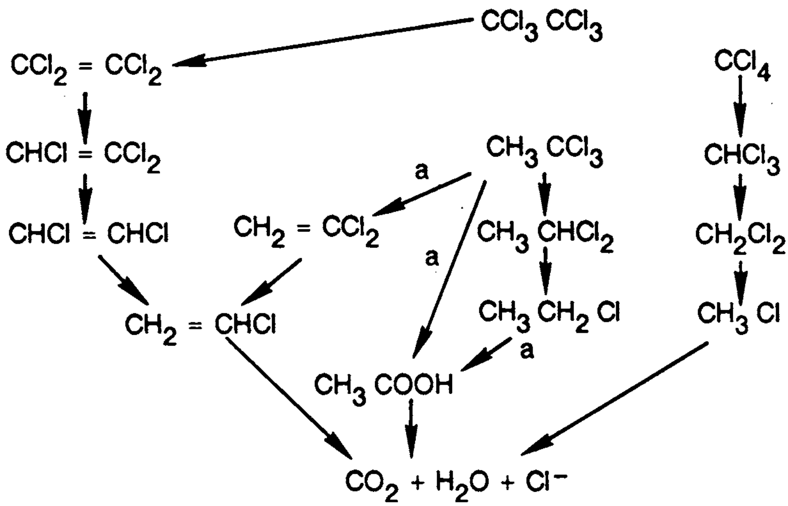

FIGURE 2.3 Abiotic and anaerobic biotic transformations of selected chlorinated aliphatic compounds. (Source: McCarty, 1988.[6])

into methane gas. By this series of biological processes, acetone would be destroyed, but, in turn, the production of several different populations of bacteria would be promoted, and the subsurface chemical environment would be altered greatly, but not necessarily for the better.

If the acetone described above were part of a mixture of chemicals--say, for example, one that contained the common chlorinated solvents carbon tetrachloride (CT), trichloroethene (TCE) and 1,1,1-trichloroethane (TCA)--then these chemicals would be likely to be impacted by the resulting chemical and biological changes in the system.[1,3] For example, within the second zone of denitrification, a good potential for CT transformation to carbon dioxide or chloroform would be created, and this potential for transformation would be enhanced by the increasing reducing conditions of sulfate reduction and methane fermentation.

TCA might begin to be transformed biologically in the sulfate-reducing zone to 1,1-dichloroethane and chloroethane, a process that would be increased in rate if the chemical reached the methane production zone. In addition, TCA would slowly be converted chemically into acetate and 1,1-dichloroethene. TCE would be at least partially transformed into an isomer of dichloroethene, which in turn could be converted into vinyl chloride. Although transformed at a slower rate, vinyl chloride might be converted biologically into carbon dioxide or ethene. These transformations are highly significant since the resulting products from transformation are considered more significant health hazards than the starting materials. Such transformations are most common and have been observed at numerous sites of contamination. At other sites, however, these changes have not occurred, largely because either the transforming bacterial populations are not present or a primary substrate such as acetone was not available to stimulate the buildup of appropriate transforming populations.

The recent development of the above knowledge about transforming processes for chlorinated solvents has been most helpful in interpreting monitoring data from contamination sites and in establishing the origins of contamination. However, we do not yet have adequate techniques for determining how the biological population at a given site will respond to a given contamination insult, the changes in the chemical environment that will result if they do respond, and what chemical changes in mixtures of chemicals actually will occur. Today we have a better understanding of what transformations can occur and why, but we still lack an ability to make adequate predictions of rates from observed surface chemical and biological characteristics. Our lack of knowledge here makes it difficult to take full advantage in a meaningful way of chemical and biological characteristics that may be determined for a given site.

LIMITS OF REMEDIATION TECHNOLOGY

Remediation Methods

Subsurface contamination frequently results from one or a series of point-source discharges of hazardous substances. As such, the concentrations near each point source often are high, and remediation generally consists of removal of the highly contaminated soils for separate cleanup, contaminant fixation, or transport and disposal in a secure landfill. This is generally the easier part of the problem and an essential first step in preventing further spread of the contaminants. What then remains are chemicals that have spread out from the original concentrated source by advection, volatilization, and dispersion, resulting in the contamination of relatively large areas with relatively dilute concentrations. Removal of soil to remediate the lower-contration areas could be exceedingly expensive and may result in far greater environmental damage than if the contaminants are left in place.

For the low-concentration, large-area contamination, several important questions arise. How might the contamination be prevented from spreading further? Is it possible to remove the contaminants from the subsurface zones for above-ground treatment and/or disposal without disturbing the integrity of the subsurface system? Is it possible to achieve in situ removal or fixation of the contaminants through chemical or biological means? What levels of cleanup are possible, and what time scales are required to achieve remediation with currently available technologies? Are there alternatives other than contaminant removal, fixation, or destruction for preserving subsurface resources that are environmentally acceptable? Answers to these questions are often difficult to obtain and depend to a large degree on the characteristics of the site hydrogeology and geomorphology and the nature, concentrations, and areal spread of the contaminants.

At one extreme would be the case described above of a spill of a single soluble nonsorbing contaminant, such as acetone, in a relatively homogeneous and porous substrata. Given an underlying ground water with sufficient nitrates, aquifer solids containing some phosphates, and the presence of sufficient sulfate and trace nutrients to satisfy the needs for bacterial growth, the acetone is likely to be degraded to inorganic end products without any human intervention other than the stoppage of further contamination. The natural assimilative capacity of the subsurface environment would restore the subsurface system, just as rivers restore themselves from a temporary insult. Undoubtedly, many, if not most, chemical spills onto the soil are cleansed in this natural way. Indeed, here in situ remediation occurs all the time.

At the other extreme is contamination of a heterogeneous subterrestrial system that is characterized by a complex of permeable and nonpermeable zones, fractured rocks, and discontinuities that become contaminated with immiscible contaminants that are resistant to biological transformation. In such cases, attempts at cleanup may be futile, and our best option simply may be to stop further contamination and prevent spread of the contamination that already exists.

In between the two extremes lie many situations where nature alone may not be able to cope adequately with insults from contamination in a timely fashion, and human intervention may be a feasible alternative. Here, likewise, some cases are simple and others are more complex. A prime goal of research and development on subsurface remediation is to push forward the frontiers of knowledge in order to increase the tools available to handle the more complex cases for which current solutions are overly costly and/or ineffective. A few examples are provided below to illustrate factors of importance, time scales, and the effectiveness of some potential remedies that are currently available or actively under consideration.

Pump-and-Treat Remediation

One of the most widely used methods for remediation of contaminated ground waters is the pump-and-treat method. Contaminated ground water is pumped to the surface, and contaminants then are removed in an appropriate treatment system so that the water can be discharged to a receiving stream, sprayed onto the soil, or perhaps reinjected into the subsurface system. Hall[4] recently presented a discussion of the difficulties and time frame involved in such treatment.

In Hall's scenario, a homogeneous aquifer with a thickness of 55 ft was contaminated over an area of 10 acres. The water in this volume could be exchanged in about 1 year by pumping at a rate of 100 gal/min. The velocity of ground water flow under the assumed conditions was about 2 ft/d, which perhaps is near the upper end that one could reasonably expect to achieve. If the contaminants were very soluble and the pumping system were very efficient, then 1 year would be an appropriate time frame for this ideal situation. However, in a practical solution, Hall indicated that 2 or 3 or more years would be required because of "tailing" effects often observed in such remedial action. Such effects are caused, for example, by contaminant migration into finer pores from which the water is only slowly exchanged with the bulk water moving through the aquifer.

If the contaminant tends to sorb, its movement with respect to that of water would be retarded. If sorption leads to a retardation factor of 5, then five years of pumping would be required under the ideal case, but perhaps 15 years would be necessary when one considers tailing. Retardation factors for contaminants such as TCE are as low as 1.5 to 2 and as high as 10 to 40 in relatively permeable aquifers, depending upon the composition of the aquifer material. Retardation factors for chlorinated benzenes tend to be much higher. Thus, pumping for 100 years may not reduce contaminant concentrations sufficiently for many chemicals, even under rather ideal conditions.

Hall went on to indicate that site remediation would be complicated exponentially if the contaminants are themselves constituents of a water-insoluble oily phase such as gasoline. Here, some gasoline would be trapped by capillary forces as described above and could not be removed easily by pumping. Individual components of the gasoline, such as benzene, toluene, and xylene (BXT), would tend to slowly bleed out into the water passing by at a rate characteristic of the complexities of each site. With reasonable assumptions and for the situation where 10 percent of the system void spaces were occupied by residual gasoline, Hall estimated it would take thousands of years to remove toluene or oxylene if no other processes were taking place.

Hall cautioned against being deceived that pumping at a faster rate would solve the problem. This would result in diluting the gasoline components as they emerged, but at some point would not increase the rate of release, for this would be governed principally by the rate of molecular diffusion. Obviously, in a system with complicated hydrogeology, the situation is even worse. Hall properly stressed the importance of understanding the system and the processes involved when projecting the time scale and effectiveness of the widely used pump-and-treat system.

In Situ Bioremediation

The limitations of pump-and-treat technology alone are becoming recognized more generally, and a search is under way for in situ techniques that do not require removal of contaminants from the subsurface system but rather treatment in place where the contaminant resides. Both chemical and biological processes are under active consideration. Enthusiasm is high for bioremediation since it has the potential not only for removing but indeed also for destroying organic contaminants by conversion to harmless inorganic end products such as carbon dioxide, water, and chloride. Thus, in situ bioremediation is an attractive alternative and, as indicated previously, is a natural process that undoubtedly rids the subterrestrial environment of many contaminants. The question arises as to how far this technology can be pushed. What are the opportunities it affords, and what are the limitations to its application? Questions of time frame and effectiveness also arise.

Studies over the past several years have indicated that natural subterranean processes are capable of transforming and do transform chemicals under conditions that previously were thought not possible.[3] Transformation of halogenated aliphatic compounds already has been mentioned. However, even aromatic hydrocarbons, such as the relatively water-soluble gasoline components BXT, are known to be degraded in the absence of oxygen,[5] given the correct conditions, which include sufficient time. We are not yet able to predict when and under what conditions this will occur, but the knowledge that it can and does naturally occur at times is now well founded.

Without letting anaerobic degradation of BXT occur naturally and without researching to find better ways to enhance this process, most efforts for in-situ bioremediation have concentrated on the aerobic process--that is, the addition of oxygen, nitrogen, and phosphorus to the subsurface environment to support an aerobic population that is well known to be capable of rapid degradation of BXT. This is one of the more established procedures for engineered in situ bioremediation. This process, however, does have its limitations, especially in heterogeneous systems where it is especially difficult to get oxygen and nutrients to the locations where the hydrocarbons reside. Again, it is important to consider the simpler case of a more homogeneous aquifer in order to learn of the minimum requirements to effect in situ bioremediation.

McCarty[6] provided an example of the requirements for remediating a ground water contaminated with 1,000 gal (6,000 lb) of hydrocarbon, say, gasoline. About 10,000 lb of oxygen would need to be introduced into the aquifer, and, if done by dissolving pure oxygen in water at one atmosphere of pressure, 30 million gal of such water would need to be injected into the aquifer. If limited in areal extent, then a limitation would be imposed on the rate of injection of the oxygen-saturated water. Even so, at a rate of 100 gal/min, this amount of water could be introduced within somewhat less than a year under ideal conditions. Along with this, about 875 lb of nitrogen (ammonia or nitrates) would need to be included, and as a result of the biological oxidation, an estimated 7,000 lb of bacteria would be produced. The latter may or may not tend to clog the aquifer, preventing normal ground water flow and perhaps reducing the efficiency by which the injected oxygen can reach the site of the gasoline spill.

Further limitations are imposed when the gasoline is trapped in micropores so that the oxygen and nutrients cannot reach the areas satisfactorily and by the normal lack of efficiency in controlling water and chemical movement so that they arrive at the particular locations where they are needed. Nevertheless, under certain conditions bioremediation may achieve restoration much more quickly than pump-and-treat technology alone. While this example may be encouraging for the application of biotechnology, one should recognize that its application would be best primarily for heterogeneous systems that can be well characterized. As with pump and treat methods, time scales for remediation are likely to be increased by orders of magnitude for contaminated heterogeneous systems.

OTHER REMEDIATION SCHEMES

There are many other potential schemes for remediation of contaminated subsurface environments that have good potential. One is vapor extraction of the vadose zone with either air or steam. This is proving to be effective for volatile chemicals, such as the halogenated solvents and petroleum hydrocarbons. The depth of the vadose zone may be extended in some cases through dewatering of the aquifer so that more of the system can be treated. However, many of the same limitations with hetergeneous systems exist here; also, the chemicals to be removed must be sufficiently volatile so that partitioning into the introduced gas phase is high. Successful application again requires a good understanding of the subsurface environment where contaminants reside.

It is not the purpose of this paper to discuss all the technologies for remediation since these will be introduced in other papers. Rather, the purpose here is to indicate how the degree of com- difficulty of remediation is a function to a large extent of the plexity of the subsurface terrain being remediated as well as of the characteristics of the chemicals associated with the contamination itself.

RATIONAL SETTING OF REMEDIATION CRITERIA

The above discussion is meant to convey a recognition that all subsurface contaminations are not created equal. Depending upon the nature of the subsurface terrain and the composition of the contaminants present, remediation may be relatively easy or virtually impossible. Advances in scientific understanding of the physical, chemical, and biological processes involved, together with improvements in technology for characterizing and remediating contaminated subsurface systems, are bound to increase the range of problems that can be addressed adequately. Nevertheless, there needs to be a recognition that there are many existing sites of contamination that, if not entirely beyond our ability for rectification in an environmentally satisfactory way, may at least require many years to remediate, may involve enormous sums of money, and may create other environmental and social problems that may be equal to or greater than that posed by the contamination itself. Because of the great diversity of the problem sites, setting criteria and priorities for cleanup is not a simple task. An easy solution is not likely to be found.

The technical difficulties, uncertainties, required time, and costs for effective remediation of contaminated soils and ground water need to be understood by regulators, policymakers, and the public so that more realistic remediation goals and expectations can be achieved. There is often a sense of frustration over the time required to make a remedial investigation and feasibility study for a given contamination site and an expectation that when this phase is completed, the job is essentially done. However, this is just the beginning. Even the effectiveness of proposed solutions is often quite uncertain because of the many unknowns inherent in site characterization and the absence of proven technologies for remediation. In such cases the most cost-effective solution often involves an iterative process in which the progress of remediation is evaluated periodically and the approach taken is modified as necessary. However, the parties who must pay for cleanup often hesitate to commit themselves to such an approach because of the uncertain costs entailed. The nature of these many problems necessitates that engineers and scientists find better ways to interact about them with policymakers and the public so that the complexities and uncertainties involved in site remediation are addressed adequately and more realistic policies and expectations are developed.

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3

What Needs To Be Done: A Policy Perspective on Ground Water and Soil Remediation

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INTRODUCTION

The process of defining and addressing ground water and soil contamination in the United States ranges from the comprehensive well-financed approach required at sites on the Superfund National Priorities List (NPL) to more modest, ad hoc, locally implemented cleanup efforts. The development of the appropriate process for different types of contamination incidents presents very different challenges for science and policy. Improvements are needed on many scientific fronts: sampling and monitoring methods, characterization of environmental and health effects, fate and transport modeling, and development of effective and reliable technologies. The challenge for policymakers is to develop the institutional framework, procedures, and guidance needed to make the most effective use of the science and achieve the best attainable environmental results given the limited financial resources available for analysis and remediation.

It is the thesis of this paper that policymakers thus far have made little progress in their effort to meet this challenge. There is much that needs to be done before the science and policy applied to ground water and soil remediation are compatible. Policy has to work with science to make sure that analytical methods complement the remediation process and that remedial technologies are affordable and well matched to the contamination problem to be addressed.

This paper explores three interrelated policy issues: financing of cleanups, criteria for making remediation decisions, and delineating the public's role in the remediation process. The paper concludes with a discussion of what needs to be done to address these policy issues and to improve our ability to respond to contamination incidents. Although the title gives equal billing to ground water and soil, the primary focus of the paper is on ground water because it is generally more costly to clean up and poses a greater challenge for science and policy. Whenever reference is made to the "resource," the discussion is intended to apply to both ground water and soil.

WHO PAYS FOR REMEDIATION?

The determination of responsibility for abatement probably is the most overlooked and yet most important factor affecting the remediation process. For a typical incident, public remediation funds are very limited. Thus, whether responsible parties (RPs) can be compelled (and have the ability) to conduct or pay for part or all of the cleanup will have an important bearing on the extent of the investigation and cleanup effort.[1] The first step in determining who will pay for remediation is to identify the lead agency's options for compelling the responsible party to (1) conduct the cleanup or (2) contribute to the cost of the cleanup (if performed or contracted out by the lead agency).

Injunctive Relief and Order Authority

Injunctive relief is the traditional method of dealing with environmental contamination and is based on statutory and common law. The agency must present its case to a court, which, if it agrees with the agency, can order the RP to conduct the cleanup.

In addition to injunctive relief, a state or local agency typically can invoke one of several statutes or ordinances to order RPs to conduct or pay for remediation activities. Local fire or safety ordinances usually provide authority to take emergency measures to compel RPs to secure the source of contamination and mitigate the imminent threat of fire or explosion (e.g., petroleum releases to soil or ground water) but probably are of limited use unless an emergency occurs; they cannot be invoked if public health only is threatened. Most states have statutory water or hazardous waste authority that enables them to order additional remediation or restoration. States also can make use of common nuisance law to order abatement.[2]

At the federal level the EPA has the authority to order cleanup of hazardous substances under §106 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), cleanup of hazardous wastes under §3008(h) of the Resource Conservation and Recovery Act (RCRA), and cleanup of oil and hazardous substances under §311 of the Clean Water Act. If ground water is contaminated, §204 of the Safe Drinking Water Act can be invoked to require RPs to provide alternative water supplies.

Cost Recovery

The lead agency's ability to recover costs from RPs is much more limited than its authority to order abatement.[3] Assuming the agency has resources that allow it to incur remediation costs, it may recover the costs of analysis, remediation, oversight, and related enforcement activities under §107 of CERCLA or comparable state authority. More limited cost recovery authority (investigation and monitoring costs) is provided in §3013 of RCRA for incidents involving hazardous wastes. If the source of contamination is an underground storage tank, §9003(h) of RCRA provides cost recovery authority comparable to §107 of CERCLA. Apart from the federal and state superfunds and the Leaking Underground Storage Tank Trust Fund, public resources typically are limited or unavailable for soil and ground water remediation.[4] Thus, there has been little impetus to develop cost recovery authority at the state and local levels. However, states may be able to recover "reasonable costs for abatement" under the public nuisance doctrine of common law.[5]

Injunctive relief and order authorities are used in an ad hoc manner without agencies having a full understanding of the attributes of the alternatives, such as (1) the time and resources required to prepare, issue, and enforce an order; (2) limitations on what actions the agency may order the RP to do; (3) the evidentiary requirements for proving liability; and (4) the probability of successfully using an order for different types of contamination incidents. Except in cases in which the lead agency needs to expedite the investigation or response action and resources are available, the lead agency should attempt to use its order authority or pursue injunctive relief against RPs rather than rely on cost recovery.

Ability To Pay

The real nightmare for the lead agency is discovering that responsible parties lack the financial resources to comply with the abatement order. Most firms insure against typical industrial accidents but often have inadequate environmental liability insurance, or environmental insurance simply is unavailable to them. The government has the power to require not only insurance but also to place certain stipulations on the minimum amount required and how it is to be allocated between abatement and third-party claims.

It seems like a simple problem; if a regulated industry is underinsured, require them to increase their coverage. However, a major obstacle in implementing "financial responsibility" regulations is that insurance either is not available or is not affordable by a large percentage of the regulated firms. An agency is faced with two unpleasant choices. It can enforce the regulations, issue fines, and/or compel firms to shut down if they fail to comply. Alternatively, the agency can suspend enforcement, allowing firms to continue operation, and shift the potential burden of remediation to the government and private parties in the vicinity of a release.

The ability of RPs to finance cleanup and the availability of public funds for this purpose will play an increasingly important role in defining the remediation process. The more we look, the more ground water problems we find. Thus, the increased demand for cleanups will exacerbate the pressure on agency resources and accentuate the need to ensure that RPs can share in the costs of cleanups.

REMEDIATION DECISIONS

Should We Clean Up the Contaminated Resource?

Economists are about the only people who would even ask this question. The public assumes that the government will compel RPs to conduct cleanups and restore the contaminated soil or ground water to its previous level of quality. This perception is predicated partly on the belief that environmental statutes and regulations require some degree of remediation. Furthermore, the "polluter pays" principle embodies the notion that firms should be held liable for damages and abatement costs associated with their activities. Yet there may be situations where remediation is not desirable. Some specific examples follow.

The Costs of Cleanup Far Exceed the Expected Benefits of Cleanup

Most environmental programs do not explicitly require or even permit the use of benefit/cost criteria for making remediation decisions. Usually, cost-effectiveness criteria are used to compare alternatives that produce similar environmental results. However, cost-effectiveness criteria are not as useful for comparing remediation and "no-action" alternatives.

There are several objections to the use of economic criteria, most of them related to the problems (and cost) of estimating the benefits of remediation. From an economic perspective, corrective action should be undertaken if the expected benefits exceed the costs. This net-benefits criterion is predicated on the assumption that there is no budget or resource constraint. If there is a budget constraint, an agency might rank cleanups in terms of the ratio of benefits to costs and conduct those cleanups with the biggest "bang for the buck" until the bucks run out. Thus, if an agency has limited resources to spend on cleanups (for which RPs are not viable), it may need to set priorities in order to allocate these funds to ground water and soil remediation.

There are two inherent problems in applying the net-benefits criterion to soil and ground water remediation: (1) the difficulty of valuing the resource before and after remediation and (2) relating remediation activities to improvements in resource quality.

Measuring Benefits. Benefits are equal to the increase in the value of the damaged resource resulting from corrective action. For example, if the water is unusable as a result of contamination, the benefits are equal to the value of the water after restoration. Even in this simple example where the value of the resource is assumed to fall to zero because of contamination, there are numerous methods available to value the resource, including the alternative cost of water as a proxy, the consumers' willingness to pay for water estimated in contingent valuation surveys, or the valuation by administrative fiat.

In cases when damages are less than the total value of the resource, benefits estimation requires placing a dollar value on the health effects associated with the contamination and evaluation of the costs of averting actions. Typically, analysts avoid monetizing health effects by expressing net benefits of remediation as a ratio of costs incurred to mitigate a unit health effect (e.g., $3 million per cancer case avoided).

Remediation and Quality Improvements. To estimate the benefits of remediation, it is assumed that the change in resource quality when a given remediation plan is implemented is known with certainty. In fact, it is often difficult to know ex ante whether a particular remedy will result in the desired improvement. There are many sources of uncertainty that affect the environmental results of remediation, including delineation of the area of contamination; knowledge of the distribution of contaminant concentration levels over this area; fate and transport properties of the floating or dispersed plume; and effectiveness of the technologies in the given environmental setting measured in terms of contaminant removal rates, ability to impede contaminant flow, and so on.

Given the problems of valuing the benefits of cleaning up contaminated resources, the net-benefits criterion would seem to have limited usefulness as a sole criterion for deciding whether to conduct remediation. Nevertheless, it is a useful way of organizing information germane to the remediation decision.

The Contaminated Resource Is Not Currently Used and Is Perceived To Have a Low Potential or "Option" Value

This case arises frequently when a release is reported by the offending party rather than detected by users of the contaminated resource. Further investigation of the incident may indicate that the contamination is confined to a shallow aquitard or aquifer of low quality or that there is no current demand for the affected resource because of the availability of cheaper alternatives. Nevertheless, the resource may have some potential future use and hence a nontrivial option value. Option value has intuitive appeal but in practice is difficult to measure. In the context of ground water, the magnitude of option value would seem to depend on the scarcity of alternative supplies as well as the consumers' willingness to insure against risks. Efforts to estimate option value have relied on the use of contingent valuation surveys.[6] However, this method is not practical in the time frame in which remediation decisions typically are made, is too expensive, and is likely to yield unreliable estimates.

How can remediation decisions be made when the damages represent a reduction in option value? Three suggestions follow. First, decisionmakers should examine the nature of water availability. If there is a strong possibility that the resource will be used in the future, remediation should be considered.[7] Second, provided the decision to conduct remediation can be put off, the time frame for potentially using the resource is also an important factor. Third, the decisionmaker might pose the remediation decision as follows: given that we do not know what the option value is, if the costs of remediation are not unacceptably large, we should consider undertaking remediation.

There Are Inexpensive Substitutes for the Contaminated Resource

In this case the remediation decision is a choice of replacing or restoring the damaged resource. If the relative cost of providing replacement water is much less than the cost of restoration (assuming comparable quantity and quality characteristics), it is desirable on economic grounds not to conduct remediation (ignoring option-value considerations). The major drawback of basing replacement/restoration decisions on the relative costs of each option concerns the "tyranny of small decisions." The tyranny of individual remediation decisions is that it is assumed that a given decision is independent from other decisions. Yet each time the decision is made to replace rather than restore a ground water resource, potential future supplies are tightened. Each replacement decision may have only a small marginal effect on the scarcity rent attached to water supplies, but when these small effects are summed up over many sites, the aggregate effect may be quite large. From a state or regional perspective, we might find that it would have been advantageous to conduct more remediation activities, even though replacement was preferred in terms of relative costs.

The Resource Will Not Be Used After Remediation Because Users Take Permanent Averting Action

This is a common problem in areas where private residential wells are used even though public water is available. Residents may have preferred the quality or taste of well water, or the high cost of extending public water lines previously discouraged conversion. The lead agency therefore must assess the likelihood of future use of the abandoned resource.

The Contamination Does Not Degrade Water Quality to a Level That Would Be Considered Unsafe or Unhealthy

For example, contamination levels may not exceed established action levels or maximum concentration levels. Agencies may be precluded from ordering or conducting remediation activities unless the threshold is exceeded. The agency probably will decide to set up a monitoring program if funds are available or may be able to force RPs to monitor or study the problem (CERCLA §104; RCRA §3013).

The Contamination Has Not Yet Affected but Threatens a Valuable Ground Water Resource

This is clearly one of the most difficult situations to assess. The decisionmaker needs to consider a number of factors, including the value of the potentially threatened resource, the potential magnitude of damages if contamination occurs, the probability of contamination, the relative cost and effectiveness of conducting remediation now as opposed to addressing the contamination later, and the availability of resources to fund remediation. The scales typically will tilt in favor of remediation, especially if the general public puts pressure on agency officials. RPs also may favor remediation to avoid potentially higher cleanup costs and third-party damages and to minimize negative publicity.

These "special" cases occur often enough to suggest that it may be worthwhile for agencies to develop policies and criteria for deciding whether remedial action should be taken.

How Much Remediation Should Be Undertaken?

Once the decision to proceed with remediation has been made, the lead agency must make three related remediation decisions. First, the agency must prepare the background analysis on the extent of the problem and remedial alternatives. Second, the agency must select the remedy. A number of criteria related to technical attributes of the remedy, environmental goals of remediation, and financial/economic factors may be considered in the selection process. Finally, after the remedy has been implemented, the lead agency subsequently may need to make a decision on when to stop remediation activities. Clearly, the necessity of making this last decision depends on the type of remedy selected.

Preliminary Analysis

The analysis required to enable an agency to select the remedy can be quite complicated and expensive and may require an inordinate amount of time to complete. For example, preparation of the Remedial Investigation/Feasibility Study (RI/FS) for a Superfund site may cost in excess of a million dollars, run several thousand pages, and take 3 years or longer to complete. Yet this effort only provides the basic information to select the remedy; additional time and expense then are required to make the decision and prepare the Record of Decision.

The Superfund RI/FS effort is not typical of the analysis that state or local agencies conduct before selecting the remedy. Even for contamination incidents similar to those in Superfund, many states have limited the time and resources available for RI/FS activities. For other types of contamination incidents, there may not even be an established protocol to guide the collection of information and analysis of remedial alternatives or resources available for such investigation.

What level of effort should be devoted to investigation? Among the factors the agency should consider are the availability of funds to finance the investigation, the time allocated to the investigation, and the information required to apply the remedy-selection criteria. Typically, funds are quite limited for investigation, or a ceiling has been placed on these expenditures. How much is spent should be a function of the contribution the analysis makes to the remedy-selection process in allowing the agency to identify the most cost-effective remedy. In economic terms, if a dollar of investigation reduces the total costs of the remedy by more than a dollar, it is desirable to expand the scope of the investigation. Unfortunately, this is a difficult calculation to make ex ante. The time required to complete the investigation also is difficult to determine. It depends partly on the nature of the analysis, characteristics of the site and the contaminated resource, and the availability of personnel to conduct and review the analysis. If the agency uses complicated remedy-selection criteria, there will be a greater corresponding demand for supporting information and analysis. If an agency decides to limit the scope of the investigation, it needs to ensure that the selection criteria can still be effectively applied. Clearly, coordination between science and policy is critical, and the technical supporting analysis needs to complement the decision framework. If this analysis of the investigation is not state of the art, its limitations need to be conveyed to the decisionmaker.

As an aside, EPA's Superfund RI/FS process recently has been criticized because of the cost of an RI/FS, the time required to complete an RI/FS, and the scope of the analysis. Some critics point to delays in reviewing the RI/FS, but most are concerned primarily with the content of the RI/FS and favor streamlining the investigation to save money and time.[8] Yet, if anything, the need for information in the remedy-selection process has increased following statutory changes made by the Superfund Amendments and Reauthorization Act in 1986.[9] Furthermore, given the criticism directed at EPA because of the perceived inadequacy of remedies at some NPL sites,[10] streamlining the RI/FS process may only invite additional criticism.

Remedy Selection

In selecting the remedy, the lead agency may apply several criteria; they may consider various technical attributes of alternative remedies, such as permanence, uncertain performance, and effect on risks (e.g., move, eliminate, stabilize contaminants). There also may be established cleanup standards or goals that the agency requires every remedy to satisfy.

There has been much debate over the question of "how clean is clean?" There are essentially three parts to this debate: (1) Should there be generic (as opposed to site-specific) standards? (2) If so, at what numerical levels should they be set? (3) When should an agency relax these requirements?

It is difficult to argue against the establishment of cleanup standards. The public perceives that environmental and health agencies are responsible for protecting their health and the environment. Standards or quality goals represent measures that, when met, provide assurances to the public that they are safe from harm. The most controversial element of the debate is the problem of selecting the appropriate numerical level; the public wants stricter standards, industry wants less burdensome standards, and agencies are caught in the middle. Until we can close the multitude of gaps in our understanding about health and environmental risks, the effectiveness of abatement technologies, and the benefits and costs of alternative numerical levels, the selection of standards will be a veritable crapshoot.[11]

The third element of the debate concerns relaxing the requirement that cleanups comply with established standards. There may be instances when the best available technology will not enable us to achieve the standard or its achievement will be extremely costly. Other factors, such as uncertainty about the environmental results of alternative remedies and funding constraints, also may suggest the need for flexibility. Agencies perhaps will have waiver provisions that consider some balancing of costs and risk reduction when remedies are not expected ex ante to satisfy cleanup standards.

Stopping Remedial Action

This is one of the more overlooked decisions that an agency has to make. A remedy has been selected and implemented and the agency is monitoring ground water quality or recovery rates. At what point can an agency terminate the cleanup? If water contaminant concentrations have dropped below established standards remediation, this is an easy decision to make. However, when remediation is having little effect on contaminant concentrations or contaminant recovery rates have dropped, the agency has to consider several factors before stopping the remediation: the relationship between current contaminant levels and the cleanup goal, the period of time over which the remedy has been ineffective, the current marginal costs of the remedy, the future availability of funds for remediation, the knowledge of the characteristics of the plume, the implications of stopping remediation for the use of the resource, and the relative costs of alternative treatment and substitute remedies. The variation in individual contamination incidents precludes the development of rigid rules for terminating cleanups, but there is little guidance available to aid decisionmakers.

THE PUBLIC'S ROLE IN THE REMEDIATION PROCESS

Once a contamination incident has occurred, the public often is involved at three stages of the process. First, the public may provide information about resource use and the nature of the contamination that helps the agency develop an understanding of the extent of the problem. Second, the public is a "client" of the agency during the initial response phase when decisions on alternative water supplies are made. The public may have to make averting decisions, working with the agency or water utilities to arrange for substitute supplies or bottled water. This stage represents an important challenge for the agency, for it must communicate the risks to the public of exposure to contamination and the options for avoiding exposure. Third, the public may have some role in making the remediation decisions discussed in the two previous sections. This role may be mandated statutorily, required in regulations, or simply may evolve because of local attention generated by the contamination incident.

Whereas the public's role in gathering information and taking averting action is desirable, the public's role in making decisions is more controversial. Among the advantages of public participation is that individuals bring professional skills to the process that may be limited otherwise by agency funding and personnel constraints, thus improving the review process; agencies are better able to determine the community's valuation of the damaged resource and their demand for restoration; and public involvement is an essential element of consensus building. However, public involvement tends to slow down the process because it creates additional levels of review. The public has a vested (and in many circumstances an emotional) interest in the outcome of the process. It may be difficult for the public or the agency to keep the magnitude of the problem in perspective.

On balance, it would be inappropriate to exclude the public from the decisionmaking process altogether. The challenge for an agency is to try to minimize the negative aspects of public involvement. There seem to be three key steps to successful public involvement. First, the agency must lay the ground work for public trust through an effective risk-communication effort and clear presentation of the public's near-term averting options. Second, the agency needs to educate the public about the remediation process and the series of decisions that are made, highlighting the balancing of interests required to reach consensus on remediation. Third, agencies must develop objective selection criteria and must prepare guidelines for assigning weight to individual criteria.

WHAT NEEDS TO BE DONE

In the previous three sections, issues in which improvements are needed before we can respond effectively to contamination incidents were discussed. This concluding section focuses on some general policy recommendations. These ideas are organized around two themes: the need to lay the ground work for responding to contamination incidents and the challenge of designing and implementing the remediation process.

Planning To Protect Ground Water Resources

An important first step in protecting ground water is developing a better understanding of the resource and its value, the current and expected future demand for water, and the availability and costs of substitute sources of water. We also need to identify the location of potential sources of contamination, the expected health and environmental impacts of these contaminants, and the likelihood of contamination. These planning activities will enable agencies to respond more quickly when an incident occurs and to determine the extent of, scope of, and demand for remediation.

State and local agencies, perhaps as part of much-needed contingency plans, should develop guidance on the options available to them for ordering abatement, including analysis of the advantages and disadvantages of each approach at different stages of the remediation process and for the various categories of contaminants. One advantage of investigating order authority as a planning activity rather than waiting until a contamination incident occurs is that environmental agencies can assess the adequacy of their existing authorities and determine whether new statutory authorities are needed. Also, agencies can better proceed with their initial investigation of a release incident if they understand the burden of proving liability and the information required by a court if the order is challenged. Agencies also need to determine whether a particular regulated community is able to meet its financial responsibilities for contamination incidents. If the government perceives that a significant proportion of regulated firms are unable to self-insure or to obtain insurance, there are options other than enforcement of financial responsibility rules at one extreme and suspension of enforcement at the other. First, the government might help uninsured firms organize private risk pools. Second, the government might want to reexamine minimum insurance requirements. If a minimum level is set that will provide adequate funds for 99 percent of incidents but only half the regulated firms can obtain or afford insurance, it may be useful to consider reducing the minimum insurance to a level at which most firms can obtain insurance, even though some percentage of incidents will cost more than firms or their insurers can contribute. If such a policy is adopted, agencies must recognize that public funding will be required to remediate some incidents or else they will be compelled to cut back on the response effort. Third, agencies may impose additional prevention measures on firms that are unable to obtain insurance (e.g., more frequent monitoring around facilities or leak detection, if appropriate). In effect, stricter preventive measures provide a way to force firms to internalize some of the costs of their production activities.

Agencies also need to assess the realistic prospects for restoring ground water quality after a contamination incident occurs and determine whether their management strategy includes the appropriate mix of prevention/detection measures and corrective action. Factors such as valuable ground water resources, few affordable substitutes, limited public and private funds for cleanup, and high costs and limited effectiveness of remedies indicate greater emphasis on prevention.

Finally, on a more global level, agencies and the public need to evaluate ground water management in a comparative risk context. Agencies need to know what the level of the public's commitment is to protecting ground water vis a vis other environmental resources and what public funds will be made available to staff the remediation program, support the remediation process, and pay for cleanups. Agencies also need to inform the public about the comparative risks and the risk trade-offs involved in a decision to remediate one problem at the expense of others. This assessment will help agencies develop a remediation framework that is consistent with the public's expectations about ground water remediation and is appropriate, given funding constraints.

The Remediation Process

The most important policy need is to develop realistic criteria for making remediation decisions. We need to find a balance between technical and economic criteria and to identify statutory constraints on what remedies can be implemented and what cleanup standards, if any, limit the selection of remedies. As indicated earlier in this paper, greater attention should be focused on developing criteria to guide the decisions concerning whether to undertake remediation and when to stop remediation.

To ensure that the remediation process can address cleanup effectively , better coordination between science and policy is required. Decisionmakers must communicate to scientists their analytical needs, the time frame for making decisions, and resources available for investigation. One major task facing scientists is how to characterize the uncertainties in the analysis of the contamination problem and the effectiveness of remedies and present this information to decisionmakers. When appropriate and affordable, sensitivity analysis should be conducted as part of the investigation. It is important also to distinguish between two types of uncertainty: uncertainty that is due to stochastic factors and the high costs of information (e.g., accurately predicting the fate and transport of contaminants in ground water) and uncertainty that can be attributed to our lack of knowledge or experience in using technologies or assessment methods. For the first type of uncertainty, science and policy must work together to ensure that the remediation process has the flexibility to evaluate and respond to information that becomes available during the remediation process or after the remedy has been implemented. For the second type of uncertainty, there are two major needs. First, agencies have made little use of retrospective studies, but these are important in helping us to determine if there is any systematic bias in our predictions of how well a remedy will work. Second, there needs to be greater exchange of information between agencies about remedies. A remedy clearinghouse would enable agencies with more limited resources to gather effectively information about remedial options. At the present time, such information networks do not exist, even in large national programs such as Superfund.

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NOTES

1. Typically, there are statutory provisions that enable private parties or public agencies to recover damages from RPs. Clearly, the threat of these actions affects RPs' ability to pay for cleanups.

2. Halper, Louise A. Public nuisance and public plaintiffs: Rediscovering the common law (Part 1). Environmental Law Reporter, 16 ELR 10-86, pp. 10292-10299; see also Anderson, D. Mandelker, and D. Tarlock, Environmental Protection: Law and Policy, pp. 638-639 (Little, Brown and Company, 1984).

3. The one exception to this general rule is the provision in CERCLA §107 for collecting treble damages in addition to recoverable costs.

4. We need to recognize that public funds for cleanups often are derived partly from taxes on the regulated community. Thus, private firms may pay indirectly for cleanups, and the private firms will, to the extent that they can, shift some of the direct or indirect costs of remediation to consumers of their products.

5. See State of New York v. Schenectady Chemicals, Inc., 103 App. Div. 2d 33, 479 N.Y.S. 2d 1010 App. Div. (1984).

6. Freeman, A. Myrick III. "Non-use Values in Natural Resource Damage Assessment. Paper prepared for the Conference on Assessing Natural Resource Damages, Resources for the Future, Washington, D.C., June 16-17, 1988.

7. On the other hand, for example, in New Jersey certain surficial aquifers are "written off" or "red-lined" as well-restriction areas because of preexisting contamination and the availability of alternative supplies (from interview with staff in the Bureau of Underground Storage Tanks, New Jersey Department of Environmental Protection, May 25, 1988).

8. See Superfund from the Industry Perspective: Suggestions to Improve and Expedite the Superfund Remediation

Process, a booklet recently published by a group of industries including ATT, Conoco, E.I. du Pont de Nemours & Company, General Motors Corporation, General Electric, and Monsanto Company. The report suggests (1) a model RI/FS for a class of sites and (2) an FS that would focus on one remedy. Inside EPA. February 17, 1989, p. 13.

9. See CERCLA section 121, Cleanup Standards, for the selection of remedial action, degree of cleanup, and other requirements.

10. See Right Train, Wrong Track: Failed Leadership in the Superfund Cleanup Program, a Comprehensive Environmental-Industry Report on Recent EPA Cleanup Decisions, Environmental Defense Fund, Hazardous Waste Treatment Council, National Audubon Society, National Resources Defense Council, National Wildlife Federation, Sierra Club, and US PIRG, June 20, 1988; and Are We Cleaning Up? 10 Superfund Case Studies, a Special Report of OTA's Assessment on Superfund Implementation, Office of Technology Assessment, Congress of the United States, June 20, 1988.

11. A similar perspective is offered by Bazelon: "[M]any times an agency must act in circumstances that make a crap game look as certain as death and taxes." Bazelon, David L. Science and uncertainty: A jurist's view. Harvard Environmental Law Review Vol. 5, No. 2, 1981, p. 212.

4

Characterization of the Distribution and Behavior of Contaminants in the Subsurface

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ABSTRACT

Information on the distribution and behavior of contaminants in the subsurface at contaminated sites is necessary (1) to understand the nature of the existing problem and the current or potential public health or ecological risks; (2) to set site-specific cleanup goals that are feasible; (3) to design a remediation program that is reliable, affordable, and likely to achieve the cleanup goals; (4) to evaluate the effectiveness of the cleanup over time and refine the remediation program, if necessary; and (5) to reach an informed consensus that the remediation program is complete. Yet the information alone is not sufficient; there also must be satisfactory understanding of what the information implies on the part of both the implementor and regulator of the site remediation.

The goal of this paper is to illustrate, by selected examples, that the scientific/technical tools are not always adequate to yield unambiguous information and that the professionals involved in the design and regulation of site cleanup are not infrequently in error in application of the tools and the interpretation of the available information. Thus, the cleanup process often has been slow and fraught with mistakes. Furthermore, rather serious incompatibilities have arisen among science, policy, and public perception: (1) policy goals (e.g., desired cleanup levels) and/or regulatory criteria may seem precise to regulators and the public but in fact are vague and perhaps practically infeasible, and (2) the apparent precision of the regulation may incorrect impression to the public that ground water contamination investigations and remediations are relatively simple matters whose slowness can be blamed entirely on bureaucracy and/or irresponsibility. While the latter two

problems certainly exist, the overall effect is to harden a process that would work much more efficiently if it were characterized by more understanding of the difficulties of every step, more trust between the involved parties, more flexibility in the regulations, and more willingness to try new approaches.

CONTAMINANTS IN A MAZE

Envision an extremely complex, three-dimensional maze in which are lost a variety of chemicals--some concentrated and localized, and some dilute and spread out. Imagine further that the chemicals all are moving at different rates and directions as a result of gravity and/or the flow of air and water through the maze. Then imagine that the internal walls of the maze are porous, like a hedge, and that the chemicals, air, or water can move into and even through them at rates that vary throughout the maze. Lastly, imagine that you must find and remove all of the chemicals but cannot enter the maze to do so.

This, in essence, is the problem confronting those trying to clean up contamination in the subsurface. It is an exceedingly complex problem to which research and practical investigations have been directed for a relatively brief period of time. Thus, because of the real or perceived urgency of remediation, large and expensive cleanups have been and will continue to be undertaken with only a limited understanding of the structure of the maze, the types and amounts of chemicals within it, and the processes that lead to the movement of the chemicals within the maze or control the removal of the chemicals from it. Furthermore, because scientific understanding of ground water contamination and remediation is expanding so rapidly, the implementors and regulators of remediation often may be unaware of new insights and investigative or remediation methods arising from the efforts of their scientific colleagues.

A number of publications have described the hydrogeologic complexities of the subsurface as they impact contaminant movement and/or the processes that lead to varying transport and fate of different contaminants within a given geologic environment (e.g., Freeze and Cherry, 1979; Miller, 1980; Cherry et al., 1984; Mackay and Vogel, 1985; Mackay et al., 1985; Feenstra and Cherry, 1988; Schwille, 1988). These publications and the results of practical investigations suggest that, with limited initial understanding of the hydrogeology and contaminant transport processes, remediation programs are likely to be inefficient, expensive, and lengthy.

Recently, Mackay and Cherry (1989) and McCarty (chapter 2, this volume) reviewed some of the reasons that ground water cleanup programs may be slow, showing by illustration the value of detailed knowledge of the hydrogeology (the structure of the maze), the distribution of contaminants, and the processes controlling contaminant removal. The purpose of this paper is to evaluate our ability to gather and interpret field data describing these important issues. Because the topic is so broad, only a few illustrative issues will be discussed, with a focus on organic contamination.

DECREASING UNCERTAINTY ABOUT THE MAZE

The first goal of a site investigation is or should be to gather as much insight as possible into the structure and permeability of the subsurface, particularly the features that are of importance to contaminant migration and removal. For fractured rock environments, currently this is nearly impossible. For granular subsurface domains, the situation is considerably better but still not completely satisfactory. For example, as much of the new research shows, the behavior of contaminants within the granular subsurface domains during uncontrolled migration or remediation programs is strongly dependent on variations in permeability and other characteristics affecting contaminant behavior (Pickens and Grisak, 1981; Pickens et al., 1981; Guven et al., 1985; Molz et al., 1986; Palmer and Nadon, 1986; Huyakorn et al., 1986; Mackay et al., 1988b; Molz et al., 1988). Mackay and Cherry (1989) illustrate that even relatively slight vertical variations in characteristics of permeable deposits can greatly reduce the efficiency of cleanup programs designed on the assumption of homogeneity. A recent field experiment on organic contaminant flushing from a highly permeable but somewhat stratified sand/gravel aquifer illustrated this point (Mackay et al., 1988b). Furthermore, the presence of low permeability clayey lenses or strata within otherwise permeable sand/gravel aquifers can reduce significantly the rate at which contaminants can be removed by flushing (EPA, 1987; Mackay and Cherry, 1989).

Unfortunately, the methods commonly applied in investigations of contaminated granular media yield data at too coarse a scale to fully characterize the variability of structure, particularly the presence of thin, low-permeability zones. Furthermore, the common analyses of aquifer tests (pump tests) and core samples miss slight but important stratification within the permeable media and generally do not address the characteristics that control the relative mobility of contaminants (i.e., sorption capacity of the solids for contaminants). Finally, aquifer tests, when applied in site-remediation investigations, are expensive to conduct, in part because of the health and safety procedures that may be required to protect workers during well installation and the conducting of the test, but also because they produce large volumes of water that may be contaminated and require disposal by expensive means.

Thus, an active area of research is the development of new techniques for characterization of fractured rock and granular aquifers. For granular media the following offer promise. New methods for collection of continuous core samples have been developed (e.g., Zapico et al., 1987; Clark, 1988) that are more representative of the in situ conditions than those collected in noncontinuous short increments by standard techniques; such samples can be subjected to a variety of analyses in the laboratory (e.g., porosity, bulk density, hydraulic conductivity, sorption capacity, etc.). Another area of considerable interest is the use of surface geophysical methods for inferring subsurface conditions (e.g., see several papers in Collins and Johnson, 1988, and references cited therein). A host of other techniques have been developed and applied, such as slug tests for hydraulic conductivity estimation (Hvorslev, 1951) and in situ flow meters for ground water velocity estimation and flow direction (Kerfoot, 1982; Guthrie, 1986; Kerfoot, 1988). Unfortunately, practical experience with many of these methods has, to date, lagged behind expectations.

Other researchers believe that field tracer tests are the best way to characterize the flow regimes in granular aquifers (e.g., Melville et al., 1988) and perhaps also fractured rock aquifers. Most tracer tests have been applied in uncontaminated granular aquifers (e.g., Pickens et al., 1981; Molz et al., 1988). Other tracer tests have been conducted in contaminated granular aquifers with the primary goals of estimating contaminant transport properties (e.g., Whiffin and Bahr, 1985; Bahr, 1989), as discussed later. Recently, Mackay et al. (1988b) tested a combination of these field approaches intended to yield estimates of both hydraulic and solute transport properties of contaminated granular aquifers. Such field tracer tests are capable of yielding considerable insight into granular aquifer characteristics pertinent to contaminant behavior but are more complicated to conduct than aquifer tests, and to date, they have been applied rarely in practice, though their potential usefulness is high.

In summary, the available tools to define the structure and permeability of the subsurface are many, but their current practical utility is surprisingly limited. There is a clear need for improved methods for granular and especially fractured rock aquifers. Furthermore, given the anecdotal evidence of misuse or misinterpretation of the available methods, there is a need for consensus on their application and interpretation.

FINDING THE CONTAMINANTS IN THE MAZE

The conceptual goal of monitoring systems should be to track through time the three-dimensional distribution and form of all pollutants released in significant quantities to the subsurface. Thus, the practical goal of monitoring systems has been to collect representative samples from the subsurface that can be subjected to analyses to determine the types, amounts, and, if possible, physical states of pollutants present. Regarding the latter, for example, many organic contaminants may exist within the subsurface in combinations or all of the following states: organic liquid (a.k.a. nonaqueous phase liquid or NAPL), vapor, dissolved in water, or sorbed to solids or colloids. As illustrated by Mackay and Cherry (1989), the design and/or efficiency of remediation programs will depend strongly on the distribution of the contaminant mass among these phases.

A considerable amount of attention has been paid by researchers, site investigators, and regulators to the tools used to detect contaminants in the subsurface. Consequently, there is a rich literature covering this broad topic, which includes techniques for monitoring in the unsaturated and saturated zones; methods for collecting representative samples from the monitoring devices; materials for construction of the monitoring and sample collection devices; and protocols for storage, transport, and analysis of the samples (see, e.g., the many papers included in the book edited by Collins and Johnson, 1988). In this brief discussion we focus on only a few issues that appear to be less well explored.

Determination of Three-Dimensional Distribution of Dissolved Contaminants

Monitoring wells must be carefully located and installed to yield representative samples or head determinations from precisely known intervals in the subsurface. Unfortunately, it appears that this is not always the case. Anecdotal reports indicate that the screened intervals of monitoring wells often are uncertain, especially for older wells. Furthermore, the screened intervals generally are rather long (10 feet or more), which may in some cases dilute understanding of contaminant distribution, particularly where there is significant geologic variability and where contaminants are likely to be present or moving in narrow strata.

Some researchers and site investigators are of the opinion that the value of monitoring would be improved through the use of multilevel sampling devices that include a number of short screen sampling points arranged vertically at a given plan location (Cherry et al. 1983 and Ronen et al., 1987). Although some equipment is on the market for such application, there is a need for improved design, lower cost, and simpler installation (particularly in unconsolidated sands and gravel). In some cases there may be a need to overcome regulatory resistance to such unfamiliar devices (e.g., insistence on well construction standards that were derived originally for water supply).

Selection of the Appropriate Analytical Methods

There is, of course, an enormous amount of literature addressing contaminant analysis. Two practical issues appear to warrant discussion here: (1) the current inability to detect all pollutants that may be present in some contaminated ground water samples and (2) the use of more sophisticated and expensive analytical methods than required for some purposes.

The Need for More Sophisticated Analyses

Regarding the first issue, it is now apparent that standard analytical protocols may not be capable of detecting or identifying all of the pollutants present in ground water, particularly in the vicinity of complex pollution sources. For example, some compounds are not amenable to analysis by the standard methods of gas chromatography (GC) or gas chromatography with mass spectrometry (GC/MS). Such compounds have been termed nonconventional or non-chromatographable pollutants (NCPs). Examples of NCPs that are known or suspected to be present in ground water in California and perhaps elsewhere are presented by Mackay et al., (1988a). The NCPs were detected via innovative analytical methods applied by the California Department of Health Services when it was noted that there was a large discrepancy between the measured total organic halogen (TOX) of the ground water and the sum of the concentrations of species identified by standard analytical methods such as EPA Method 624/625 (Dr. Robert Stephens, personal communication). Since this discrepancy often is observed in investigations of ground water contamination, more research clearly is needed to determine what classes of compounds are present, what analytical protocols can be used to detect them, whether they present health or environmental risks, and whether their presence significantly influences the behavior of other contaminants.

The Need for Less Sophisticated Analyses

The second issue is in some ways the opposite of the first. Here we refer to the need for reliable, rapid, and inexpensive analytical methods for aspects of site characterization and monitoring during remediation. Of considerable practical concern is the not infrequent use of expensive GC/MS analyses for routine sampling, even when careful review of the initial GC/MS analyses show that less expensive laboratory analytical methods would be capable of detecting all of the contaminants, perhaps even with a lower detection limit. Furthermore, given the recent advances in portable analytical devices, there appears to be good reason to conduct a portion of the analytical work in site investigations in the field. For example, when properly utilized, portable gas chromatographs can yield very reliable data at a fraction of the cost of analyses conducted by commercial labs, with no delay or need for storage and transport of samples. Other analytical advances with potential for application in contaminated site investigations are the in situ methods based on remote fiber spectroscopy recently reviewed by Klainer et al. (1988) and Chudyk (1989).

REMOVING CONTAMINANTS FROM THE MAZE

There have been many approaches proposed for the remediation of contaminated soil and ground water. However, in the majority of the cases to date, the approaches have relied on the removal of ground water contaminants in the dissolved form (i.e., through so-called pump-and-treat programs). The following discussion focuses on some of the information on contaminant behavior that is required from site characterization programs for the design of pump-and-treat programs, including the determination of their likely duration and effectiveness. Such information may even be more valuable in the design of innovative approaches such as in situ bioremediation that rely in part on control of the distribution and movement of the contaminant and other introduced chemicals required for the process reactions.

Distribution and Dissolution of Nonaqueous-Phase Liquids

In many cases, organic contaminants have been released to the subsurface as NAPLs, which are immiscible with water (e.g., chlorinated solvents--trichloroethene [TCE], tetrachloroethene [PCE], etc.--and petroleum hydrocarbons--gasoline, aviation fuel, oil, etc.). As illustrated by Feenstra and Cherry (1988) and Mackay and Cherry (1989), the migration of significant volumes of NAPL within the subsurface may follow complex paths, resulting in the distribution of NAPL in large and small pools and also in zones of residual saturation (containing myriad droplets and/or small ganglia of NAPL). This distribution of the NAPL may be widespread relative to the areal size of the source, owing to heterogeneities of the subsurface. A review of information from relatively well-documented sites of known NAPL contamination indicates that the mass of contaminants present in the NAPL form, even years after the contamination originated, may be much greater than that dissolved in the resulting ground water plume.

Cleanup programs for such sites clearly should be designed on the basis of information on the distribution and behavior of the NAPL masses. Unfortunately, neither type of information generally is available or adequate. Although NAPLs less dense than water often can be located in pools floating on the water table, there is little known about their behavior during remediation (i.e., dissolution by ground water flowing beneath the pool, effects of smearing of the NAPL mass within the aquifer as the water table rises and falls from pumping or natural events, and so on). For NAPLs more dense than water, which in some cases may migrate downwards below the water table, the situation is worse: there are no reliable methods for location of the NAPL mass within the saturated zone and little understanding of the rates at which NAPL in various distributions (droplets, pools, ganglia, etc.) will be dissolved by flowing groundwater.

As illustrated by Mackay and Cherry (1989), the course of ground water cleanup programs will be dominated by subsurface NAPLs when they are present in significant quantities. Thus, there is a great need for improved methods of NAPL detection and location, at the least. To allow more insightful design and operation of cleanup programs, practitioners need quantitative insight into NAPL movement and dissolution, validated by carefully conducted field and laboratory investigations.

Mobility of Dissolved Contaminants

There has been a tremendous amount of research conducted on the behavior of contaminants dissolved in ground water, yet it is surprising and disappointing how little is currently useful in practice. For example, there are hundreds of computer models that address the transport of contaminants in ground water in ideal environments, but few reliable methods exist for estimating the parameters required to define contaminant behavior in real, heterogeneous aquifers. In the following discussion we focus on one of the important processes affecting the movement of dissolved contaminants--that is, interaction with (sorption by) the aquifer media.

Sorption is an important process because it leads to reduced mobility of the contaminant relative to the flow of ground water, a phenomenon termed "retardation." As illustrated by Mackay and Cherry (1989), the progress of ground water cleanup programs can be affected significantly by contaminant sorption and desorption, especially in heterogeneous aquifers. Thus, there is a need for quantitative insight into and preferably predictive ability for contaminant retardation. The magnitude of the effect often is described in terms of a retardation factor--the average velocity of the ground water divided by the average velocity of the retarded contaminant--a parameter that, Theoretically, could be utilized in computer models. It is important to note, though often forgotten, that the retardation factor has an unambiguous definition only when the sorptive interactions are at equilibrium, which now appears unlikely to be the case generally. Nevertheless, the term is widely used and useful in the present discussion.

Table 4.1 lists the convincing field evidence to date that organic contaminants are, in fact, retarded in their mobility during transport by ground water in sand/gravel aquifers. These are the field studies that have yielded reliable estimates of the retardation, expressed in the table as retardation factors. A review of the table indicates that the contaminants, many of which are common in ground water plumes, may be retarded significantly, in some cases with retardation factors as high as 30. This implies that in many cases the mass of contaminant sorbed to the aquifer media exceeds that dissolved in the ground water (with a retardation factor of 30, twenty-nine-thirtieths of the mass in a given aquifer volume would be sorbed). On the other hand, at two of the sites some of the contaminants are nearly as mobile as the ground water in some or all of the aquifer (TCE, 1,1,1 = trichloroethane [TCA] and PCE with retardation factors of 1, implying insignificant sorption by the aquifer media).

A perfectly efficient pump-and-treat program for a plume containing only dissolved and sorbed contaminant (i.e., no NAPLs) would have to extract more than the currently contaminated volume of ground water, namely that volume times the retardation factor for a perfectly uniform, homogeneous aquifer (neglecting dispersion). However, considering that remedial programs are unlikely to be perfectly efficient and that aquifers certainly are not uniform and homogeneous, the volume of water that has to be removed to flush the contaminants completely will be even greater, perhaps considerably so (EPA, 1987; Mackay and Cherry, 1989). Considering that many plumes contain billions of gallons of contaminated water (Mackay and Cherry, 1989), this could be a significant effect that might influence the design or selection of alternative cleanup programs or the decision to remediate at all. Thus, estimates of contaminant retardation and the significance of heterogeneity would be valuable if not critical information in remedial investigations and feasibility studies.

Unfortunately, reliable site-specific estimates of contaminant retardation rarely are available during site investigations. The few data that are available (Table 4.1) indicate that such data are necessary since retardation varies among contaminants for a given site and among sites for a given contaminant. The potential methods for estimating contaminant retardation appear to be:

TABLE 4.1 Field Studies That Have Yielded Reliable Estimates of Organic Contaminant Retardation in Sand/Gravel Aquifers

Site Location Test Type (reference)[a]	Retardation Factors Determined for Listed Contaminants Contaminant	 Factor	Organic Carbon Content of Solids (reference)
Palo Alto, California			nr[c]
Forced gradient (1)	Chloroform	2.5-3.8	
	Bromoform	6.0	
	1,1,1-Trichloroethane	12.0	
	Chlorobenzene	33.0	
R. Aare, Switzerland			nr
River infiltration (2)	Tetrachloroethene	5.0	
Gloucester, Ontario			0.1-0.35% (4, 5)
Forced gradient (3, 4)	1,4-Dioxane	1.4	
	Tetrahydrofuran	2.2	
	Diethyl ether	3.0	
Plume interpretation (4, 5)	1,4-Dioxane	1.6	
	Tetrahydrofuran	2.2	
	Diethyl ether	3.3	
	1,2 Dichlorobenzene	7.6	
	Benzene	8.8	
	Carbon tetrachloride	23.0	
Borden, Ontario			0.02% (6, 11)
Natural gradient (6, 7)	Bromoform	1.9-2.7	
	Carbon tetrachloride	1.8-2.5	
	Tetrachloroethene	2.7-5.9	
	1,2-Dichlorobenzene	3.9-9.0	
	Hexachloroethane	5.0-7.9	
Moffett Naval Air Station, California			0.11% (8)
Forced gradient (8)	Trichloroethene	6-9	
	1,1,1-Trichloroethane	1.4-2.0	
Otis Air Force Base, Massachusetts			0.01-0.75% (9)
Plume interpretation (9)	Trichloroethene	1.0	
	Tetrachloroethene	1.0	
	Dichlorobenzene	1.0-1.1	
	DTBB[b]	2.4-2.6	
	P-Nonylphenol	1.1-3.3	

TABLE 4.1 continued

Site Location Test Type (reference)[a]	Retardation Factors Determined for Listed Contaminants Contaminant	Factor	Organic Carbon Content of Solids (reference)
Rocky Mountain Arsenal, Colorado			0.005% (12)
Forced gradient (10)	Trichloroethene	1-2	
	1,1,1-Trichloroethane	1-2	

[a] References: (1) Roberts et a., 1982; (2) Schwarzenbach et al., 1982 (3) Whiffin and Bahr, 1985; (4) Patterson et al., 1985; (5) Jackson et al., 1985; (6) Mackay et al., 1986a; (7) Roberts et al., 1986; (8) Semprini et al., 1987; (9) Barber et al., 1988; (10) Mackay et al., 1988b; (11) Ball et a., 1989; (12) Mackay et al., unpublished results.

[b] DTBB is 2,6-di-tert-butyl-p-benzoquinone.

[c] nr: not reported.

1. Relatively large-scale field tests of contaminant elution (flushing). Two such field tests have been implemented successfully by research teams for direct observation of retardation behavior within plumes (Whiffin and Bahr, 1985; Mackay et al., 1988b). These are likely to yield the most reliable insight of the various methods, in part because the physical scale of the study may allow determination of the effects of heterogeneity in the aquifer, and the temporal scale of the study may allow insight into the rates of desorption. However, currently they are not readily implemented by practitioners, although the potential is considerable for development of a standardized method that would yield information on both hydraulic and contaminant transport properties of contaminated aquifers (Mackay et al., 1988b).

2. Relatively small-scale field tests of in situ contaminant retardation. Gillham et al., 1990 have developed a device installed through a bore hole that isolates a portion of the aquifer and conducts a small-scale tracer test within it. Thus, contaminant retardation may be observed in situ for transport or elution over tens of centimeters. The device seems to offer promise for estimating retardation and perhaps for elucidating desorption kinetics, although more work is necessary (and planned) to compare the small-scale estimates with those from larger-scale, carefully conducted transport tests.

3. Analyses of the sorption capacity of core samples of aquifer media. In field studies conducted by research teams (e.g., Mackay et al., 1986a; Mackay et al., 1988b; Semprini et al., 1987), estimates of contaminant retardation based on laboratory analyses of core samples have matched the field observations reasonably well. For example, Curtis et al. (1986) measured the sorption capacity (K_d) of the aquifer media from the Borden site and calculated the retardation factor using a standard, simple equation. However, they used subsamples from a very large, homogenized sample, thereby avoiding a key problem with such a method, which is the spatial variability of the aquifer (e.g., Mackay et al., 1986b). Furthermore, their work and other efforts (Wu and Gschwend, 1986; Ball, 1989; Brusseau and Rao, 1989) illustrate that complete description of the sorptive interactions requires an investigation of the kinetics, which is very time consuming and difficult. Such analyses are not offered by most commercial laboratories and might not lend themselves to standardization.

4. Correlation of sorption capacity to other characteristics of the aquifer media. There has been hope in the past that sorption (and therefore retardation) could be estimated reliably on the basis of the organic carbon content of the aquifer media in the same way that contaminant sorption has been estimated successfully for soils and stream sediments (e.g., Karickhoff, 1984). However, the available evidence suggests that this method will not generally work for two reasons: (1) the method applies reasonably well only when the organic carbon content is well above about 0.1 percent (Karickhoff, 1984), whereas Table 4.1 illustrates that the values are often in that range or significantly lower for sand/gravel aquifers, and (2) the measurement of organic carbon contents at such low levels currently is unreliable, with significant potential for large errors. Although correlations of sorption with other characteristics of the aquifer media are conceivable (Karickhoff, 1984), it is the author's opinion that these are unlikely to be used reliably in practice.

Overall, then, it would appear that the best methods for characterization of contaminant mobility in ground water are the large-scale tracer tests and the smaller-scale in situ tracer tests. Neither are currently used in practice. More research is needed to make both more useful in practical investigations. It may be that the best approach is a combination of the two: the latter to assess spatial variability and the former to determine hydraulic as well as volume-integrated contaminant transport parameters.

THE PEOPLE GRAPPLING WITH THE CONTAMINATED MAZE

The above discussion hopefully has made the point that the knowledge of processes controlling the distribution, detection, and mobility of contaminants in subsurface is accumulating rapidly but still riddled with significant gaps that leave the practitioner with fewer useful tools than generally might be recognized. In essence, we all are still on the very steep part of the learning curve for ground water contamination and remediation, and there are not very many people in the academic, consulting, regulatory, or public arenas with significant experience specific to these problems, although the numbers are increasing rapidly.

Unfortunately, since the number of site investigations has risen dramatically, the available experience among practitioners has been spread very thin indeed. The gaps have been filled with relatively inexperienced people, some of whom are literally learning as they work. Discussions with consulting engineers and hydrogeologists indicate that this problem often is exacerbated by the practice of removing staff from field work as soon as they have gained some experience and using them to fill gaps in project management. This perhaps unavoidable process leads to relatively inexperienced management of very inexperienced field crews. If true, this dilemma may explain the not uncommon need to repeat site investigations to correct past mistakes or omissions. One hears of many examples in which consulting firms hired to continue site investigations begun by others find that much of the accumulated information is unusable (uninterpretable, inconsistent, or of uncertain quality).

The same problem of experience and training is true of the regulatory environment, of course, and the workload is likely to be as bad as or worse than that in the consulting world. The classic problems this creates are slow reviews of proposed projects; changing interpretations of regulatory requirements; resistance to innovations that do not seem to fit the apparent intentions of the regulations; and insistence on unnecessary precautions, analyses, monitoring wells, and so on. Often, just as a regulator gains some experience, he or she will leave the regulatory environment for more lucrative or seemingly less frustrating working conditions.

So, in essence, in many cases the regulators and consultants addressing contaminated sites will be equally overworked and underexperienced. Generally, they will not have time to follow the rapid developments published in the literature or presented in the many workshops and conferences that address aspects of the problem. In the best cases, which fortunately do occur, regulators and the consultants working on a given site may have a substantial pool of experience to share, can learn from each other, and may try innovative approaches to site characterization and remediation. This is particularly true when the regulations have some flexibility and when the regulators are aware of the flexibility and willing to utilize it.

But will the involved public and legislators allow some flexibility into the site investigation and remediation process? Perhaps so, given the same insight as that hard won by the regulators and consultants grappling more directly with the problems. However, that insight is possessed by few representing the public and perhaps by fewer in legislative positions. Hence the establishment of or demand for patently unattainable cleanup goals (e.g., zero residual contamination) with little consensus on how to determine when any cleanup goal is met, hence the apparent assumption that slow cleanup results only from bureaucracy and/or the irresponsibility of the site owner, rather than acknowledging that cleanup also is hampered severely by complicated and poorly understood physics and chemistry; and hence the assumption that "studying the problem to death" is necessarily an evasion rather than an inevitable consequence of unsatisfactory scientific understanding and investigative tools applied to extraordinarily complex problems. Clearly, the involved public and legislators must share some of the responsibility, improve their own understanding of the problems, and lend some support to the process.

CONCLUSIONS

Characterization of contaminated sites yields data on numerous factors that must be understood for a variety of purposes, including the design of efficient and economical remediation programs. However, the tools for characterization of various factors are imperfect or, in some cases, unavailable. Furthermore, the personnel involved in site characterization or review/regulation of the process often are inexperienced and overworked. The result is often inefficient but expensive data collection efforts, imperfect and often sparse data, and relatively poor understanding of existing conditions and contaminant distributions. On such foundations, remediation programs essentially are very loosely controlled experiments. We need to acknowledge that such is the state of the art and that scientific understanding is accumulating rapidly but lags behind our urgent need for it. Progress under such circumstances requires understanding of the current constraints; flexibility in regulation; willingness to try new approaches to speed the process; and a more cooperative attitude among the involved regulators, consultants, site owners, and the public.

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5

Tools and Resources Available: Policy Issues

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INTRODUCTION

Instead of "Water, water everywhere, but nary a drop to drink," perhaps the best subtitle for this paper is "Tools and resources everywhere, but nary a one that's useful." That is an overly pessimistic statement, but it captures the sense that in dealing with the policy aspects and the public's perception regarding soil and ground water contamination, both public demands and policy imperatives have sought far more certainty than current technical capabilities can deliver in a reliable, effective, and timely manner.

For this colloquium it seems appropriate, although potentially dull, to review briefly the current array of procedural tools and resources now in place to deal with the pollution of soil and ground water and to intersperse that catalog with relevant policy issues. Broader issues then will be considered, and, finally, suggestions made as to some actions that would move us farther and faster in the direction of actual remediation rather than studies of problems. But first--the catalog of tools and resources.

POLICY, REGULATORY AND PROCEDURAL TOOLS, AND RESOURCES CURRENTLY IN USE

A comprehensive (but not necessarily exhaustive) catalog certainly must include the following:

- relevant laws and regulations;
- techniques for preliminary site characterization and immediate cleanups;

- formal site investigations;
- risk assessment methodologies;
- cleanup standards for soil and water;
- models for the transport, fate, and effects of contaminants in soil and ground water;
- quality assurance and quality control;
- public hearings and meetings, and
- consent decrees and administrative orders.

Some of these are not normally seen as tools or resources, but when viewed from the perspective of the actual cleanup process, all are pertinent.

Laws and Regulations

The alphabet soup of federal laws relevant to soil and ground water cleanup is recited quickly: Resources Conservation and Recovery Act (RCRA), Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, the first federal Superfund law), and Superfund Amendments and Reauthorization Act (SARA); their implications, however, cannot be summarized quickly. These laws and their implementing regulations comprise an elaborate scheme that embodies a set of complicated rules to affect behavior and establishes a set of quantitative standards to be met. The overall goals are to correct what are now perceived to be the flaws of past practices and to reduce the future occurrence of such problems.

Each of the non-Superfund laws is in itself complex, and some are more complex than others. But perhaps the most thorny overall policy issues reside in Superfund, since both CERCLA and SARA simply picked up and embodied by reference the requirements and standards created by the other laws, thus drawing into Superfund any technical and policy uncertainties that are unresolved in the other laws. More explicitly, the most recent Superfund legislation (SARA) sets the stage for conflicts by introducing in Section 121 a requirement (seemingly benign at first glance) that Superfund decisions reflect the "applicable or relevant and appropriate requirements" (ARARs) from other laws. This applies to all media, including air and surface water as well as ground water and soil.

Identification of the ARARs for a particular site is no small task, owing to the many federal and state regulations, standards, and guidelines. The choice of which set of ARARs will control a cleanup invariably is controversial. Here we may have too many tools for water, such as maximum contaminant levels (MCLs) versus maximum contaminant level goals (MCLGs), and too few for soils, such as generally agreed upon values for acceptably low levels for contaminants. The honing of the specific tools, such as the development of final quantitative requirements for soil and water contaminants, is a technical task and not a policy issue. However, providing the funds to carry out this work is a policy matter. In my opinion, additional resources devoted to this task via the EPA, the National Institute of Environmental Health Sciences (NIEHS), the National Toxicology Program, the Agency for Toxic Substances and Disease Registry (ATSDR), and perhaps other federal agencies would pay solid dividends if all involved constituencies, both technical and nontechnical, simultaneously develop an increased level of confidence in the resulting standards.

Techniques for Preliminary Site Characterization and Immediate Cleanups

This is an area where necessary, obvious needs for rapid remedial actions, particularly regarding hot spots of soil contamination and obvious sources of current and future ground water pollution (pits, ponds, lagoons, leaking tanks, etc.), are all too often held hostage to other, less immediately threatening factors before remedial actions are taken. This is not due to a purely technically based drive to "study the site to death." For example, in CERCLA/SARA there are strong incentives to develop a site characterization that contains enforcement quality information; such information is far more extensive and thus takes far longer to obtain than the engineering-quality information that would be needed to guide short-term and even certain medium- and long-term remedial actions, especially for soil but also for ground water. The concern of other parties, such as neighbors or another unit of government, that may strongly desire a permanent solution in the long term may in effect delay the implementation of a short-term remedy that can bring sudden and often dramatic reductions in public health or environmental risks. Private parties (e.g., corporations) may be afraid of taking immediate steps because of concerns that such early actions may increase their liability later (for instance, by such actions being characterized as a tacit admission of guilt).

Formal Site Investigations

The best known of these is the remedial investigation/ feasibility study (RI/FS) approach, which from a technical perspective provides a generally sound conceptual framework for determining the conditions at a site and arraying the options for dealing with those conditions. This sound concept, however, is often badly bruised by the inadequacy and inefficiency of the current techniques for site evaluation and the relatively few remediation choices available.

Risk Assessment Methodologies

Risk assessment is a relatively new tool and, as such, is still relatively crude. While advances have been made, there is still the need for a substantial amount of judgment, rendering the tool potentially less useful than policymakers would like; generally, this also leaves an affected community skeptical. Certainly the distinction between risk assessment and risk management is a critical one both for policy and practice.[1] But the assessment process as a policy tool all too often founders on the shoals of inadequate amounts of more fundamental information, ranging from the movement of contaminants in soils and ground water and the specific routes and levels of exposure to the pharmacokinetics of individual contaminants in mammalian systems.

A current policy debate is whether the general process of risk assessment for chemical hazards in the environment is consistently highly conservative--that is, overly protective. The trend of opinion seemed until recently in the direction that current approaches are overprotective, but a recent paper suggests that this is not the case.[2]

A significant current policy initiative is the proposed revision to the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).[3] A key feature is how EPA proposes to treat risks from chemical exposure.

> For noncarcinogenic chemicals, EPA has concluded that protection is achieved when exposures are such that no appreciable risk of significant adverse effects to individuals over a lifetime of exposure exists. For carcinogens, EPA uses health-based ARARs to set remediation goals when they are

> available. When an ARAR does not exist, EPA guidance has been to select remedies resulting in cumulative risks that fall within a range of 10E-4 to 10E-7 individual lifetime excess cancer risk.[4]

EPA also proposed an alternative narrower range of risk, from 10E-4 to 10E-6, and explicitly sought comments on both.

The agency also highlighted several issues that fuse technical and policy matters, such as "the ability of treatment technologies to achieve cleanups at specified levels of risks" and whether the effort should be "to attain very low levels of risk at a limited number of sites, or to achieve cleanup at more sites (at somewhat higher levels of risk for some sites) with a greater reduction in overall risk."[4] I, for one, am very curious to see how EPA deals with these matters in the final NCP.

Cleanup Standards for Soil and Water

The most extensive set of quantitative standards is for water, with EPA generally using MCLs. Soil standards are few and far between since setting them is technically difficult. In the United States, quantitative requirements for soil contaminants exist only for PCBs and dioxin; for dioxin it is an action level rather than a true standard. Other countries--notably Canada, Great Britain, and the Netherlands--have progressed further than the United States in setting soil standards for soil remediation.[5] The relative dearth of soil standards tends to render the decisionmaking process more contentious.

The Use of Models

The use of models is well established in several areas of pollution control. As a general rule, of course, the models are conservative--that is, cautious and protective in estimating both possible exposures and consequences. For example, regarding possible exposure to contaminated soil blown from a site, the typical scenario assumes a person sits on a fence post bordering the site for 70 years and that the dust is always blowing toward that person. Similarly, a lifetime's exposure from drinking contaminated ground water from a private well is used as the starting point for analysis of individual risks from that source.

Such an approach is the prudent one when there are large uncertainties in either empirical knowledge or the detailed operations of complex systems. However, models can take on a certain rigidity that make them resistant to change even when fairly compelling evidence has accumulated pointing to the deficiency of the model. This can cut in two directions: a model may be shown to have been either too conservative or not conservative enough. For example, there is a general consensus that, regarding ingestion of contaminated soil, a 70-year exposure period is unrealistic since, generally speaking, pica (the eating of nonfood objects by humans) generally ends at an early age, rarely lasting until the age of 8 and usually ending much earlier.[6]

More worrisome are surprises in the other direction. Perhaps the clearest current example is the quite legitimate concern about dense, nonaqueous pollutant layers that are a common feature of sites involving significant quantities of chlorinated solvents.[7] This phenomenon casts a whole new light, a rather depressing one indeed, on the use of most ground water models that have been used to predict transport of these classes of contaminants in aquifers. It also means that we may need to reevaluate the applicability of standard pump-and-treat techniques that have been used with some effectiveness for floating layers of hydrocarbons (e.g., from a leaking underground storage tank for hydrocarbon fuels) or dissolved contaminants. Experienced field hands draw a clear distinction between "the floaters, the sinkers and the swimmers"; our models should do the same. And finally, models can have virtually no relevance to certain common situations, such as Karst systems, for example. My own experience is that uncertainties in geological information all too often wreak havoc on any attempt at ground water modeling; the time it takes to calibrate the model adequately often costs more than the model's results are worth.

Quality Assurance and Quality Control (QA/QC)

This set of tools is a standard one for laboratory work and might seem relatively trivial. However, the landscape is littered with false starts (often costly ones) regarding site assessments and so on because of breakdowns in what should be standard practices of sampling, holding times, and so on. There are occasions when even certified laboratories have not met their own internal QA/QC requirements, even when field work and sample handling were done properly. With an RI/FS now routinely costing $1-2 million and taking 2 years or longer, botching QA/QC can cost both real dollars and real time if the study process has to be repeated. Even more important, in the meantime more contaminants may have leaked from the point of origin, resulting in substantially greater ground water contamination; this potentially increases risks and certainly increases the total dollars and time for remediation. But beyond these traditional problems is the need for more pervasive attention to the quality of the entire process, cutting across all the tools and techniques covered already. In this regard, the demand for action has outstripped the pool of qualified people to meet the need to ensure uniformly high-quality work in these inherently complicated areas. This resembles the situation regarding toxicologists in the years immediately after the passage of the Toxic Substances Control Act (TSCA).

Public Hearings and Meetings

It may seem unusual to class these events as "tools," but I believe it is a useful way to look at them. One definition of a tool is "something useful in the practice of a vocation or profession." Anyone who has practiced the vocation of cleaning up contaminated soils or ground water at a publicly visible site knows that if the neighbors are not persuaded that you are on the right track, they can very effectively derail the train. Seasoned veterans also know that the routine public hearing and semimandated public meetings toward the end of the study process are the least effective tools for informing and hopefully achieving a consensus in the community on a remediation strategy. The goal should be to present as accurately and clearly as possible the site conditions and characteristics at the earliest possible time and to continue such presentations as more information emerges. While it is difficult, special emphasis should be placed on the risks that may be associated with the conditions as they are understood at each point in time. If for no other reasons than (1) the conditions at a site will change over time, and (2) our knowledge about the conditions will change, this has to be seen as a process, not an occasional event.

The communication aspects are not trivial. Kasperson of Clark University has put the matter well, as "the formidable task of communicating uncertain risks to skeptical publics."

Consent Decrees and Administrative Orders

Administrative and judicial orders are time-honored tools in the environmental field. If anything, they are becoming ever more common in dealing with soil and ground water contamination problems. EPA has placed increased emphasis on them in the Superfund program in recent years, and they have always been a common feature of the RCRA program. But when soil and especially ground water are the media of concern, we are now seeing a new time horizon for these tools. SARA itself mandates a reevaluation of site conditions every 5 years, until compliance with the ARARs is achieved. The standard for designing a ground water remediation system is typically for a period of operation of 30 years for both RCRA and Superfund sites, and generally less for leaking underground storage tanks. While not as long as the custodial time needed for a repository for nuclear wastes, such periods are longer than those typical for standard air or surface water pollution requirements. One consequence is continued potential liability for the private parties who agree to or are ordered to undertake such tasks. Another factor is that we have inadequate knowledge of the technical efficacy in the field of techniques used over this period of time.

HOW POLICY IS AFFECTED BY TOOLS

The Effect of Tools on Policy

Everyone knows about the advances in analytical technologies that have revealed new problems in the environment. Some of these problems are real, and some are only perceived to be problems. While some people have suggested, to paraphrase Shakespeare, that perhaps the first thing to do is kill all the analytical chemists, it is important to remember the rest of the story. Along with the advances in the ability to detect trace chemicals in the environment has come the understanding that exposure to relatively low levels of certain contaminants can have adverse effects on man and mouse alike. Given our general social commitment to prevent needless disease, the combination of improved detection techniques and improved knowledge of the consequences of exposure to trace contaminants contaminants has had a dramatic effect on policy. The policy of setting standards that embody safety factors or low risk levels is firmly established.

Conflicts between tools can hinder rather than help policy decisions. At this stage in the state of the art, particularly for ground water problems, empirical data can appear wildly at variance with what a model suggests. Even empirical data can be in conflict. In such circumstances site-specific policy decisions can become even more judgmental than usual. As a result, those persons affected by the final decision, be they neighbors or those being regulated, can be expected to challenge a decision not in accordance with their preferred goal; in many cases, the challenges come from several directions at the same time. This phenomenon is not due solely to the uncertainties in the technical tools but also feeds in part on the unfortunate fact that the EPA has, for a variety of reasons, lost some of the credibility it enjoyed in its earliest years. Much of this loss is traceable to events in the early years of the Superfund program itself, an unfortunate coincidence since this is one of the main program areas where good credibility would help substantially in dealing in a timely manner with soil and ground water contamination.

As noted earlier, one of the prime procedural tools these years is Superfund's RI/FS process, which is mandated by law for Superfund sites on the National Priorities List. The essence of this approach is being adopted ever more widely for similar situations, both in a regulatory and nonregulatory context (e.g., in commercial and industrial real estate transfers).

This has placed incredible stress on an already overburdened labor pool, both in the public and private sectors. The problems at EPA have been well documented, such as a 27 percent turnover of staff in the Superfund program in the 1987-1988 fiscal year.[8] The situation in the private sector is similar, although statistics are hard to come by. The modest training program at NIEHS created by SARA is welcome in this regard but is best viewed as better late than never, and better small than not at all.

Implications of the Limitations of Technical Tools on Policy

There are other ways in which tools affect policy, some more benign than others. In the ground water area, for instance, without the remedial tool of activated carbon, our current policy approach to dealing with aquifers contaminated with solvents would be quite different from what it is now. The proven tools for dealing with contaminated soil, by contrast, are much cruder at this stage: cap or otherwise contain, excavate and bury someplace else, or excavate and burn. As a consequence of major (though differing) problems with each, as well as other uncertainties mentioned earlier, policy debates will continue to be vigorous regarding the remediation of contaminated soil.

As a corollary, if there were one or more major breakthroughs in remediation technology for contaminated soils that provided efficient, effective, and economical new tools, we might see policy debates on soil remediation simmer down quickly. This is an area of vigorous research and development, in areas ranging from bioremediation to more high-tech approaches, including one that researchers at the IIT Research Institute are developing to boil solvents out of soil using radiofrequency energy.[9] As someone who has been caught in the cap/bury/burn dilemma more than once, I for one would welcome some new technical tools making policy decisions easier.

HOW TOOLS ARE AFFECTED BY POLICY

One of the clearest examples of the effect of policy on tools is the absence in the primary federal laws related to soil and ground water remediation of an adequate research, development, and demonstration (RD&D) program. CERCLA, as the starkest example, had virtually no RD&D component, reflecting the view of Congress in 1980 that already existing tools and techniques were adequate to do the job. This was a badly mistaken assumption. SARA improves the situation, but only modestly.

In contrast, prior environmental legislation covering air and water pollution, for example, coupled an aggressive federally funded research program with the regulatory program in a way that strongly benefited the regulatory program. This is not the case for soil and ground water pollution. Whether the broader concern about the federal deficit will prevent effective policy changes on this score is not clear at this point, although some hope can be found in the current administration's statements in support of a greater federal role in R&D.[10] I believe a substantial increase in the federal R&D effort in this area is needed; a target of an increase equal to 3 percent of the total program budget for the Superfund and RCRA efforts seems reasonable.

Sometimes a subliminal policy conflict affects the use of technical tools. In some respects Congress has never explicitly resolved the policy issue as to whether the Superfund program is basically a public works program (through the fund-funded cleanups), a public health program, or a regulatory/enforcement program, although SARA tips the balance more toward the latter. A consequence of a regulatory/enforcement focus is the demand for technical information that can be taken into court, thus leading to more intensive site studies to provide enforcement-quality data. As suggested earlier, this may be one of the root causes, at least from a policy perspective, for the slow progress toward actual cleanups.

CONCLUSIONS AND RECOMMENDATIONS

What is the path out of this morass? Unfortunately, there is no quick and easy one, but there are some policy steps that may pay off in solid technical advances in the midterm and one that could help in the near term.

In the midterm, first, a policy commitment to increase the R&D effort would, as just stressed, pay solid dividends. The emphasis should be on the topics described in a report published by the President's Council on Environmental Quality in 1986.[11] Also included should be retrospective studies on the effectiveness in field applications of past remedial actions, as recommended in other papers in this colloquium. In this case, policy equates to funds. Second, a commitment to increasing the pool of trained people at all levels, as has begun modestly at NIEHS, would also help. Third, efforts to improve both the public's understanding of the risks posed by ground water and soil contamination and the public's confidence in the decisions of relevant regulatory bodies would help.

None of these three will help in the near term. For this there perhaps is only one promising prospect; fortunately, it is one already embodied in policy--in the NCP. Unfortunately, it has not been used as often as it could be--and therein lies the promise. This is the so-called removal approach to cleanups and the related "expedited response action." These are emergency and semiemergency options available in Superfund both to EPA for fund-funded cleanups and to other parties if they are footing the bill directly. There have been some wonderful success stories here, both for EPA and for responsible party groups. One great success in which I was involved was the complete cleanup of a PCB site with nearly 7 million pounds of PCB-contaminated materials in less time than it would have taken for the site to be evaluated formally simply to determine if it belonged on the National Priorities List.

With modest effort, the same approach could be used not only far more extensively in the Superfund program but also grafted onto other classes of cleanups by embodying appropriate substantive requirements in administrative orders or consent decrees issued by EPA or state agencies under RCRA or other laws. This is the only approach that could result in much faster progress in the near term. But, overall, as Pogo states, we seem to be "confronted by insurmountable opportunities."

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NOTES

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3. Federal Register 53, 51394 ff, December 21, 1988.

4. Ibid., pp. 51425-51426.

5. For a useful review, see Fitchko, J. Criteria for Contaminated Soil/Sediment Cleanup. Pudvan Publishing Company, Northbrook, Ill., 1989.

6. Mushak, P., A. F. Crocetti, M. Bolger, J. Briskin, J. Cohen, J. M. Davis, H. Falk, L. D. Grant, S. Lee, R. Levin, D. C.

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8. Office of Technology Assessment. Assessing Contractor Use in Superfund, U.S. Congress, 1989.

9. U.S. Patent Number 4,670,634, issued June 2, 1987. See also Dev, H., P. Condorelli, J. Bridges, C. Rogers, and D. Downey. In situ radio frequency heating process for decontamination of soil. Chapter 27, pp. 332-339, in Solving Hazardous Waste Problems, J. H. Exner, editor. American Chemical Society Symposium Series 338, American Chemical Society, Washington, D. C., 1986.

10. Long, J. Federal 1990 Budget Agreement: Good News for Science Community, C & E News 67, 19-20, 1989; see also Environmental Health Letter 28, 50, 1989.

11. Council on Environmental Quality, Executive Office of the President. Report of an Expert Meeting on Research Needs and Opportunities at Federally-Supervised Hazardous Waste Site Clean-ups, October 1986 (available from the author of this paper if it is no longer available from the Council on Environmental Quality).

6

Current Practices and Applications of Ground Water and Soil Contamination/ Remediation: Successes and Failures

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From a national perspective, the estimated amounts of money required for cleanup of contaminated soil and ground water are staggering. Because of the current and anticipated future large investments of monetary resources into site cleanup work, considerable public attention is focused on these efforts. Cleanup expenditures should be made, following appropriate studies, on those technologies having the greatest likelihood of success. However, this may not always occur, as evidenced by several studies critical of remediation efforts. This paper examines current practices relative to the use of remediation technologies, including a pertinent, scientifically based rationale as to why successes or failures are being experienced. Sections are included on relevant definitions, comparative studies on cleanup efforts, reasons for experienced success or failure, available remediation technologies, novel and innovative technologies, actions to increase the likelihood of cleanup success, and some pertinent technical needs to enhance cleanup activities.

DEFINITIONS

It has become fashionable in recent years to be critical of soil and ground water remediation efforts, particularly regarding the Superfund program operated by the EPA. In most cases, after-the-fact criteria are applied to cleanup activities that are in progress. It is important to note that, depending upon the success/failure definition, a given project could be viewed as either a success or failure. Examples of success-focused definitions include the following: A remediation project will be successful if it reduces contaminant concentrations in soil and/or ground water to (1) the agreed-to cleanup standard(s) in X years; (2) the agreed-to pertinent cleanup standard(s) (no time period specified); or (3) background levels in X years (specific concentrations not specified). It should be noted that if cleanup success is defined based on returning sites to a pristine condition, then it would be proper to conclude that most cleanups have not been successful (Baes and Marland, 1987). Another definition is that a remediation project will be successful if it reduces the public health risk associated with contaminated soil and/or ground water (the risk reduction, specific concentrations, or time period not specified); finally, a remediation project will be successful if the contamination is remediated sufficiently to allow reclamation and redevelopment activities.

COMPARATIVE STUDIES ON CLEANUP EFFORTS

Several recent comparative studies have identified limitations and deficiencies in the implemented cleanup efforts. For example, during the summer of 1980, a nationwide survey was conducted to determine the status of remedial actions applied at uncontrolled hazardous waste disposal sites (Neely et al., 1981). A total of 169 sites were identified as having been subject to corrective measures; the measures usually consisted of containment and/or removal of the hazardous materials. Nine sites were studied in detail; remedial actions were completely effective at two and only partially effective at the other seven.

The U.S. General Accounting Office (GAO) has published at least four reports in recent years that have been critical of the Superfund program, particularly when viewed in terms of the number of successful cleanup efforts (U.S. General Accounting Office, 1984; 1985a,b; 1986). The 1984 study focused on the costeffectiveness of remedial actions at three sites: (1) the Laskin/Poplar Oil Company site in Ohio, (2) the Lipari landfill site in New Jersey, and (3) the Picillo Farm site in Rhode Island (U.S. General Accounting Office, 1984). Interim measures had been taken or proposed at the three sites; however, additional studies were needed to develop complete cleanup plans. The GAO noted that until EPA completes the studies necessary to define the long-term cleanup goals for each site, it will not be possible to determine whether the cleanup or containment approach at these sites will be successful and costeffective. The issue of "stopgap" cleanup measures also was addressed in a 1985 GAO report (U.S. General Accounting Office, 1985a).

Partial or temporary remedial actions were also highlighted in a second 1985 GAO report (U.S. General Accounting Office, 1985b). A review of the number of permanent treatment technologies selected for implementation at Superfund sites was included in a 1986 report (U.S. General Accounting Office, 1986). The statistics indicated that during the first 5 years of the Superfund program only 27 of the 121 cleanup decisions included permanent technologies. However, it was noted that the EPA selected permanent treatment technologies more frequently each year the program has been in operation. Out of an original list of 888 sites needing cleanup, the GAO report indicated that only 15 had been cleaned up during Superfund's first 5½ years of existence.

Several comparative studies of Records of Decision (RODs) for remedial actions at Superfund sites have been completed recently at the University of Oklahoma (Baris, 1986; Haiges, 1987; Hajali, 1987). Ground water-related remedial actions at 36 Superfund sites were evaluated by Haiges (1987) based on the information in the pertinent RODs. An interesting issue from the 36 RODs was that only 56 percent of the sites had an estimated cleanup level; 11 percent of the sites deferred a cleanup level to the future; 14 percent of the sites had no estimated cleanup level; and for 19 percent of the sites, this criterion did not apply. For those sites with a specified cleanup level, the range of approaches used to establish the level was very diverse, including the use of ground water performance standards, drinking water standards, Resource Conservation and Recovery Act (RCRA) standards, maximum contaminant levels (MCLs), alternate concentration limits (ACLs), suggested no-adverse-response levels (SNARLs), background levels, contaminant stabilization, and the 10-6 cancer risk level (Haiges and Knox, 1988). The estimated time to achieve stated cleanup levels or goals also was reviewed by Haiges and Knox (1988). The required cleanup time is directly dependent upon the selected remedial action alternatives and the cleanup target levels and goals. Therefore, to have an estimated cleanup time, the ROD must state a cleanup goal. The results for the 36 sites were as follows: 50 percent of the sites have an estimated cleanup time, 14 percent of the sites deferred a cleanup time to the future, 17 percent of the sites have no cleanup times, and for 19 percent of the sites, this criterion is not applicable.

The Office of Technology Assessment (OTA) (1988) has conducted a comparative review of 10 case studies of recent

Superfund site cleanup programs. The 10 studies are representative of programs developed under the requirements of SARA; they were chosen following the review of over 100 RODs. Based upon this comparative review, the summary of technically oriented issues and concerns were delineated in three groups as contained in Table 6.1 (Office of Technology Assessment, 1988).

REASONS FOR EXPERIENCED SUCCESSES OR FAILURES

As denoted in the previous section, several issues may be basic to perceived and actual successes or failures of remedial action programs at Superfund or other waste sites. An underlying issue is the relative newness of this field and the inexperience of various design professionals and decisionmakers working on remediation efforts. Some of the technically oriented reasons typically associated with perceived and actual failures of cleanup efforts include the following:

1. The frequent selection and use of technologies previously used for other sites without considering the uniqueness of the cleanup needs at the particular site in terms of hydrogeology, contaminant characteristics and combinations, contaminant treatability, and limitations of the technologies themselves.
2. Use of technologies that are dependent upon subsurface transport and fate processes without having an adequate understanding of the contaminant plume; subsurface environmental features affecting dispersion, diffusion, adsorption, and degradation; and the necessary testing protocols for system design. (An example would be attempts to use soil flushing for contaminants that are tightly sorbed onto the soil media.)
3. Lack of clear protocols on site characterizations and development of technology design criteria. Protocols are needed to delineate hydrodynamic testing, in situ chemical and biological treatability determinations, contaminant flushing opportunities, and above-ground treatment schemes for extracted ground water.
4. Inability to achieve uniform mixing in the subsurface with abstraction and injection well operations being used for in situ chemical and/or biological treatment schemes. Limitations in achieving uniform mixing of added nutrients, oxygen, and/or

TABLE 6.1 Technical Issues and Concerns from 10 Case Studies

Evaluation and Selection of Permanent Treatment Technologies

- **Many good, permanently effective waste treatment technologies are on the market but, too often, are not fully examined or are not selected for use.**
- **Describing a cleanup technology as a "treatment" can be misleading.**
- **There is no clear line between sufficient and insufficient technical and economic data for selecting among cleanup technologies.**
- **Information used to compare treatment technologies often is inaccurate and incomplete.**
- **Contractors may quote a wide range for direct costs per unit of material treated for any given treatment technology.**
- **Contractors estimate cleanup costs by adding to direct costs substantially different levels of indirect cost (burden or markup).**
- **RODs cannot always depend on the results of treatability tests done for other sites.**
- **When they are done, most treatability studies are not done early enough.**
- **Some RODs choose technologies that are in EPA's Superfund Innovative Technology Evaluation (SITE) program, an indication that a technology has not yet been proven.**
- **The chemical character and complexity of site contaminants and how they affect the use of some technologies do not get enough attention.**

Impermanent Technologies

- **When wastes are left in the ground or in ground water or are redisposed in a landfill, an ROD may claim that the remedy is permanent when, in fact, it is not.**
- **Contrary to the law, containment/land disposal decisions seldom analyze the risk of future failure, damages, and further cleanup.**
- **Sometimes an ROD does not commit to a definite outcome even though it appears to have selected a technology.**
- **Impermanent remedies, which provide less protection than permanent ones and do not assuredly meet cleanup goals, often are selected purely because they are cheaper in the short run; in the long run they are very likely to be more expensive.**
- **EPA is less responsive to community concerns about a remedy being impermanent than to interests that favor a lower-cost impermanent remedy.**
- **In selecting cheap, impermanent remedies, claims of comparable estimated costs may hide the truth that low cost was the key deciding factor.**

TABLE 6.1 Technical Issues and Concerns from 10 Case Studies

Risk Management and Cleanup Goals

- **There are often problems with how risks are assessed and how cleanup goals are met.**
- **RODs do not consider cumulative exposures and risks from multiple sources of similar hazardous substances.**
- **The risks of transporting hazardous materials offsite for land disposal or even treatment are not considered.**
- **Most RODs seem uncertain about or do not address future land and water use in judging whether a selected remedy will be safe and permanent.**

SOURCE: Office of Technology Assessment, 1988.

other chemicals will lead to less than optimum treatment and thus preclude the attainment of cleanup standards in a reasonable time period.

5. Limitations of ground water flow and solute transport models for evaluating proposed remediation schemes. In many cases models are not used at all; in other cases they may be used but with many necessary simplifying assumptions. Stochastic predictions rather than single-number predictions should be developed for time requirement predictions, concentration reduction predictions, and remediation system configuration and design.

6. Frequently, a great deal of uncertainty as to desired/required cleanup standards and concentrations and the time required for their achievement. Systematic policy development can aid in reducing these uncertainties.

7. Perhaps a lack of systematic comparisons of alternative technologies or a limited selection based on considering only a portion of the problem. Decisionmaking should be based on the systematic comparisons of composite and integrated plans as well as on specific technical components within a plan. However, the comparisons may be inconsistent based on uneven data availability for the plans and/or technologies.

8. Attempts to satisfy competing objectives in a remediation program that may lead to a nonoptimum approach. Examples of these competing objectives include (1) the desire to clean up the contamination as quickly as possible versus technically driven requirements of several years to achieve cleanup, (2) the desire to select a least-cost plan versus a more costly plan with more likelihood of achieving cleanup, and (3) the desire to reduce

public health and environmental risks versus increasing costs and uncertainties associated with plans having greater possibilities for actually reducing risks.

9. The increasing development of technologies, providing more choices for cleanup. However, all technologies do not accomplish the same thing; thus, it is necessary to group technologies and use sequential decisionmaking in plan/technology selection.

10. Many cleanup programs that are focused on only one aspect of the site problem. Thus, these programs are not completely addressing all of the needs at a given point in time. Examples of this piecemeal approach include (1) contaminant source remediation without cleanup activities for the unsaturated and saturated zones, (2) ground water remediation without source control and unsaturated zone cleanup, and (3) soil and ground water remediation without source control.

AVAILABLE REMEDIATION TECHNOLOGIES

There are numerous potentially applicable control technologies for contaminated soils and ground water. Canter and Knox (1985) identified three major technology categories: (1) physical control measures, such as well systems, interceptor systems, surface capping and liners, sheet piling, grouting, and slurry walls; (2) postextraction ground water treatment measures, such as air or steam stripping, carbon adsorption, biological treatment, and chemical precipitation; and (3) in situ treatment measures involving chemical treatment and/or biological stabilization. Table 6.2 summarizes some information on potential control technologies (Canter et al., 1987). Engineering design information has been summarized by Nyer (1985) in accordance with (1) physical/chemical methods for organic contaminant removal (including design and application methods for pure compound removal, air stripping, and carbon adsorption); (2) biological methods for organic contaminants (traditional treatment systems and specific treatment systems for ground water treatment); (3) treatment methods for inorganic contaminants (including methods for removing heavy metals, nitrates, and total dissolved solids); and (4) in situ methods for organic contaminants (including aquifer and unsaturated zone cleanup).

Table 6.3 illustrates examples of recently selected technologies as identified in nine RODs. In this group are three

TABLE 6.2 Summary of Major Control Technologies

Group/Technologies	Description
Source control strategies I Volume reduction measures Physical/chemical alteration	Source control strategies represent attempts to minimize or prevent ground water II pollution before a potential polluting activity is initiated. The objectives of source control strategies are to reduce the volume of waste to be handled or reduce the threat a certain waste poses by altering its physical or chemical makeup.
Well systems I Well point systems II Deep well systems III Pressure ridge systems IV Combined systems V Immiscible (hydrocarbon) contaminant recovery systems	Well systems for ground water pollution control are based on manipulation of the subsurface hydraulic gradient through injection and/or withdrawal of water. Well systems also are used for recovery of water and recovery of immiscible contaminants, usually hydrocarbons, that float on the water table.
Interceptor systems I Collector drains A. Leachate collection systems B. Interceptor drains C. Relief drains II Interceptor trenches A. Actively pumped systems B. Gravity flow, skimmer pump systems	Interceptor systems involve excavation of a trench below lthe water table and possibly the placement of a pipe in the trench. The trench can be left open (interceptor trench), or backfill can be placed on a pipe in the trench (collector drain). Interceptor trenches can be either active (pumped) or passive (gravity flow). These systems function similarly to an infinite line of extraction wells by effecting a continuous zone of depression running the length of the trench.
Surface water control, capping, and liners I Natural attenuation (no liner, no cap) II Engineered liner III Engineered cover IV Engineered cover and liner	These three technologies are used in conjunction, each serving a unique ground water pollution prevention purpose. Surface water control measures reduce potential infiltration by minimizing the amount of surface water flowing onto a site. Capping is designed to minimize the infiltration of any surface water or direct precipitation that does come onto a site. Impermeable liners provide ground water protection by inhibiting downward flow of low-quality leachate and/or attenuating pollutants by adsorption processes.

TABLE 6.2 continued

Group/Technologies	Description
Impermeable barriers I Steel sheet piles II Grout curtains or cutoffs III Slurry walls	Barriers are measures designed to influence the subsurface hydraulic gradient by placing a low-permeability material into the subsurface. Barriers typically are constructed with driven sheet piles, injected grouts, or dug slurry walls. Sheet piles provide immediate impermeability, whereas grouts and slurries both are emulsions that require a hardening period to achieve impermeability.
In situ treatment I In situ chemical II In situ biological	The in situ treatment methods involve adding materials to the subsurface so as to cause or increase the rate of a reaction that will render a contaminant immobile or to remove the contaminant. The in situ chemical technologies attempt to immobilize contaminants through some chemical reaction, whereas the in situ biological techniques are designed to provide an environment suitable for microorganisms to utilize the contaminant as a food source.
Ground water treatment I Air/steam stripping II Carbon adsorption III Biological treatment IV Chemical precipitation	Various treatment technologies are utilized above ground to treat contaminated ground water. The technologies most widely applied to organic contaminants are air stripping, car adsorption, and biological treatment. Chemical precipitation is used for inorganics and metals removal.

Source: Canter et al., 1987.

TABLE 6.3 Examples of Recently Selected Technologies

Location/EPA Region (reference)	Type of Site	Remedial Action	Problems	Selected Technologies
South Brunswick, New Jersey/2 (U.S. Environmental Protection Agency, 1987a)	Municipal/ hazardous waste landfill	Second	VOCs and Fe in ground and surface water	On-site contamination via a leachate collection/ treatment system, slurry wall, clay cap, and gas venting system. Post-remedial ground water, surface air monitoring.
Baltimore, Maryland/3 (U.S. Environmental Protection Agency, 1987b)	Municipal/ hazardous waste dump	First	Organics and metals in soil and ground water	Removal of drums and top 0.15 m of soil to off-site location; site stabilization by regarding, capping, and revegetation.
Powersville, Georgia/4 (U.S. Environmental Protection Agency 1987c)	Municipal hazardous waste landfill	First	VOCs, organics, Pb, Cr, and pesticides in soil and ground water	Surface capping using artificial material or clay, site grading, extension of the municipal water supply line as an alternative water supply, and monitoring wells to determine cap-area leaching and migration.
Zellwood, Florida/4 (U.S. Environmental Protection Agency, 1987h)	Industrial site and wetland area	First	Soil and ground water contamination from old drums and two evaporation/ percolation ponds	Excavation of soils and sediments with on-site incineration and testing of residuals to determine appropriate disposal, ground water pump and treatment with flushing of the treated ground water back through the abandoned drum

TABLE 6.3 continued

Location/EPA Region (reference)	Type of Site	Remedial Action	Problems	Selected Technologies
				area to facilitate cleanup of residual contamination, and a long-term ground water monitoring program for nearby private potable water wells.
Fridley, Minnesota/5 (U.S. Environmental Protection Agency, 1987d)	Industrial site	Second	TCE and other organics in alluvial ground water discharging to Mississippi River	Ground water pump and treatment with discharge to a sewer system, ground water monitoring, and implementation of institutional controls with land use restrictions to mitigate against near-term usage of contaminated ground water between the site and the Mississippi River.
Twin Cities Army Ammunition Plant, Minnesota/5 (U.S. Environmental Protection Agency, 1987e)	Ammunition plant site	Third	VOCs, other organics, and metals in ground water moving off site; ground water is water supply for two local towns	Ground Water extraction and treatment via air stripping.
Sand Springs, Oklahoma/6 (U.S. Environmental Protection Agency, 1987f)	Petro-chemical complex with pits, ponds, and lagoons	First	Bis(2-ethylhexyl)-phthalate, toluene, Pb, Zn, Cr, and Ba in soil and ground water	On site thermal destruction of wastes, excavation and off-site thermal destruction of sludges, solidification and/or stabilization of all remaining sludges with containment of the resulting matrix in an on-site hazardous waste RCRA cell, and implementation of chemical and physical treatability studies.

TABLE 6.3 continued

Location/EPA Region (reference)	Type of Site	Remedial Action	Problems	Selected Technologies
Old Midland Products, Arkansas/6 (U.S. Environmental Protection Agency, 1988)	Wood creosoting plant lagoons	First	Pentachlorophenol and polynuclear aromatic hydrocarbons in soil and ground water	On-site thermal destruction of the contaminated surface soils, lagoon sludges, and drainageway sediments with on-site disposal of waste residuals and a vegetated cover; ground water pump and treatment using carbon adsorption.
San Fernando Valley, California/9 (U.S. Environmental Protection Agency, 1987g)	Industrial site	First	TCE, PCE, and other VOCs in ground water	Pump and treat using aeration and granular activated carbon-air filtering units, with discharge to a pumping station for chlorination and distribution.

NOTE: VOCs, volatile organic compounds; TCE, trichloroethene; PCE, perchloroethylene.

municipal/hazardous waste landfills or dumps, five private industrial sites, and one governmental site. The problems being addressed are fairly typical--that is, various organics and metals in soil and/or ground water. The selected technologies listed in Table 6.3 include waste removal to an off-site location, on-site incineration of contaminated soil, physical containment measures for contaminant plumes, and ground water pumping and above-ground treatment schemes. Of the nine examples, six represent the first remedial action, two are second remedial actions, and one is a third remedial action. These nine RODs illustrate the phasing of remedial actions at hazardous waste sites, and they also indicate that the second and subsequent actions frequently are dependent on the effectiveness of the first remedial action plan.

Based upon the available technologies and their usage, the following reminders are in order: (1) there is no single optimum technology owing to the multiplicity of contaminants and hydrogeological features within and across sites; (2) many above-ground treatment technologies have been used and developed for industrial and/or municipal waste-waters; (3) combinations of remediation measures typically are needed at a site (e.g., source control, vadose zone flushing, and pump and treat); (4) cost comparisons often are made based on assumptions (limited modeling) related to the time to achieve a specified cleanup; (5) decisions may not be based on appropriate consideration of residuals (e.g., environmental impacts) of technologies or on a limited time period of effectiveness of the technology (e.g., slurry walls); and (6) ground water remediation may only be one part of site remediation (other parts may include removal/treatment of contaminated soil and physical removal of drums, sludges, liners, etc.).

NOVEL AND INNOVATIVE TECHNOLOGIES

A number of novel and innovative remediation technologies are being researched and demonstrated. Examples within the physical control category include polymeric overpacks for 55-gal. drums and the block displacement method (BDM) (Hill, 1984). Surfactants and chelating agents can be used to enhance the in situ washing of contaminants from soils (Griffin and Roy, 1988). Surfactants lower the interfacial tension between hydrocarbons and water, and laboratory studies have demonstrated that anionic and nonionic surfactants enhance the removal of hydrocarbons and PCBs from soils in batch extraction and column configurations. In addition, the EPA and U.S. Air Force have conducted a research test program on the removal of hydrocarbons and chlorinated organics from a sandy soil by in situ soil washing using surfactants (Nash, 1987). Key issues that need to be explored further include the optimum types and concentrations of chemical additives, the extraction interval and sequence, and the collection and proper treatment of the surfactant/chelate leachate (Griffin and Roy, 1988).

A detailed study of the biological treatment potential of 56 hazardous chemicals in soils recently has been completed (Sims et al., 1988). The chemicals were considered in four categories: (1) 16 polynuclear aromatic hydrocarbons (PAHs), (2) 22 pesticides, (3) 13 chlorinated hydrocarbons, and (4) 5 miscellaneous chemicals. Treatability screening studies were conducted to determine biological degradation rates and the influence of abiotic soil processes for the 56 chemicals. Detailed information on the treatment potentials for these 56 chemicals is available and can aid in the identification and planning of remedial action measures (Sims et al., 1988).

Finally, in 1986 the EPA established the Superfund Innovative Technology Evaluation (SITE) program to promote the development and use of innovative remediation technologies (Hill, 1988). As of July 1988, thirty technologies have been accepted into the SITE program, including three with chemical treatment, six with biological treatment, five with physical treatment, eight with thermal treatment, and eight involving solidification/fixation. Demonstrations of the effectiveness of these technologies at field sites are being conducted.

ACTIONS TO INCREASE LIKELIHOOD OF CLEANUP SUCCESS

Based upon the earlier listed reasons for the perceived failures of cleanup actions and on both available and novel and innovative technologies, several actions should be taken to enhance the likelihood of choosing, designing, and implementing effective remediation programs. Six actions will be addressed: (1) design and testing for containment systems, (2) design and testing for in situ bioremediation systems, (3) planning and conduction of treatability studies, (4) use of modeling for remediation system planning and design, (5) development and use of remedial action cost information, and (6) use of systematic decisionmaking on remedial action alternatives.

Design and Testing for Containment Systems

Physical containment systems may include the use of covers at waste sites, slurry walls around waste sites, and/or hydrodynamic barriers based upon a combination of withdrawal/injection wells at the site. Slurry wall application systems are particularly suited to sites having a sandy surficial aquifer underlain by fine-grained deposits at depths of 60 ft or less. From the perspective of performance, however, site hydrogeologic conditions are the key determining factor (Need and Costello, 1984). The integrity of slurry walls with respect to the contained wastes is fundamental to contaminant retention. In some cases the wall integrity is breached. For example, Trezek (1986) described two Superfund sites where the contained chemical wastes changed the properties of the containment system. Specifically, the permeability of a bentonite slurry wall was increased by several orders of magnitude in the presence of a chemical waste leachate. Accordingly, laboratory testing should be used to examine the integrity of proposed physical barriers (Tobin and Wild, 1986).

Design and Testing for In Situ Bioremediation Systems

A remediation technology that has been expanding in usage is in situ bioremediation, also sometimes referred to as enhanced bioreclamation or enhanced natural degradation. Applications typically include enhancement of the native microbial population in conjunction with the usage of pumping and above-ground biological treatment processes (Lee et al., 1988). Nutrients and oxygen (or ozone) or hydrogen peroxide may be introduced to the subsurface via injection wells and circulated through the contaminated zone via pumping wells (Wilson et al., 1986). Hydrocarbon remediation projects are the most frequent users of in situ bioremediation schemes. Development of a bioremediation plan for a site requires a thorough understanding of the hydrogeologic and geochemical characteristics of the contaminated area, the biological degradation potential of the contaminant(s), and the requirements for nutrients and oxygen. Laboratory studies can be used to assemble information on the latter two items. For example, bench-scale studies for evaluating the potential for biological cleanup of ethylene glycol-contaminated ground water have been described by Flathman et al. (1984). One of the major needs is for the conduction of controlled field evaluations of process effectiveness. One field evaluation program will be noted as an example, with the program focused on remediation of halogenated aliphatic compounds at Moffett Naval Air Station, Mountain View, California (Semprini et al., 1987).

Planning and Conduction of Treatability Studies

In addition to laboratory studies for in situ bioremediation or in situ chemical remediation schemes, studies also are needed to determine appropriate treatment processes and design factors for extracted ground water. In fact, it may be necessary to conduct tests on the flushing potential of contaminants prior to treatability testing. Soil column testing can be used as a means of evaluating soil flushing as a remediation technique at a hazardous waste site (Penniman, 1986). Technical factors that can be examined include the hydraulic loading and desorptive capacities of different site soils and the influence of the type of flushing agent and the rate and total quantity of application.

Treatability studies are particularly important because of the potentially wide range in numbers, types, and concentrations of contaminants. Shuckrow and colleagues (1986) have described bench-scale evaluations of treatment processes for contaminated leachates and ground waters from four hazardous waste sites: (1) Ott/Story site, Muskegon, Michigan; (2) Gratiot County Landfill, Gratiot County, Michigan; (3) Marshall Landfill, Boulder, Colorado; and (4) Olean Wellfield, Olean, New York. The study results illustrate that no single treatment process is uniformly the best (Shuckrow et al., 1986). For example, at the Ott/Story site the ground water contains numerous organic contaminants. The process train that has performed best is granular activated carbon (GAC) adsorption followed by activated sludge treatment. The problem at the Gratiot County Landfill involves ground water contaminated by polybrominated biphenyls (PBBs) and metals. The PBBs and metals are relatively insoluble and are associated primarily with solids and sediments. Therefore, the best potential treatment scheme includes gravity sedimentation and granular media filtration. The Marshall Landfill has numerous priority and nonpriority organic compounds in the ground water; thus, total organic carbon (TOC) can be used as an indicator of treatment performance. GAC adsorption provides the best TOC removal (168 mg/liter to 23 mg/liter). Finally, the Olean Wellfield ground water contains 120 to 250 mg/liter of TCE, and the best process for TCE removal (>99 percent) is packed-column air stripping.

Treatability studies also may be needed for metals removal, either along with or without the removal of organics. In one case on-site pilot-scale treatability studies have been conducted to examine chemical precipitation for removal of iron, manganese, and heavy metals and high-temperature air stripping (HTAS) for removal of volatile organics (Lamarre et al., 1983). Chang and Peters (1985) have described process development and optimization for the removal of cadmium from contaminated ground waters by coprecipitation and adsorption in a lime-soda ash water-softening scheme.

Use of Modeling for Remediation System Planning and Design

Modeling remedial action plans for contaminated soil and ground water is a vital component in planning and implementing potentially successful remedial actions. Modeling may be focused on contaminant transport through the unsaturated zone, ground water flow and contaminant transport through the saturated zone, the effectiveness of ground water pumping schemes, an analysis of the influence of physical control systems, determining the number and placement of injection and withdrawal wells in a hydraulic barrier scheme, developing a design for an in situ biological or chemical treatment program, process design for above-ground treatment, and/or combinations of these emphases. Models can range from simple analytical approaches to statistical models to complex numerical codes. Several modeling efforts may be required for a given contaminated soil and ground water site. A compendium of information on modeling remedial actions has been assembled in a recent book by Boutwell et al. (1986).

Ground water flow and contaminant transport modeling is necessary for contaminant plume delineation and for predicting plume movement. This type of information is basic to the identification of potential remediation plans. Modeling can be used to design and analyze physical barriers and hydraulic barriers at contaminated sites. For example, Stevens and coauthors (1987) described the use of the Prickett/Lonnquist Aquifer Simulation Model (PLASM) to design a remedial action program at a 600-acre mine-tailings evaporation pond in southwestern Wyoming. Tsang et al. (1983) also have presented the results of simulation studies for physical barriers or pumping wells to contain or remove a contaminant plume. An integrated finite difference numerical model was used.

Ground water pumping and treatment schemes without recharge also can be designed and analyzed via models. For example, Chen and Woodside (1988) described the development of an analytical model that can be used to determine the number, location, and pumping rates for withdrawal wells extracting dissolved solutes from contaminated aquifers. Freeberg et al. (1987) used the United States Geological Survey (USGS) method of characteristics (MOC) model at an industrial site where TCE and other industrial solvents had contaminated a shallow sand aquifer. After calibration with field data from the site, the model was used to predict the influence of a four-well withdrawal system. The USGS MOC model also has been used by Satkin and Bedient (1988) to evaluate different well patterns in an aquifer restoration scheme under eight sets of hydrogeological conditions. Estimated cleanup times were developed for the varying conditions.

Development and Use of Remedial Action Cost Information

Owing to the importance of cost considerations in decision-making related to remedial action plans, it is critical that economically defensible estimates for both capital and operation/maintenance costs be developed. Because of the longer-term nature of many remedial action plans, it is also critical that technically defensible estimates of the time requirements for cleanup operations be developed. The latter estimates can be improved via the use of modeling. Cost estimates frequently are difficult to develop and depend highly on the collective history of the use of the technology, the uniqueness of site problems, the size or scale of the operation, and regional and local economic conditions. Since there are potentially extensive time periods between initial site studies and the initiation of cleanup actions, inflation can become an important factor to consider both in terms of capital costs and operation/maintenance costs.

Aggregation of cost information on remedial actions is made more difficult because of the relatively short time period over which remedial actions have been implemented. Also, one of the problems in dealing with remedial action plan costs is the wide variations between initial cost estimates and the received contractor bids for the remediation work. As more information becomes available on remedial actions, the database for cost information will improve. An early effort to aggregate remedial action cost information was completed in March 1982 and subsequently published as a book (Rishel et al., 1984). Conceptual design cost estimates for 32-unit operations were costed in mid-1980 dollars for the Newark, New Jersey, area. A compendium of costs of remedial technologies recently was developed based on 31 case studies (Yang et al., 1987). The compendium highlights actual expenses incurred during remedial responses for seven major types of engineering technologies as listed in Table 6.4 (Yang et al., 1987). Data are given in a unit-cost form; these unit costs typically include all related costs,

TABLE 6.4 Engineering Technologies with Available Cost Information

Technology	Subtechnology
Surface water controls	Surface sealing Grading Drainage ditches Revegetation
Ground water and leachate controls	Slurry wall Grout curtain (Aspemix) Sheet piling Grout bottom sealing Permeable treatment beds Well point system Deep well system Extraction/injection well system Extraction wells/seepage basins Subsurface drain
Aqueous and solids treatment	Activated sludge Anaerobic, aerobic, and facultative lagoons Rotating biological contactors Air stripping Carbon treatment Oil/water separator
Gas migration control	Pipe vents Trench vents Gas barriers Carbon adsorption
Material removal	Excavation/removal, transportation, and disposal Hydraulic dredging Mechanical dredging Drum handling
Water and sewer line rehabilitation	Sewer line replacement Sewer line repair Water line repair Water main replacement
Alternative water supplies	New water supply wells Water distribution system

SOURCE: Yang et al., 1987.

such as material, labor, equipment, and other capital costs. Operation and labor costs are given when they are applicable and available. Some supplemental information also is included on the cost of protection for on-site worker health and safety. All costs were indexed to constant 1982 dollars using the Engineering New Record (ENR) construction index. Finally, a manual has been prepared by the EPA to delineate remedial action costing procedures (Burgher et al., 1987). The manual provides specific procedures for the cost-estimating and economic-analysis steps required for the various remedial action-planning phases.

Use of Systematic Decisionmaking on Remedial Action Alternatives

Several alternative remedial action plans typically are considered at a contaminated site. The use of systematic decisionmaking techniques in selecting a remedial action plan from several alternatives can aid in ensuring that a cleanup program with a greater likelihood of success is implemented. Techniques should provide an opportunity for conducting a trade-off analysis involving the comparison of remedial action plans relative to a series of decision factors (evaluation criteria). Table 6.5 displays a trade-off matrix with nine decision factors; the following approaches can be used to complete the matrix (Canter and Knox, 1985):

- qualitative approach in which descriptive information on each remedial action plan relative to each decision factor is presented;
- quantitative approach in which quantitative information on each remedial action plan relative to each decision factor is displayed;
- ranking, rating, or scaling approach in which the qualitative or quantitative information on each remedial action plan is summarized via the assignment of a rank, rating, or scale value relative to each decision factor (the rank, rating, or scale value is presented in the matrix);
- weighting approach in which the importance weight of each decision factor relative to each other decision factor is considered, with the resultant discussion of the information on each remedial action plan (qualitative; quantitative; or ranking, rating, or scaling) being presented in view of the relative importance of the decision factors; and

TABLE 6.5 Trade-Off Matrix

Decision Factor	Remedial Action Plan 1	2	3	4
Cost [a]				
State approval				
Community acceptance [b]				
Technical feasibility				
Short-term effectiveness				
Ability to reduce or eliminate toxicity, volume, or mobility of the wastes				
Degree of permanence				
Overall protection of health and environment[c]				
Compliance with federal and state environmental standards[d]				

[a] Consider construction and operation/maintenance costs; to determine the latter one must have information on the time required to achieve cleanup.
[b] This may need to be ascertained via a public participation program.
[c] This could be based upon risk assessment principles, and may also include an assessment of the potential impacts of each plan on the biophysical, cultural, and socioeconomic environment.
[d] This can be used as a basis to establish cleanup standards for the site being remediated.

- weighting-ranking/rating/scaling approach in which the importance weight for each decision factor is multiplied by the ranking/rating/scale of each remedial action plan, and then the resulting products for each plan are summed to develop an overall composite index or score for each plan.

Detailed information on factor importance weighting techniques and techniques for ranking, rating, or scaling remedial action plans is presented by Canter and Knox (1985). Personal computer software that is user friendly has been developed to aid in the evaluation of competing alternatives (Klee, 1988); this software can be used in decisionmaking for remedial action plans. Finally, risk assessment and management and/or risk-cost-benefit analysis can be used as a basis for systematic comparisons and decisionmaking among alternative remedial action plans for a given site (Rodricks, 1984; Partridge, 1987; Salmon and Brown, 1987).

TECHNICAL NEEDS TO ENHANCE CLEANUP ACTIVITIES

Based upon the analysis of several comparative studies, the review of remediation technologies (including emerging technologies), and consideration of six things that can be done to improve site remediation, several needs still remain, relative to enhancing opportunities for designing and implementing potentially successful remediation plans. These technical needs are as follows:

1. It would be desirable to develop an expert system on remediation technologies; this system would provide a summary of the collective knowledge of numerous professionals and would be of value to less-experienced professionals currently engaged in selection, design, and implementation of remediation programs.
2. Because of the extensive geographical nature of some sites with soil and ground water contamination, as well as the increasing emphasis being given to cleanup of nonpoint sources of contamination, it would be desirable to develop a systematic approach that would enable geographical problem prioritization at remediation sites. Problem prioritization schemes then could be used to target geographical concerns that should be addressed in the shorter term as well as to delineate opportunities for remediation over the longer term.
3. It is vital that remediation plans be developed based on the usage of scientifically defensible protocols for site characterization and contaminant removal and treatability. Accordingly, research is needed on the development of protocols for remediation technology delineation, design, and implementation.
4. There is a vital need for follow-up comparative studies to review remediation plans adopted at particular sites and to examine the effectiveness of these plans, including the lessons learned. The EPA currently is involved in a 5-year research effort (1987-1992) focused on evaluating the effectiveness of ground water remediation activities at several Superfund sites. This project is surveying remedial investigation/feasibility study

reports and compliance monitoring documents from several sites. The project also will evaluate data acquisition techniques and their relation to the use of mathematical models in remediation performance evaluation.

5. Owing to the importance of cost information in decisionmaking, it is vital that additional actual information on expenditures be developed and communicated to various user groups. Although some information is being developed, and certainly more information is available now than in times past, there are still additional needs for enhancing this database. Accordingly, research is needed to compare cost information systematically for remediation programs.

6. Because of the relatively brief history of the application of remediation technologies, there is a vital need for increased communication of information among scientists and engineers relative to successes and failures of technologies. This communication could be organized by the conduction of technology transfer workshops as well as the aggregation of information on actual case studies.

7. A vital element in decisionmaking relative to cleanup activities is associated with the communication of information on the technologies and, more particularly, the communication of information relative to the risks and risk reductions that might occur as a result of technology implementation. Accordingly, additional research is needed on methods and techniques that can enhance the communication of remediation program information to a variety of interested technical and nontechnical publics.

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Policy Aspects of Current Practices and Applications

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DISCLAIMER

The views contained in this paper represent those of the authors and do not necessarily represent those of the EPA.

INTRODUCTION

This paper offers insight on the progress of the EPA in the remediation of contaminated ground water and soil given the technical uncertainties, time constraints, and public and political demands. There are numerous complexities and problems decisionmakers must address as they define remedial objectives and choose remedial alternatives. This is true especially in the area of ground water remediation. At present, the remediation of ground water is a time-consuming, costly, and complex process in the remedial program. In region III, the average Remedial Investigation/Feasibility Study (RI/FS) that does not involve ground water remediation costs approximately $500,000, whereas the average RI/FS for a site that has a ground water problem costs approximately $900,000. Actual ground water remediation costs run into the millions and may take more than 20 to 30 years to achieve.

Complexities exist not only in the area of site remediation where our scientists and engineers must understand the non-homogeneous subsurface environment, but they also exist in the context of the legislation of statutes that were enacted between 1972 and 1986 to protect the environment. The Clean Water Act (1972), Safe Drinking Water Act (1974), Resource Conservation and Recovery Act (RCRA) (1976 and 1984), and Superfund statutes (1980 and 1986) all were intended to protect public health and the environment (including ground water). Although none were prepared in a vacuum without knowledge of their predecessors, there are noticeable differences when enforcing each of them separately and a vast array of problems when applying them together. To the outside observer these laws often may appear contradictory and chaotic--without any sense. At times they are indeed chaotic, and their application is always extremely complex. However, overall there is a great deal of sense and an underlying rationale for each of the statutes, all of which have the same fundamental purpose: the protection of our nation's ground water--our most precious natural resource.

This paper is divided into five sections. The first section briefly discusses the importance of ground water and the reasons for taking such great pains and making such an effort to protect this resource. The second section discusses how ground water is addressed by EPA's remedial program and presents an overview of the Superfund and RCRA remedial programs. Included is a case study that illustrates current real-world problems regularly addressed by region III decisionmakers. The next section discusses the evaluation and modification of remedial action decisions as we acquire additional knowledge and experience. The final section provides a summary of some current policy issues and briefly describes a recent management tool being used to identify areas that may be particularly vulnerable to ground water contamination.

IMPORTANCE OF GROUND WATER

Approximately 97 percent of the drinking water for rural communities comes from ground water. Ground water is the source of 35 percent of the fresh water withdrawn by municipal water supply systems. In addition, ground water provides 40 percent of the water used for irrigation and more that one-fourth of the water used by industry, excluding water used for hydroelectric power.

Even though there is a vast amount of ground water--an estimated 8 trillion acre-feet--not all of it can be recovered from the water-bearing formations in which it is found. Some ground water is in formations with such low permeability that it is economically unfeasible for it to be utilized. Other large-volume reserves are found in rock formations that are so deep that pumping costs alone negate their usefulness.

Ground water quality is being impacted rapidly not only from close proximity to our industrialized and heavily populated areas but from our nation's rural farming communities as well. Increased pumping rates in coastal areas are creating severe salt water intrusion problems. So dependent is the economy on the water supply that in some areas water shortages have limited the amount of new construction and the expansion of existing communities.

It is the responsibility of all of us--scientists, engineers, policymakers, and the regulated community--to protect this critical resource for current and future use. We must manage ground water as a limited resource and prevent future contamination from potential threats. We must carefully evaluate and order our priorities in these problem areas before they overwhelm us, and we must remediate to the maximum extent practicable in a reasonable amount of time.

OVERVIEW OF SUPERFUND AND RCRA REMEDIAL PROGRAMS

For both RCRA and Superfund cleanups, the first step is to eliminate the source of ground water contamination by

- capping the contaminated soil or providing other containment measures;
- removing the source of contamination;
- technologically treating the source of contamination; or
- any combination of these options.

After this is accomplished, EPA must decide how to deal with the plume of contamination in ground water.

In Superfund the use, value, and vulnerability of the ground water at the site first is determined by using EPA's Guidelines for Ground Water Classification. Class I ground waters are valued highly because they are extremely vulnerable and there is no reasonable alternative source of drinking water available or because they are ecologically vital and support a unique habitat. Class II ground waters are all other ground waters that are either currently or potentially used as a source of drinking water. Class III ground waters are not considered a potential source of drinking water and are, therefore, of limited beneficial use. These are ground waters that are either highly saline (i.e., total dissolved solids are greater than 10,000 mg/liter) or are otherwise contaminated beyond levels that allow restoration with reasonable methods employed in public water systems. This condition may not be attributed to a release from a specific site.

The area impacted by the classification process is not specified, although the guidelines mentioned above usually call for a 2-mile radius around the site. If the aquifer around the site is determined to be a class III aquifer, Superfund gives the remedial project manager (RPM) broad discretion for how to remediate the contamination. Requirements to restore the aquifer to drinking-water quality do not apply. Rather, the primary concern with class III ground waters from a remediation standpoint is whether they discharge to quality surface water or a higher-class aquifer or whether they impact environmentally sensitive areas.

If the aquifer around the site is classified as class I or II, EPA efforts are aimed at restoring the aquifer to a quality suitable for drinking. Drinking water standards defined as maximum contaminant levels (MCLs) or more stringent state standards must be met. Where such standards do not exist, efforts are made to achieve a risk level in the 1×10^{-4} to 1×10^{-7} cancer concern risk range, with 1×10^{-6} as the point of departure.

When the waste source has been left in place, these standards are to be met from the edge of the "waste unit" (source of contamination or area of source treatment) to the limits of the contaminant plume. When the source has been removed or treated to acceptable levels, then standards should be achieved throughout the site and at all areas off site.

At present in RCRA, an aquifer classification process is not conducted prior to establishing ground water protection levels. Rather, there are regulatory requirements that depend upon whether the unit is used to manage RCRA hazardous waste or whether cleanup of RCRA Solid Waste Management Units is in progress.

For hazardous waste units, prospective ground water monitoring requirements are imposed and cleanup levels are based on background levels, or certain MCLs, or may be set on a site-specific basis called alternative concentration limits (ACLs). Regardless of what limitations are imposed, the point of compliance is in the uppermost aquifer at the downgradient edge of the waste management area. If there is more than one waste management area at the site contributing to ground water contamination, a circle is drawn around the areas, and the point of compliance is in the uppermost aquifer at the downgradient edge of the circle.

If remediation is conducted under RCRA corrective action requirements, there is, as yet, no final guidance for imposing ground water limitations. At this time a comprehensive regulatory approach is in the final stages of review prior to publication in the Federal Register. The EPA strongly encourages public comment on the many aspects of this proposal, particularly the determination of cleanup standards. It is equally important that the public provides comments on the recently proposed Superfund revisions to the National Contingency Plan. One approach to setting ground water cleanup standards under RCRA corrective action requirements is to use MCLs or, in the absence of MCLs, a concentration that will provide protection in the 1×10^{-4} to 1×10^{-7} risk range and applying them to the edge of the waste unit. However, some have argued that the site boundary is a more appropriate point of compliance.

After Superfund establishes limitations and the point of compliance for ground water remediation in class I or II aquifers, restoration time frames are evaluated based on several factors, such as current use or impending need of ground water, cost, and feasibility of providing an alternative water supply. After a preferred time frame is established, Superfund evaluates alternatives and selects the technology needed to achieve the remediation level within the desired time frame. RCRA does not require the evaluation of a restoration time frame when selecting remediation measures. However, one would expect that this would be one of many factors considered in choosing a remedy.

Superfund recognizes that there are special situations in which it may not be practical to restore ground water actively in class I and II aquifers. These situations include the following:

- widespread plumes from a nonpoint source;
- hydrogeological constraints, such as complex fracture systems in bedrock, karst topography, or low transmissivity; and
- contaminant constraints such as the presence of dense nonaqueous phase liquids (DNAPLs).

For such cases the Superfund program may provide wellhead treatment and/or rely on natural attenuation with institutional controls to prevent any risk.

It should be stated that both Superfund and RCRA impose cleanup levels for class I and II aquifers without regarding the location of human receptors. The levels are imposed at the unit or site boundaries instead of the location of the nearest users, which may be nearby or at extreme distances from the site. In this respect the ground water requirements could be considered overly protective in terms of eliminating risk to receptors and expensive in terms of treatment needed. However, this approach in both RCRA and Superfund ensures the protection of ground water near the site for future use.

As noted earlier, it is extremely important that contaminated soil at a hazardous waste site be remediated properly not only because of the risk from direct contact but because the soil is commonly the source for ground water contamination. Remedial action at hazardous waste sites needs to account for all potential routes of human exposure, for current and potential future land use patterns at the site, and for all potentially exposed human populations. Soil cleanup levels are established based on a health risk assessment and involve the following four steps:

1. Identification and evaluation of all exposure pathways.
2. Characterization of existing soil contamination.
3. Relationship of exposure levels to health criteria.
4. Assessment of the soil contamination level at which significant adverse health or environmental effects would not be expected to occur.

In order to choose the most appropriate technology to remediate soil contamination, the RPM must prescope the RI/FS carefully and collect the necessary data to perform treatability tests on the soils and wastes of concern. To obtain the necessary data, the entire site may have to be gridded and soil samples taken from various depths to characterize fully the horizontal and vertical extent of contamination. In order to perform treatability studies during the RI/FS process without introducing any unnecessary delays, the RPM must anticipate the type of technical information that will be required. To assist the RPM, he/she may include experienced personnel from a variety of disciplines in the scoping process (i.e., hydrogeologists, engineers, chemists, laboratory technicians, wetlands experts, treatment technology specialists, and management).

A key aspect of remediating ground water at a site is to ensure that further degradation of the aquifer does not continue because of contaminants leaching from the soils above them.

The majority of sites presently under investigation require the remediation of contaminated soil. An important issue for the decisionmaker is to determine the urgency of the need to clean up the soil. Certain site conditions, such as permeable soils, shallow aquifers, high contaminant concentrations, and/or nearby receptors, may demand a fast-tracked evaluation and remediation of the contaminated soil. Similarly, high levels of contaminants already in the ground water may warrant the immediate supply of an alternative water source to the exposed population. In other cases remediation may proceed at a slower pace and may possibly mean significant cost savings.

A second key aspect is to ascertain that the public has a clear understanding of the contamination at a nearby site and that they are aware of the present and potential impact it may have on their health and the environment. In many cases the lack of proper communication creates a hostile relationship between the public and regulatory agencies. Decisionmakers must place themselves in the public's shoes when communicating risk, explaining site conditions and requesting public input on the proposed remedial alternative. Not only does the public have a legal right to be involved in this process, but it is also critical that they are included in the decisionmaking process since it is their lives that have been disturbed and it is their protection that is the core of our regulatory program.

The EPA can provide technical assistance grants of up to $50,000 for each Superfund site to assist the public in interpreting technical information. A properly informed public can be our greatest ally; a poorly informed public may disrupt the remedial process, causing the RPM to spend a large amount of time defending the agency's decisions. It is extremely important that the agency is aware of the public's perception of the problems that exist, be responsive to their concerns, integrate their suggestions when appropriate, and provide understandable responses to their questions and concerns, particularly in areas as complex as ground water remediation.

The public's interest is only one of the many considerations that can impact the remedial process. The RPM must negotiate with the potentially responsible parties (PRPs), initiate appropriate enforcement actions, and prepare cost recovery documentation. Decisions must be made to determine whether the site requires immediate stabilization, whether it needs remediation in a phase-by-phase approach, or whether particular areas of the site need more urgent action to allow the remaining remediation to proceed on schedule. RPMs must be aware of the entire range of applicable federal, state, and local laws that must be considered as they remediate a site, and they must coordinate closely with their state and federal counterparts throughout the process. Remedial alternatives must be evaluated for effectiveness, timeliness, cost, and implementability, especially in light of the new and rapidly expanding treatment technologies. Furthermore, managers are faced with a high rate of staff turnover and a limited number of available qualified personnel. Figure 7.1 illustrates some of the varied and complex concerns of decisionmakers that affect the remediation of hazardous waste sites.

The next section presents a case study that illustrates the types of decisions that face management on a daily basis. The case described is a Superfund site where the initial remedy for the source of contamination was modified because the waste generator unexpectedly requested the use of an innovative technology for the cleanup.

TYSON'S SUPERFUND SITE

Tyson's Superfund site, located in Montgomery County, Pennsylvania, is a former quarry where waste solvents and sewage sludge were disposed in unlined lagoons. Two major lagoon areas at the site posed a threat to public health from direct contact with contaminated soil. Volatile organics, many of which are carcinogens, leached from the lagoons to contaminate the ground water underlying the site. The banks of the Schuylkill River are approximately 2,500 yds downgradient of the lagoon areas, and there is a drinking water intake less than 1 mi downstream from the site. Traces of trichloropropane were found at the drinking water intake.

In 1983 EPA took emergency action to fence the site and to collect and treat the leachate streams. The agency decided to remediate the remaining site problems in two phases: the first phase addressed the source of contamination in the lagoon areas; the second phase addressed the contaminated ground water.

The PRPs--the generators of the waste--declined the opportunity to conduct the RI/FS. EPA selected an alternative to remediate the soil to background levels by removing approximately 30,000 cubic yds of soil and disposing it in an off-site RCRA landfill. This remedy was estimated to cost $20,000,000.

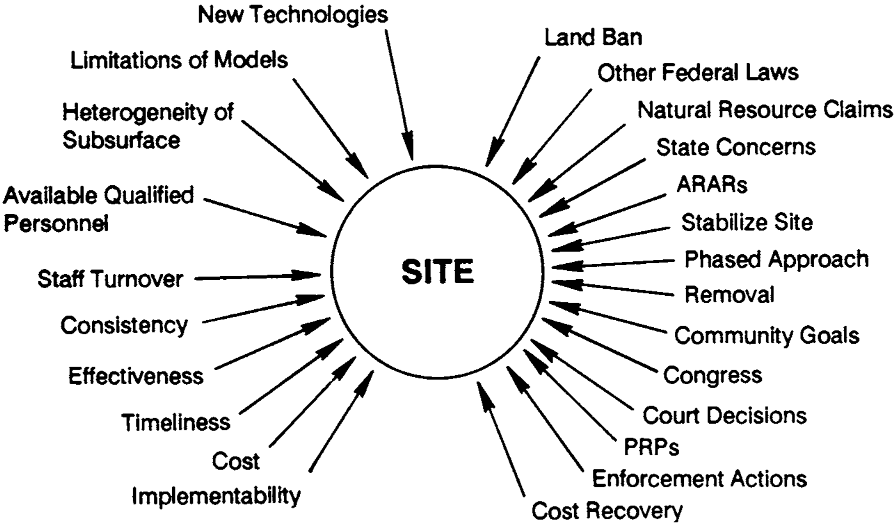

FIGURE 7.1 Considerations for remedial decisionmakers.

Unknown to EPA, the PRPs had conducted a separate RI/FS on their own. Immediately preceding implementation of EPA's chosen remedy, the PRPs proposed to fund an alternative remedy that included in situ treatment of the soil and treatment of the contaminated ground water. The soil treatment involved vacuum extraction of volatile organics from soils located above the water table. The ground water treatment included the installation of barrier ground water wells located between the site and the Schuylkill River to pump and treat both shallow and bedrock ground water. The PRPs estimated that their remedial alternative would cost $10,000,000. There were several advantages and disadvantages to the PRPs' proposal that EPA had to consider. The advantages included

- an immediate savings of $20,000,000 to Superfund,
- destruction of contaminants versus EPA's proposal to relocate the waste in a RCRA landfill, and
- remediation of the bedrock aquifer.

The disadvantages were as follows:

- some contamination in the soil would remain on site;
- EPA would have to establish appropriate soil cleanup levels to prevent future leaching of contaminants and to protect the public from direct contact;
- an unproven technology would be used and there would be a need for another alternative in case of failure to meet all criteria; and
- there would be the possibility of jeopardizing EPA's alternative unless a consent decree could be signed by the PRPs within 3 weeks before the publication of the RCRA Land Ban.[1]

In order to calculate appropriate soil cleanup levels, EPA had first to identify health-based acceptable human intake levels for each contaminant. Acceptable intake levels based on MCLs, 1×10^{-6} cancer risk, and state standards were applied to the following exposure scenarios:

1. A hypothetical well is placed at the boundary of the lagoon. It is assumed that the residual contamination in the soil is released into the ground water and that potential receptors are exposed throughout their lifetime. Soil cleanup levels are back calculated after acceptable ground water levels are established.
2. There is direct human contact with the soil. Exposure routes include ingestion of soil, inhalation of dust, and dermal absorption.

Cleanup levels were established for 41 contaminants under each scenario, and the most stringent level for each substance was chosen as the final soil cleanup level. In almost every instance, the most stringent level was generated from the hypothetical well scenario.

Both EPA and the PRPs determined that the vacuum extraction technology should be capable of achieving the soil cleanup levels. The consent decree established a 70 percent reduction of soil contamination after 1 year of operating the vacuum extraction technology. This assessment is scheduled for November 1989. If this goal is not achieved, the PRPs have the option of continuing with this technology or proceeding with an alternative remedy. After 2 years the PRPs must achieve a level of 50 parts per billion for the primary contaminants of concern--1,2,3-trichloropropane, benzene, trichloroethane, and tetrachloroethane.

As previously discussed, a second concern was the quality of the ground water and its effect on the Schuylkill River and the downstream drinking water intake. The PRPs initially installed a ground water pump and treat barrier well system consisting of seven wells located between the lagoon area and the river. Under a consent order with EPA, the PRPs undertook an RI/FS to establish a more permanent treatment methodology. EPA established risk-based ground water cleanup levels based on MCLs, 1×10^{-6} cancer risk, and state standards, with the point of application being the river bank.

The record of decision developed by EPA based on the PRPs' RI/FS recommended steam stripping as the preferred technology to achieve the cleanup levels. If organic compounds are encountered that are not remediated to their respective cleanup levels, they will be removed by the addition of a liquid-phase carbon adsorption system. EPA and the PRPs recently have completed negotiations for the implementation of this remedy.

It is still too early to determine if the vacuum extraction system will remediate the soil to the cleanup levels. If not, the PRPs will have to make a major decision: either continue with the remediation as planned and risk litigation or choose an alternative remedy that will probably increase the cost but remediate the site to the protective cleanup levels within the required time frame. As shown in this case study, unanticipated complexities may arise, but appropriate innovative technologies must continue to be explored for the protection of human health and the environment.

EVALUATING PERFORMANCE AND MODIFYING REMEDIAL ACTIONS

Even when a detailed hydrogeologic evaluation is performed, there are several reasons why the actual performance of a remedial action may not meet or exceed the predicted performance. These include

- complex behavior of contaminants in the ground water,
- heterogeneity of hydrogeologic systems,
- limitation of present ground water flow and solute transport models, and
- limitation of available technologies to withdraw contamination from geologic units.

Performance evaluations of the full-scale remedial action based on actual field data provide information regarding the effectiveness of the selected alternative. Figure 7.2[2] illustrates a decrease in contaminant concentrations over time for three ground water remedial actions of varying effectiveness. Line A represents a remedial action that should achieve the original cleanup level within the restoration time frame. Line B represents a remedial action that is predicted to achieve the cleanup level but not within the original time frame. Line C represents a remedial action that may never achieve the desired cleanup level, regardless of the time frame.

Ground water monitoring data provide the basis for evaluating the effect of the remedial action on ground water quality. Sampling events should be shortest (i.e., weekly, monthly) at the beginning of the remedial action and adjusted accordingly based on site-specific conditions. In many cases monthly sampling intervals may be appropriate during the first year for a detailed evaluation of the chosen technology. Initial data may be used to evaluate data gaps and uncertainties, to further characterize the aquifer, and to identify locations for additional monitoring. The monitoring system should be designed to characterize fully the movement and quality of the contaminated ground water as the remedial action progresses. The overall monitoring program also should evaluate other environmental effects, such as salt water intrusion, land subsidence, drawdown effects on uncontaminated water supply wells, and effects on wetlands or other sensitive habitats.

A performance evaluation should be conducted within the first 6 months to fine tune the remedial process. More extensive performance evaluations should be conducted at regular levels to determine if the cleanup levels have been or will be achieved in the desired time frame. If an evaluation reveals that the remedial objectives will not be met by the chosen technology, the decisionmaker should consider the following options:

- upgrade or replace the remedial action to achieve the original objectives, or
- modify the remedial action objectives and continue remediation if appropriate.

If the performance evaluation indicates that the remedial action has achieved the desired cleanup level within the restoration time frame, the remedy is complete. In other cases the performance evaluation may indicate that it is technically

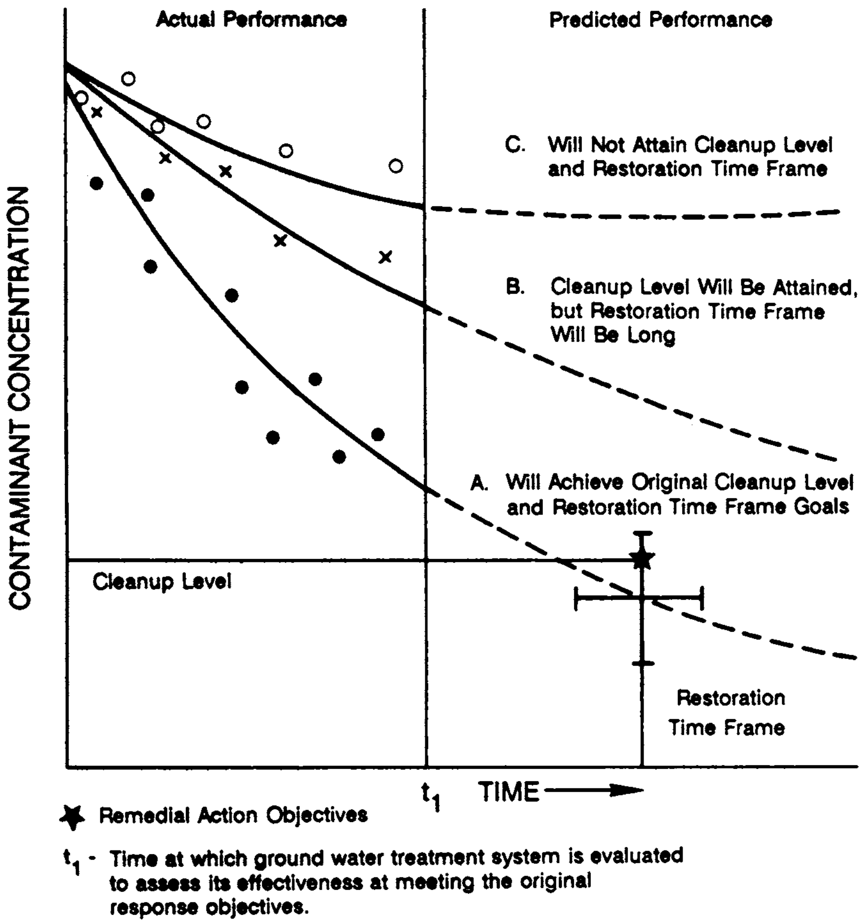

FIGURE 7.2 Predicting remediation action performance from monitoring data.

impractical to achieve cleanup levels in a reasonable time (i.e., contaminant mass removal has not reached significant levels), and a waiver to meeting cleanup standards may be warranted. There is always the possibility that additional information regarding on-site conditions or other factors may indicate that less-stringent cleanup levels still will protect human health or the environment. The public will be notified of any changes in protection standards and will be given the opportunity to comment before implementation.

PRESENT POLICY ISSUES CONCERNING SUPERFUND

There are a number of significant issues currently being addressed by EPA's policymakers. During the confirmation hearing of EPA's new administrator, William K. Reilly, he pledged a thorough internal review of the Superfund program. This study is progressing on schedule and is focusing on ways to make midcourse corrections that will increase the pace, number, quality, and cost effectiveness of site cleanups.

One of the issues being investigated is the need for consistency in the selection of remedies. However, prior to initiating policy in this area, we must first define what we mean by the word consistency. Should consistency be defined as the same cleanup level for each specific contaminant, the same remedial technology chosen for a particular type of site, or the remediation of all sites to the same risk level?

There are other issues facing the Superfund program. Should we always be remediating sites for permanent cleanup or should we take an interim remedial approach for certain sites while waiting for a better, more reliable technology for the "permanent" remedy? Is it cost effective to remediate ground water continually, or should we accept wellhead treatment and rely on natural attenuation for the aquifer? If we do, then what will be the long- and short-term impacts on surface water and the environment? These issues will not be resolved overnight, but they are being considered carefully and will continue to be addressed as the program evolves and progresses. Issues such as these are not limited to the Superfund program but have wider implications for all ground water management.

There were great expectations for the Superfund program when it began because no one realized the complexities that would be encountered. Originally, we were confident long-term ground water remediation (i.e., pump and treat) could be accomplished in approximately 20 years. Now, with our present knowledge and experience, many professionals suggest these actions may take much longer--in some cases up to 100 years. An appropriate analogy is that when characterizing the hydrogeology of a site from three bore holes it appears quite easy; there may be a uniform layer of sand below the topsoil, grading into a fine silt, followed by bedrock. However, if you put in a second round of 15 additional bore holes, you discover that there are a number of clay lenses, a meandering gravel bed that is the remnant of a stream that existed 10,000 years ago, and a bedrock aquifer that responds differently to pump tests in wells located 150 feet apart because of a complex fracture system.

But when do we stop investigating and begin to remediate? When do we begin to reduce the long-term risks that may plague a community? (Immediate risks are remediated by EPA's Emergency Response Program when necessary). How do we explain to concerned citizens that we still cannot begin to clean up the chemical site adjacent to their homes because we're not sure if the technology will work? The only answer is that we must prioritize our sites, plan carefully, work efficiently using all of our resources, and continue to monitor the results to ensure we are protecting both human health and the environment. Because of the many complexities encountered, we never will have all of the answers; however, we must evaluate the available information and make our decisions accordingly.

One recently developed management tool for prioritizing areas for ground water remediation is the use of a computer-based geographic information system (GIS). GIS has the capability of mapping all waste sites, be they covered by RCRA, Superfund, or the Underground Storage Tank Program, and comparing them to ground water usage data (i.e., location of municipal water wells). Such an approach gives us the ability to set priorities for remediation, to concentrate on areas where problems are clustered, and to evaluate the entire risk to ground water from such sources of contamination.

A vulnerability priority (high, medium, or low) can be assigned to specific areas based on data such as permeability and transmissivity of the soil and bedrock, depth to the aquifer(s), number of contaminant sources, degree of contamination, and the population served. A recent project mapped the location of all facilities throughout a specific geographic area with underground storage tanks that were 15 years of age or older. The location of municipal water wells also was mapped, and high-, medium-, and low-vulnerability areas were shaded accordingly. The final map has proven extremely useful in assisting with the planning and scheduling for underground storage tank inspections.

It makes eminently good sense to study small geographic areas where multiple sources of contamination are degrading the same aquifer and where remediation activities can be applied in tandem to maximize the efficiency of remediation. Initiatives such as this, as well as the evaluation and improvement of present and potential technologies, must continue to progress if we wish to protect this critical resource effectively.

CONCLUSION

An important concept should remain in focus as we evaluate past and current remedial actions: the scientific community, the regulated community, and the regulatory agencies must work together for continued progress with remediation. Rather than waiting for technical advances and changing policy accordingly, EPA sets policy based on the protection of human health and the environment. Often, present technology may not be able to fully meet the Agency's standards, which require additional scientific and engineering advances. In this way EPA provides specific direction for today's research, thereby promoting and directing future scientific progress.

We must increase our understanding of subsurface fate and transport processes and refine our current models to better predict the flow of ground water and the transport of contaminants It is equally important to continue to develop and evaluate alternative technologies that can remediate both ground water and contaminant sources and to exchange that information effectively between scientists and decisionmakers.

The EPA recognizes the inconsistencies among its programs regarding cleanup levels in the different statutes and is confronting the complexities and problems that are the result of having to integrate four separate statutes into one ground water policy. The deputy regional administrators recently have evaluated these problems and have drafted a proposed policy as a starting point. The agency is aware that it should provide national ground water-quality criteria to encourage and assist states to establish their own standards since they will continue to have the primary responsibility for managing local ground water resources. The EPA will continue to progress with the assistance from the scientific community, the regulated community, and the other regulatory agencies to fully develop and maintain a holistic ground water protection program that will remediate present problems and prevent future ground water contamination.

ACKNOWLEDGMENTS

The authors express their sincere gratitude to the following individuals for their timely and thorough review of the preceding paper: Michelle Anders, Richard Brunker, Basil Constantelos, Abraham Ferdas, Jennifer Haley, Merrill Hohman, Meg Kelly, Rick Otis, and Jeffrey Wentz. Special thanks is extended to Bruce Smith for supplying the case study and original draft of "Overview of Superfund and RCRA Remedial Programs." Last, and most importantly, this paper would not have been possible without the assistance of Patricia Corbett and her staff, especially Marie Owens and Stella Bregman, for their invaluable assistance in preparing it for publication.

NOTES

1. The Land Ban sets specific treatment standards based on best demonstrated available technology for certain wastes that must be met before these wastes legally can be land disposed.

2. U.S. Environmental Protection Agency. Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites. OSWER Directive No. 9283.1-2, December 1988, p. 7-2.

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8

How Scientists Make Decisions About Ground Water and Soil Remediation

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INTRODUCTION

Are science, policy, and public perception compatible for ground water and soil remediation? This question posed by the colloquium reflects the doubts expressed by many of the stakeholders (public, industry, Congress, contractors, scientists) in the hazardous waste site remediation program. Indeed, this program has been the object of considerable criticism since its inception.

We consider that science, policy, and public perception would be compatible if solutions to hazardous waste problems were seen as fair and equitable by all the stakeholders. At this juncture it is safe to say that the stakeholders do not achieve such consensus regularly. The remediation process has been so troubled that Congress has seen fit to limit the discretion of the EPA through legislation containing mandated schedules and preferences for permanent remedies. Recent reports by both the Office of Technology Assessment and the Hazardous Waste Treatment Council, and the formation of an industry coalition (the Superfund Coalition) to study Superfund implementation, further indicate the current lack of consensus.

Why have solutions remained so elusive? We contend that the Superfund process is flawed by a misapplication of technology in defining the problem and deriving acceptable solutions. The public perceives hazardous waste problems as very serious because of the potential threats they pose to public health and the environment and the high costs of site assessment and remediation. Federal policy clearly acknowledges the severity of the problem and has sought to reduce the risks to acceptable levels through a risk assessment procedure. Unfortunately, the tools and methods used in remedial decisionmaking are unable to cope with the large technical uncertainties characteristic of hazardous waste sites. The result has been a highly contentious (and litigious) program environment.

This paper first describes the policy issues associated with the Superfund program and how the program differs from other environmental programs. The paper then describes the unique technical problems of hazardous waste remediation that derive from the high degree of uncertainty characteristic of all hazardous waste site investigations. The traditional civil engineering paradigm of study, design, build is unable to cope with this scale of uncertainty. Finally, a discussion follows of a method derived from geotechnical engineering--the observational method--that we propose to manage this uncertainty and promote solutions to satisfy the criteria of science, policy, and the public.

REGULATORY FRAMEWORK

Superfund

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or Superfund) sets a policy to provide cost-effective remediation of hazardous waste sites to protect public health and the environment. A significant feature of this policy is that it allows remediation goals to be set at something less than total removal. In setting this policy the architects of CERCLA sought equity among all stakeholders.

Under the law, responsibility for cleanup is directed to those who deposited the waste. CERCLA also established a fund to pay for abandoned hazardous waste sites at which no responsible parties could be found. EPA policy seeks to conserve the fund by using the tests of "cost effectiveness" and "protection of the public health and the environment." Remedies are targeted to achieve contaminant levels that represent "no significant adverse effects"; these usually are very different from "background," "no detection," or other extreme levels.

The environmental problems that motivated the creation of CERCLA also imparted a sense of urgency to its implementation. The legislation aimed to set a program in motion immediately to identify problems and begin remediation on the sites posing the greatest threats. Consequently, no studies were undertaken on how to set performance standards, nor was time set aside to develop remedial technologies. The Superfund program was assembled from existing technical disciplines and methodologies. Each brought its own assumptions, knowledge base, and built-in limitations.

Sites on the National Priorities List (NPL) are investigated and their risk to human health and the environment assessed in accordance with the National Contingency Plan (NCP) (see Figure 8.1). The remediation process, as described by the EPA (U.S. Environmental Protection Agency, 1988a, b), begins with a remedial investigation and feasibility study (RI/FS) "to assess site conditions and evaluate alternatives to the extent necessary to select a remedy" (achieve manageable uncertainty). The remedial investigation "serve[s] as a mechanism for collecting data for site and waste characterization and for conducting treatability testing." The data are used to develop a baseline risk assessment that "will help establish acceptable exposure levels for use in developing remedial alternatives in the FS." The feasibility study "serve[s] as a mechanism for the development, screening, and detailed evaluation of potential remedial alternatives." In this study remedial alternatives are analyzed against the criteria required by the NCP. Risk assessments are conducted for each potential remedial alternative to determine whether the remedy can reduce the health and environmental risks to acceptable levels.

The EPA selects the remedy and documents it in its record of decision (ROD). This decision is expressed graphically in Figure 8.2. The curve is a schematic representation of the level of residual risk remaining across a range of remedial efforts (Conway, 1988). Remedies to the right of the acceptable risk point (a judgment made based on specific site characteristics) would not be considered cost effective (and in the case of fund-financed remedies, not fund conserving). Remedies to the left of that point would not be sufficiently protective of human health and the environment. This decision step is followed by a remedial design and action (RD/RA).

Comparison with Other Environmental Laws

CERCLA is technically quite different from the earlier environmental statutes--the Clean Air Act (CAA) and the Clean Water Act (CWA). Both CAA and CWA seek to prevent environmental degradation by placing controls on discrete, future discharges to primary media (water and air). These statutes set specific end-of-pipe or stack discharge standards to be met through engineering controls on discrete waste streams.

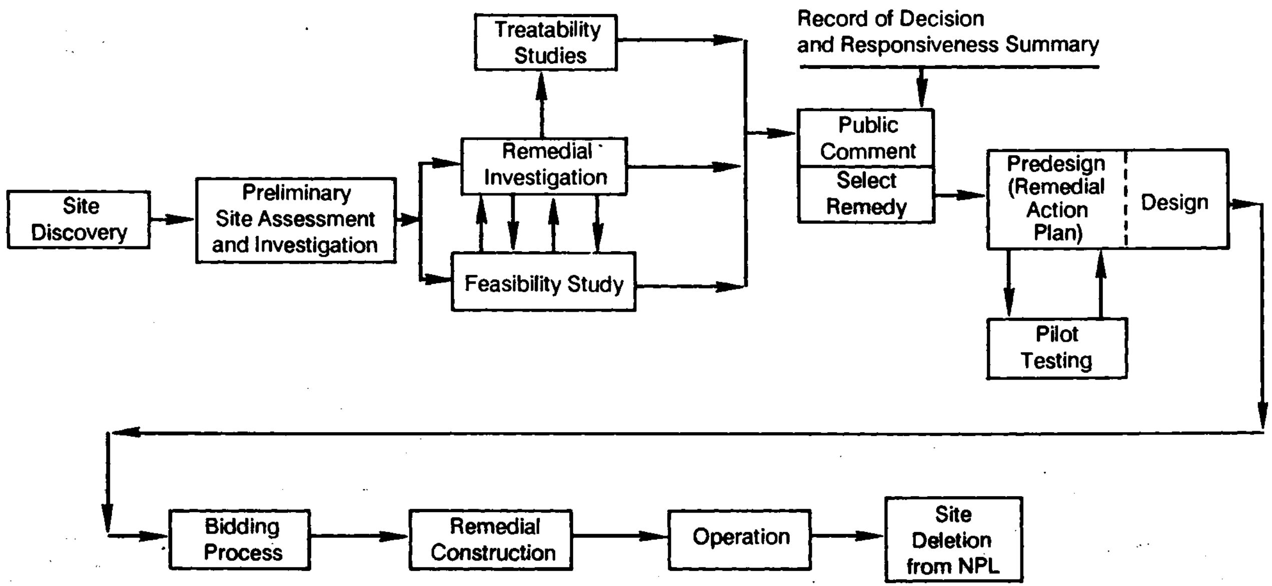

FIGURE 8.1 The Superfund remedial process.

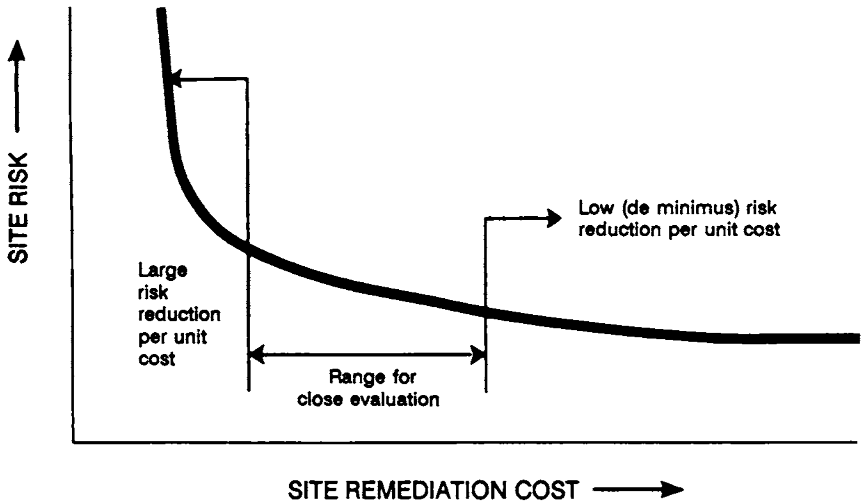

FIGURE 8.2 Cost effectiveness. (Source: Conway, 1988.)

Success is measured by the ability to achieve specific concentration limits for specific chemicals discharged into the environment.

In contrast, Superfund is both more ambitious and more ambiguous; its goal is environmental remediation of past, uncontrolled disposal practices that resulted in releases of hazardous substances to the environment. It does not target discrete waste streams. The statement of the problem at hazardous waste sites is more complex and ill defined than at those covered by CAA and CWA regulations. Containment and treatment systems are designed based on estimates of how contamination might move below ground and come into contact with human populations or sensitive environments. Success is measured by the ability of the system to keep contamination contained and/or reduce contaminant concentrations to acceptable levels. Acceptable levels of specific contaminants are not set by regulations. Rather, they are set site by site through arisk assessment that weighs the hazardous properties of the contaminants in relation to the specific environmental situation in which they reside.

This risk assessment process provides an important distinction between CERCLA and the related statutes. In the CAA and CWA the work of the policymakers who make risk management decisions and the work of the engineers and scientists are clearly separated. Under these two acts, the standard-setting process (determining an acceptable level) is disconnected from the site-specific act of meeting the standard (placing engineering controls on discharges). But under the Superfund risk assessment process, the work of the scientists and engineers helps determine the standards. Judgments about where to look for contamination, development of transport and fate models, estimates of the quantitative relationship between dose and response, and assessments of remedy performance are connected inextricably to the determination of the appropriate target level and the appropriate response at the specific site. Communities also participate directly in establishing site-specific regulations for environmental contamination in their neighborhoods.

The Superfund Amendments and Reauthorization Act (SARA) requires a pace of major risk management decisions that has not been observed under simpler regulatory programs. Typically, it takes several years for an EPA office to promulgate a final rule for an acceptable chemical concentration, and this rule usually covers a chemical in only one environmental medium in one exposure setting. For example, EPA took an average of 4 years from the date of listing to final action (setting standards) for six carcinogens under the CAA. More than 5 years passed between the advance notice of proposed rulemaking and the final maximum contaminant levels for eight volatile organic compounds under the Safe Drinking Water Act (Office of Technology Assessment, 1987). Yet at almost every hazardous waste site, the remediation goals must cover tens of chemicals in several environmental media over several current or potential exposure settings. The choice of remedial technology also must consider the rate of remediation. SARA requires that 375 remedial actions be initiated within 5 years of passage (1986). Decisions must be made (documented in the ROD) before a remedial action can begin.

CURRENT TECHNICAL APPROACH

Study, Design, Build

Nominally, the role of science in hazardous waste remediation is to assess the physical, chemical, and biological threats posed by the sites. Engineers "transform the findings of scientists (e.g., hydrogeologists and toxicologists) into products useful to man" (Conway, 1988). In so doing, they follow a traditional engineering paradigm of study, design, and build. Starting with an expressed objective, budget, operating conditions, and constraints, the engineer studies the situation, assesses possible alternatives, and recommends the solution most suitable. Once an alternative is selected, designs are produced. Construction proceeds in accordance with the design of the engineer.

The objective of this traditional engineering approach is to reduce the uncertainties early in the life of the project. It is reasoned that time and effort invested at the investigation and study phase will result in a better design and fewer contingencies. A body of experience and standard practice has developed in the traditional engineering services (e.g., waste water treatment plant construction) such that most of the uncertainty is reduced to manageable levels at the study phase. However, the scale of uncertainty at a Superfund site challenges the paradigm of study, design, build.

Severity of the Problem

The high potential risks of hazardous waste sites and the high cost of remediation (now estimated to average $20 million to $30 million per site) demand extraordinary precision and accuracy in the remedial work performed. High risk and high cost also define the level of care appropriate for remediation activities. The engineer needs to understand the technical risks extremely well (as well as the risk perceived by the public) in order to devise a remedy that is seen as truly protective of public health and the environment. The task of the engineer is to produce a remedy that incorporates the right combination of technical effectiveness, reliability, and cost.

In general, the engineers, scientists, policymakers, and public have understood that the cost of being wrong in hazardous waste remediation is high and that remediation faces great uncertainties. These uncertainties have inspired massive efforts to identify sources of contamination and characterize sites. The RI/FS process developed over the past years has become very comprehensive in an attempt to reach the required level of precision and accuracy. However, in reality that level is never reached. Hazardous waste sites pose a major challenge to current technologies.

Uncertainties and Their Implications

Major technical uncertainties complicate all the key components of a Superfund site assessment.

Contaminant Location and Identification

Waste quantities as small as 100 liters can contaminate an aquifer.[1] The direct methods of subsurface drilling and ground water sampling are the only technologies available to locate large and small quantities of waste. Techniques such as ground-penetrating radar or resistivity can scan larger areas but are not accurate enough to pinpoint small deposits. Even if the site investigation team is prepared to honeycomb the site with soil borings and monitoring wells (at enormous cost), it will not be able to say with confidence that all significant contamination has been located.

Subsurface Complexity

The hazardous contaminants at any particular site may be found in widely varying concentrations and potency throughout a highly variable subsurface environment. Soil, sand, clay, and rock layers of varying permeability and integrity provide a multitude of underground pathways for contaminant movement and, consequently, many opportunities for contaminants to reach critical receptors (the public or critical environments). For example, the intensive investigations at Love Canal provided over 2,600 borings on 40 acres, and yet the soil volume analyzed was still only 0.01 percent of the site. Although the cost of retrieving this kind of data is high, from $15,000 to $50,000 per boring, even such intensive sampling is insufficient to obtain a truly accurate portrait of fine details such as cracks and sand lenses in the substrata.

Fate and Transport Models

The models used to estimate how contaminants may reach receptors are based on physical and chemical characterization of subsurface media and include nonlinear processes. Inadequate specification of the site conditions because of uncertainties in subsurface characterization can lead to substantial differences between model predictions and observed results. In addition, the RI/FS typically only allows enough time for a "snapshot" of conditions, but critical temporal dependencies may show up only in longer-term studies. Our limited understanding of complex fate and transport interactions provides further limitations in the development of models. Some data inherently are stochastic (e.g., rainfall), and this contributes further uncertainty.

Exposure Characterization

The chemical dose that could be received by a receptor is another critical component of Superfund site assessment. The dose will depend on the activities of the receptor (e.g., residential, industrial, or recreational activities), as well as the conditions of the exposure media (soil, air, water, biota) and the exposure route (ingestion, inhalation, dermal contact). Uncertainties here range from inadequate knowledge about receptor activities to lack of models for some exposure routes and unknown chemical-specific parameter values.

Toxicity assessment

The science of toxicology still is in an early stage of development. Substantial scientific work is needed yet on the characterization of potential effects of toxic substances, dose-response functions, potential synergistic or antagonistic effects, and the translation of animal data to humans. Furthermore, substantive toxicological information currently is available on only a minority of the chemicals in commercial use (National Research Council, 1984).

Performance of Remedial Technologies

For the most part, technologies for hazardous waste site remediations have not been proven to be effective. While many of these technologies have been used for treatment or destruction of some waste streams, effectiveness for one type of waste stream does not mean effectiveness for another. Moreover, performance under laboratory conditions does not guarantee performance under field conditions.

These uncertainties inherent in hazardous waste assessment have three consequences for the traditional engineering paradigm of study, design, build:

- It is generally assumed that more study will reduce uncertainty. But, to date, there has been no full recognition that the marginal value of further studies at Superfund sites declines rapidly. At some point more study does not lead to better information. Figure 8.3 qualitatively compares hazardous waste engineering to traditional engineering.
- Traditional engineering makes an effort to design the ultimate remedy that can operate with little change following construction. But the high uncertainty in the subsurface environment requires flexibility in remedial design and construction as well as continued monitoring. In most cases it will not be possible to walk away from a Superfund site; monitoring will be required regardless of the chosen alternative.
- In the presence of substantial uncertainty, there is considerable opportunity for the various stakeholders to adopt different assumptions and interpretations. Disputes over which is the most appropriate remedy are initiated by parties seeking to improve their cost position. It is relatively easy for any stakeholder to create an alternative set of equally credible assumptions to dispute the assumptions of another. The inability of the current system to discriminate among alternatives is depicted in Figure 8.4, in which the simple curve of Figure 8.1 is replaced by a broad shaded area representing the uncertainty in the risk-cost relationship.

ALTERNATIVE FOR MANAGING UNCERTAINTY: THE OBSERVATIONAL METHOD

Recognizing the orders-of-magnitude uncertainties inherent in hazardous waste problems has led us to look for new ways to approach remediation. In examining the problem of uncertainty, we looked to the geotechnical engineering field, where physical uncertainty has always been a confounding element. Early work by Karl Terzaghi and R. B. Peck pointed out that the highly variable physical conditions in the subsurface make it impossible to obtain more than a rough approximation of the physical constants used in the design equations for foundations and dams. The risk features of foundations and dams are similar to those found in hazardous waste site remediation.

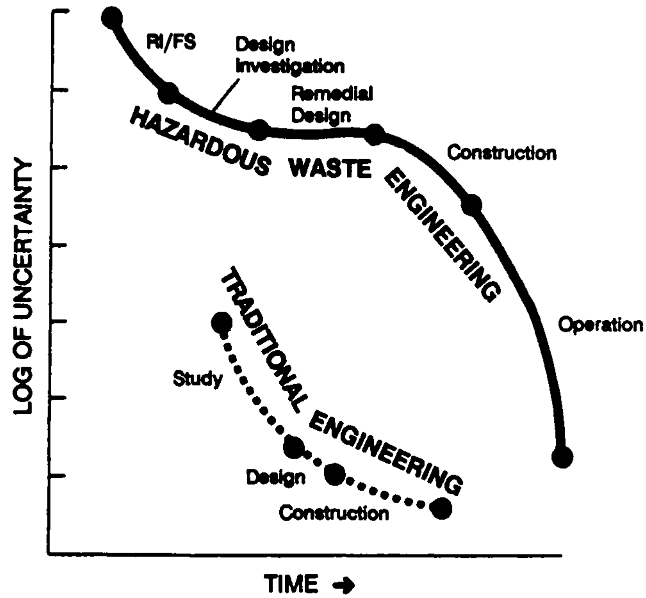

FIGURE 8.3 Uncertainty in hazardous waste engineering and traditional engineering.

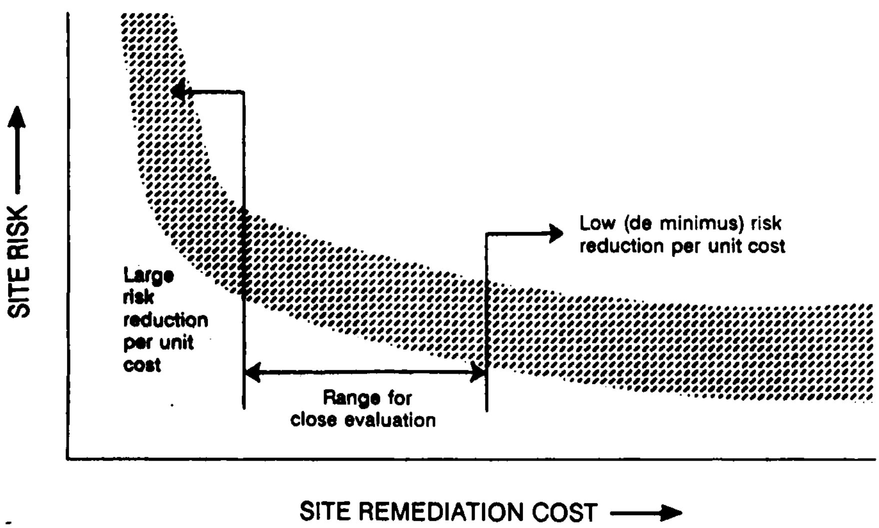

FIGURE 8.4 Cost effectiveness with uncertainty.

For many years geotechnical engineers have been using the experimental or observational design method developed by Terzaghi and Peck. They base the design on the best information available but account for reasonable deviations during design and construction.

The following rather lengthy quote from a 1945 text of Terzaghi on dam foundations is repeated here because of its applicability to Superfund (emphasis added):

> In the engineering for such works as large foundations, tunnels, cuts, and earth dams, *a vast amount of effort and labor goes into securing only roughly approximate values for the physical constants* that appear in the equations. Many variables, such as the degree of continuity of important strata or the pressure conditions of water contained in the soils, remain unknown. Therefore, the results of computations are not more than working hypotheses, subject to confirmation or modification during construction.
>
> In the past, *only two methods have been used for coping with the inevitable uncertainties: either to adopt an excessive factor of safety, or else to make assumptions in accordance with general, average experience.* The designer who has used the latter procedure has usually not suspected that he was actually taking a chance. Yet, on account of the widespread use of the method, no year has passed without several major accidents. It is more than mere coincidence that most of the failures have been due to the unanticipated action of water, because *the behavior of water depends, more than on anything else, on minor geological details that are unknown.*
>
> *The first method is wasteful; the second is dangerous.* Soil mechanics, as we understand it today, provides *a third method which could be called the experimental method.* The procedure is as follows: Base the design on whatever information can be secured. *Make a detailed inventory of all the possible differences between reality and the assumptions.* Then compute, on the basis of the original assumptions, various quantities that can be measured in the field. For instance, if assumptions have been made regarding pressure in the water beneath a structure, compute the pressure at various easily accessible points, measure it, and compare the results with the forecast. Or, if assumptions have been made regarding stress-deformation properties, compute displacements, measure them, and make a similar comparison. On the basis of the results of such measurements, gradually close the gaps in knowledge and, *if necessary, modify the design during construction.*

> Soil mechanics provides us with the knowledge required for practical application of this "learn-as-you-go" method. (Quoted by Peck, 1969.)

Peck condensed this observational method into eight key elements. These have been refined further by Brown et al. (1988) for use on hazardous waste sites:

1. Define the scope of work. Establish goals and objectives, review existing data, develop a conceptual model, and identify data gaps.
2. Conduct an initial screening of general response actions.
3. Collect information on site conditions, including the nature and extent of the contamination.
4. Use the information collected to construct a conceptual model of the site to establish probable conditions and reasonable deviations.
5. Prepare a modified feasibility study. Evaluate the remediation alternatives and prepare conceptual contingency plans as a response to identified deviations. Recommend the most effective alternative, given probable conditions at the site.
6. Design the chosen remedial action, select parameters to observe, and prepare contingency plans.
7. Implement remedial action and measure responses.
8. Respond to deviations.

Using this method, the scientist or engineer does not solve the uncertainty problem but enters the design and implementation phases better prepared. Remedial decisions are made with an awareness of the potential deviations, and plans are set to cope with them.

Inherent in this method is the admission that more data and more analytical rigor will not reduce the uncertainties present. This honest acknowledgment of the limits of technology and the consequent contingency planning incorporated into this methodology may help to improve public trust in the process.

CONCLUSION

Superfund is unlike other environmental laws. Its goal is remediation of past uncontrolled disposal practices, whereas other laws focus on future, specific, end-of-pipe releases. Success under CERCLA is measured by the ability to keep contaminants contained and/or reduced to acceptable levels.

Soil and ground water remediation decisions are made through a process codified in federal regulations. This process is based on developing risk estimates for the existing site conditions and the potential remedial alternatives. In making their decisions, scientists and engineers must take into account the enormous uncertainties involved in the fate, transport, and toxicology of hazardous contaminants. Although these uncertainties are generally recognized, less recognized is the degree to which uncertainty affects the remedial process.

The severity of soil and ground water contamination problems (high risk to public health and the environment, high cost to remediate) combined with the current federal policy for remediation (take cost-effective action to remediate to the point of acceptable risk) requires a high level of precision and accuracy in the remediation process. However, in reality this level is not achievable. With current site investigation and remediation technologies, it is not possible to locate all significant contamination, nor can anyone accurately predict contaminant movement, fate, exposure, effects, or remedial technology performance.

Here we propose a new method for managing the uncertainty inherent in hazardous waste cleanup: the observational method. Routinely used in geotechnical engineering, the observational method appears to offer a way out of the current impasse created by the limitations of technology and financial resources in the face of the public's demand for action.

NOTE

1. If, for example, 100 liters of trichloroethene are released to an aquifer, 3×10^{10} liters of waters can be contaminated at 5 mg/liter, assuming simple dilution.

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9

Decisions Based on Public Policies and Perceptions

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INTRODUCTION

The purpose of this paper is to discuss the various models that have been considered, accepted, and rejected by public policymakers over the last decade in making decisions concerning ground water remediation projects. Because it would be a back-breaking and self-defeating task to attempt to analyze all the models developed at the federal, state, and local levels for the environmental programs that affect the cleanup of ground water contamination, this paper instead considers the broader outlines of the federal policy debate. Specifically, the paper focuses on the debate before and within Congress that accompanied the consideration and passage of the Superfund Amendments and Reauthorization Act (SARA) of 1986.

Superfund is not the only or maybe even the premier program that has the potential for determining how clean we intend to get ground water over the next several decades. By focusing on the legislative debate that accompanied SARA's passage, I do not mean to endorse or even encourage the chauvinism that increasingly has characterized the Superfund program within the EPA. Because the program is in such tragic disarray and because its mandates are in many ways unique--that is, they involve the cleanup of past legacies of pollution rather than prevention of pollution--Superfund's lessons may have limited utility for a comprehensive national ground water remediation strategy.

But there are two immediate, practical reasons why I believe that a focus on the SARA reauthorization debate is both appropriate and necessary in framing the policy issues that should be considered in formulating a comprehensive ground water policy. First, the SARA debate is the most recent and by far the most meaningful occasion during which Congress, the EPA, the environmental community, and industry actively thought, wrote, and wrangled about these issues. The value of their mutual consideration of these problems far outweighs the limitations imposed by the fact that Superfund is in many ways a unique environmental program. Second, I was an active participant in that debate as staff counsel to the House Subcommittee chaired by James J. Florio, and I am therefore better qualified to discuss it than other subjects or perhaps than other authors may be.

It is the thesis of this paper that SARA's *statutory* approach toward determining the nature and scope of ground water cleanups is the best model we have to impose on an admittedly complex and difficult problem. SARA's statutory provisions would apply very strong, even rigid, health-based cleanup standards on ground water remediation projects in the first instance. SARA would achieve necessary flexibility in the development of actual cleanup plans through the application of several specific "affirmative findings," or waivers, that allow those stringent, upfront standards to be set aside when necessary. In practice, SARA's statutory provisions have been modified profoundly by EPA, perhaps because the political pressure the agency anticipates would accompany the exercise of waivers is perceived by decisionmakers as too overwhelming. In place of the strong standards with waivers approach, EPA has substituted a hybrid decisionmaking model that depends on selective and erratic application of strong standards, supplemented by a risk assessment approach to cleanup decisions.

I argue below that EPA's substitution of a hybrid risk assessment model for SARA's statutory model will have some long-term consequences that will make the formulation of good public policy in this area much more difficult, if not impossible. Because EPA's approach has served only to exacerbate public despair about the effectiveness of the program, it will become increasingly difficult for EPA and state agencies to initiate a realistic dialogue with affected communities about the limitations science and available resources impose on the cleanup of ground water and other environmental problems. Over the next decade the casualties of continued distrust by the people of their government also may claim some unforeseen casualties, including the rational siting of new industrial facilities. In sum, improved public policy depends on improved public trust in the integrity of government and the selection of a decisionmaking model that can accomplish both results.

DEFINITION OF SUBSTANTIVE FACTORS EMPHASIZED BY ALL MODELS

Before I attempt to analyze available decisionmaking models, it is crucial to identify and briefly define the substantive factors that must be considered by whatever model is selected. They are as follows:

- *Protection of human health and the environment.* This factor involves mitigation of adverse impacts on human health and the environment without regard to costs.
- *Restoration of natural resources.* This factor means the preservation or restoration of such natural resources as aquifers without regard to whether they are used currently and therefore pose an exposure hazard to people.
- *Cost.* This factor can have two separate, and mutually exclusive, meanings. First, cost can be considered in the absolute sense of which remedy costs least as a total bottom line. Issues involved in this type of cost analysis include the quantification of long-term versus short-term costs as well as the prediction of the costs of no- or little-action alternatives. Alternatively, cost can be considered in the sense of SARA's cost-effectiveness standard, which means that *once an adequately protective remedy has been selected*, it should be implemented effectively at the least cost.
- *Community acceptance.* Community acceptance can mean as little as the mustering of political support for a decision or as much as the considered acceptance by an informed citizenry of long-term versus short-term risks.
- *Enforcement.* This factor means the ability of the government to assert that potentially responsible parties are liable for cleanup costs at a site and then to recover its total costs from them. Given the American legal system's emphasis on due process and the fairness and impartiality of bureaucratic decisionmaking, models that result in uniform results from site to site on the basis of objective, scientifically justified factors will fare considerably better in the enforcement arena than models that result in inconsistent, arbitrary results.
- *Speed of cleanup.* This factor means the rapidity of cleanup, without reference to the effectiveness of cleanup.
- *Permanency of cleanup.* In contrast, this factor means the effectiveness of cleanup in eliminating any hazard over the long term, without reference to the speed or cost of cleanup.

Each of the models described below considers most or all of the substantive factors defined above in arriving at remedial decisions. The more flexible the model, the more difficult it is either to predict in advance or to characterize after the fact which factors have most influenced cleanup decisions. The most flexible approach--the ad hoc model--could be applied in a manner that emphasizes cost above all else or that ignores cost in favor of a rigid application of the protectiveness and restorative criteria. Similarly, because "background" can be difficult to define, this model can be subject to intense manipulation, with the result that cost overrides protectiveness or vice versa.

The two relatively less-flexible models--SARA's strong standards with waivers and the risk assessment approach--have as their ostensible theoretical rationale, a firm commitment to protectiveness, with cost (in the cost effectiveness sense) the only qualification. In practice, it is far from clear that this theoretical emphasis would or could be realized by either model. EPA's application of a hybrid model that blends the two approaches is driven by cost in the cost-benefit sense at least as much as protectiveness. SARA's pure scheme has never been implemented, so we have no empirical evidence of its translation into practice.

What is clear is that the EPA hybrid model is virtually a total failure in successfully achieving community acceptance and speed or permanency of cleanup. Ironically, the hybrid model's failure to achieve community acceptance or speed and permanency of cleanup is far more important in evaluating its overall desirability than the supposedly more important factors of protectiveness and cost.

ANALYSIS OF AVAILABLE DECISIONMAKING MODELS

During the SARA debate, Congress considered four basic models for determining the nature and scope of ground water remediation projects. I think it is fair to say that, with some modification, these models reflect the full range of alternatives now identified in the literature on this subject. The four models are:

1. Ad hoc, case-by-case;
2. Cleanup to background;
3. Strong, uniform, and specific national standards with waiver provisions to give necessary flexibility in the cleanup process; and

4. Development of site-specific risk assessments to determine cleanup levels and remedies.

Each is defined and evaluated separately below, with reference to the emphasis they place on the key substantive factors that were identified above.

The Ad Hoc, Case-by-Case Model

This model prevailed in the Superfund program prior to the passage of the 1986 amendments and still characterizes much of the cleanup work done voluntarily by private parties or mandated by the states. The model has several defining characteristics. First, it depends on a wide variety of factors and information in making decisions, including scientific investigations and findings, available resources for cleanup, and the political power of various constituencies participating in the cleanup process. Because it has no uniform, objective, internal criteria, the model has gotten a deservedly bad reputation as being extremely susceptible to politics as the determinative factor in the decisionmaking process. By "politics," I mean something more than simply the fundamental and inevitable influence of specific personalities on the final decision. Rather, in the vacuum of any other fixed, determinative factors, such as required health-based standards, politics acquires a legitimacy and assumes an overriding role. Decisionmakers speak without embarrassment about the need to satisfy a certain politician, achieve a better record in a part of the country where the political interests in charge feel vulnerable, satisfy a specific industrial interest, or cater to an aggressive an media-talented environmental community.

A second defining characteristic of the ad hoc model is its unpredictability compared to other models. Because it is not uniform on a national or even a regional level, observers of the process must possess a large amount of information about the specifics of the site and engage in considerable guesswork to predict the final cleanup decision. This uncertainty undermines industry efforts to clean up sites voluntarily, with minimal supervision by federal and state agencies, and concentrates control over the cleanup process in the bureaucracy.

A third defining characteristic of the ad hoc model is that it exacerbates public cynicism about the "fairness" of the cleanup process. When the model is applied, the public ends up believing that a waste site community will be disadvantaged because it is low income, because it has a substantial minority population, because it voted Democratic or Republican, or because its elected representative is asleep at the switch. In decisions believed to affect the health and well-being of the entire community, this perception that politics remains supreme, this "you can't beat City Hall" conviction, is extremely damaging to the credibility of either a remedial *or* prophylactic environmental program.

Of course, under certain circumstances, the ad hoc model could lead to more rapid cleanup and even more effective cleanup. Those circumstances are the presence of a bold and extremely powerful central decisionmaker who is able to prevail in the face of legal and political challenges from either end of the spectrum of affected constituencies. Such circumstances are extremely rare in the United States today. The publicity that environmental projects attract (especially those affecting drinking water), the litigious nature of our society, the due process requirements of the Constitution, and our distrust of authoritarian systems make it unlikely that the ad hoc model could flourish for long in any important, high-profile environmental program.

A final consideration to keep in mind is that application of the ad hoc model may present legal problems when EPA attempts to recover cleanup costs from potentially responsible parties under Superfund's strict joint and several liability scheme. Because the model leads to widely varying results for similar sites, and therefore sharp distinctions in the total price tags for cleanup, its application allows defendants to argue that they should not be forced to reimburse the government beyond the costs of the least expensive cleanup ordered for a similar site. Clearly, the success of these arguments will depend on the defendants' ability to persuade the courts that sites are fungible and that there is something fundamentally unfair in EPA's efforts to recover costs differently. But the possibility that such arguments could prevail is worth keeping in mind.

The ad hoc model was rejected firmly by Congress during the SARA reauthorization debate because it had been discredited thoroughly by political scandals at EPA in the immediately preceding years. It is doubtful that any legislature or agency would adopt the ad hoc model as a conscious expression of official future policy, as opposed to the status quo of an ongoing program.

Although the ad hoc approach has been discredited so thoroughly, I have discussed it at some length here in an effort to define a baseline by which to assess all other models. Each of the other models has elements of site-by-site flexibility that remain a constant temptation of bureaucrats and others frustrated by the red tape that more elaborate standards can produce. Unless the pitfalls of the ad hoc model are kept firmly in mind, any of these other models can be eroded and end up functioning in a fundamentally ad hoc manner.

Cleanup to Background Model

The cleanup to background model depends on the deceptively simple premise that the nature, scope, and degree of contamination in a geographic area *before* the Superfund site despoiled it can be defined with some precision. Then, the goal of the cleanup becomes removing whatever contamination is directly attributable to the Superfund site, leaving the area contaminated at whatever these background levels were.

There are several technical problems that make application of this model problematic. First, Superfund sites are often sprawling areas of buried wastes that have been leaching into the environment for decades. EPA historically has had tremendous difficulty in defining the boundaries (especially the subterranean boundaries) of such sites, with the result that entire towns sometimes are put on the Superfund National Priorities List (e.g., New Brighton, Minnesota). Second, even if the Superfund site could be defined, the agency often has equal difficulty in measuring background levels in surrounding areas. The technical means to measure such levels sometimes fail. Even if accurate measurements can be taken, EPA often finds itself mired in a quagmire of dispute over whether high levels of contamination reflect background levels or instead reflect the actual creeping effects of the Superfund site.

There are also serious political (or, to put it euphemistically, policy) problems that accompany the application of the background model. If background levels are defined to be higher than "safe" or acceptable levels, and they often are, the agency ends up in the awkward position of cleaning up only to a point that must be perceived as highly unsatisfactory to communities affected by the site. The public will not easily accept the rationale that Superfund exists only to clean up arbitrarily defined piles or pits of waste and, not to protect human health and the environment.

The background model does have the potential to be less uncertain and erratic than the ad hoc model, although this advantage could be squandered easily by failing to define the criteria and protocols for measuring background and defining sites with precision.

However, assuming those criteria and protocols are defined, the background model makes more sense from an enforcement perspective than any of the other models available. Assuming that background is defined accurately, how could any defendant argue successfully that it should not have to pay the costs of remedying only the contamination caused by its precisely defined waste site?

During the SARA debate, the background model was endorsed enthusiastically by a faction of waste site community groups led by Lois Gibbs, the original leader of the citizens' protest at Love Canal. So strongly did Gibbs and her constituency feel about the issue that they ended up in a better confrontation with representatives of such national environmental groups as the National Resources Defense Council (NRDC) and the Environmental Defense Fund (EDF). Gibbs' group felt that the background model would result in better, more effective cleanups and that if background was defined fairly and accurately, the sites would be cleaned up beyond safe levels. National environmental representatives disputed these assumptions, predicting that cleanups often would fall far short of protective levels. Industry groups pretty much sat out the debate, believing (probably correctly) that they had nothing to gain and much to lose from participating in it.

Gibbs' group did not win the debate before Congress, which opted instead for the next model on the list.

Strong National Standards with Waivers Model

In a sense, it is accurate to say that the genesis of SARA's approach to cleanup standards was the struggle between community groups and national environmental groups regarding the background model. Key members of Congress and their staffs not only were influenced by this struggle but helped determine its outcome by clearly indicating their preference for the strong standards with waivers approach.

Once again, the premise of this model is deceptively simple. It is based on the concept that other environmental programs at both the federal and the state levels have established specific health-based or technological standards for the levels of pollution that will be allowed and that Superfund should simply apply these standards. Four types of standards are involved: (1) permissible levels of contamination for specific hazardous substances (e.g., maximum contaminant level goals under the Safe Drinking Water Act and water quality criteria under the Clean Water Act); (2) design standards (e.g., landfill liner requirements under the Resource Conservation and Recovery Act); (3) technology standards (e.g., best available control technology requirements under the Clean Air Act); and (4) location standards (e.g., controls on dredging in a wetlands area or other sensitive location). Application of such standards is justified by the concept that Superfund cleanups should comply with the laws of other *preventive* programs or, put another way, that Superfund sites should be viewed as sources of pollution that must be controlled just like any operating industrial source.

The Superfund version of the strong standards with waivers model overlays one other goal on top of this complex matrix of existing standards: use of treatment and destruction technologies that ensure the permanency of cleanup. It is becoming increasingly clear that this goal may have more profound implications than the basic injunction to control emissions under the other standards as permanently as possible. At the risk of caricaturing their position, advocates who believe permanency should be *the* top priority in formulating cleanup decisions would rather leave sites unaddressed or barely contained until a technology is available that can remedy the problem permanently.

I do not believe that Congress intended to emphasize permanency to this extent when it wrote SARA's mandate to consider permanent treatment "to the maximum extent practicable." Whatever Congress may have realized, I predict that as the policy debate matures over the implementation of SARA's standards, permanent treatment could evolve into a model of its own, with aspects that are mutually exclusive from other decisionmaking models. But I do not think the debate has developed yet to that point, and, for the purposes of this paper, I mention permanency only as an aspect of the strong standards with waivers model that is the centerpiece of SARA.

The main problem with the SARA model is that the nature and behavior of pollution from Superfund sites are often far more complicated than operating industrial sources. Operating industries have the ability to control and characterize their emissions and their waste streams, whereas it is sometimes far from clear what components make up a Superfund waste stream or how they are behaving. The destination of emissions also is difficult to predict. Because technology lags behind (some would say very far behind) the erratic and dangerous pollution problems at Superfund sites, it is impossible to force cleanups to adhere to a rigid set of standards designed for industrial operations and get anything done.

A second problem is that, especially when state standards are added to the list of standards that already must be considered, there is often more than one standard that could apply to the cleanup of any given set of contaminants in any given location. The simultaneous application of all three types of standards to a given site situation could be either physically impossible or prohibitively expensive.

Enter waivers or, as SARA politely calls them, "affirmative findings." The waivers are designed to allow Superfund decisionmakers the flexibility they need to achieve relatively rapid, cost-effective cleanups while still applying to the greatest extent possible the elaborate set of health, design, and technological standards developed with such care for other federal environmental programs. The congressional debate over the precise content of these waivers was relatively brief, with remarkable consensus regarding how they should be defined. Six are permitted by the statute:

1. The cleanup at issue is only the first stage of EPA's efforts.
2. Compliance with specific standards will cause greater environmental or health risks.
3. Compliance is technically impracticable from an engineering perspective.
4. There is another equally good way to go about the cleanup.
5. In the case of state standards, if the state has not applied the standard consistently, it may be waived.
6. Fund balancing which means that the cleanup of a specific site will consume such a disproportionate share of Superfund resources as to compromise the fund's ability to address sites posing a significantly more serious health threat.

In the 2 years since SARA was enacted, the EPA has not invoked any of these waivers in explaining a remedial decision at any of the close to 200 Superfund sites where final Records of Decision have been signed. There are two possible explanations of this behavior--one incredible and one credible. The incredible explanation is that the agency thus far has been able to meet the strong standards contained in the law without resort to the waiver provisions. The far more credible explanation is that the agency has reinterpreted SARA's upfront health-based cleanup standards to give it adequate flexibility in making decisions at sites, in the process distorting the model established by the statute. The implications of the agency's approach are discussed further below.

Before leaving the strong standards and waiver model, two further characteristics of the model should be mentioned. First, the model is without question difficult to implement politically, for it requires decisionmakers to acknowledge that they will be unable to accomplish adequately protective cleanups for a variety of reasons which means that people affected by such decisions may have great difficulty accepting them. For example, the model may require decisionmakers to say that chemicals must remain present at dangerous levels because it simply would be too expensive to reduce the levels any further or because scientific technology lags behind the community's needs. In the long-run, the kind of honesty the models requires, if handled carefully, could end up restoring public confidence in the integrity of the process, especially if sites were not pronounced "cured" or "finished" but instead were monitored in the hopes that more could be done later. Once again, the implications of the model for the rehabilitation of public perceptions not only about Superfund but about the effectiveness of environmental protection programs in general are explored in greater detail below.

Second, the model has some clear advantages from an enforcement perspective because, if firmly applied, it has the potential to result in relatively uniform cleanups that would be more difficult for defendants to challenge on the grounds that they were arbitrary decisions by the bureaucracy.

Risk Assessment Model

The risk assessment model involves a two-level analysis of the problems posed by pollution: first, available scientific information about the health effects of various chemicals must be assembled, and second, this information must be applied to information about the levels of exposure that may result from the Superfund (or other ground water) site. When health effects data are applied to exposure data, a "risk range" can be extrapolated. The risk range predicts the number of deaths that will occur if a certain exposure is permitted.

Unfortunately, as desirable as it sounds to develop this type of prediction, the risk assessment model encounters difficulties at both levels of analysis. Health effects data often are limited or nonexistent. Further, the so-called pathways of exposure analysis information at Superfund sites frequently is not developed in time to adequately inform the agency's decisionmaking process.

Despite these problems, risk assessment is the major alternative EPA has adopted in applying a hybrid and mangled version of the SARA statutory model to its decision at Superfund sites. EPA clearly is ambivalent about the risk assessment approach, announcing at one point in its recently proposed National Contingency Plan (Superfund's implementing regulation) that the overall risk range that will be acceptable for cleanups is between 1 in 10^{-4} and 1 in 10^{-7} and stating at another point in the same discussion that risk ranges will be used only when another standard is not available. Despite this ambivalence, risk assessment clearly is the approach that is currently driving Superfund cleanup decisions, with the result that the consideration of strong standards is erratic and unpredictable and the invocation of waivers nonexistent.

A careful study of the Records of Decision that have been issued since SARA's birth will not reveal a clear definition of how risk assessments are developed or computed. In fact, the major characteristic of the approach at this point in the program's development is the tremendous discretion risk assessment leaves to the agency in both calculating the risk range and having its decisions clear enough to enable scrutiny by affected outside parties. Because the model boils down to a decisionmaking "black box" with input, output, and throughput only vaguely understood even by those operating the box, it also could pose problems from a public confidence and liability/litigation perspective. Once again, these implications are discussed further below.

MODELS CURRENTLY IN USE

As explained above, the approach that dominates EPA's hybrid Superfund decisionmaking model is risk assessment, although the agency constantly is looking over its metaphorical shoulder because it perceives correctly that the statute had something else in mind. Is this approach likely to change, or do we expect it to become the prevailing model used for Superfund cleanup decisions?

As a practical matter, the most significant risk of EPA's current approach is that it will someday be overturned by the courts because it misreads SARA's statutory mandate. An adverse court decision could happen either in the context of one comprehensive challenge to Superfund's implementing regulation, the National Contingency Plan (NCP), or in the context of several lawsuits challenging individual site cleanup decisions. For a variety of reasons, those anticipating such a challenge probably should not hold their breath.

Despite extreme restlessness in the environmental community, EPA has so delayed issuance of the NCP that hundreds of site decisions will be completed before the regulation is ripe for challenge. As for challenges to individual site decisions, SARA contains provisions barring review of the remedy selected at a site until it has been completed. At most sites remedies take years to implement. Therefore, effective legal challenge to the risk assessment approach on a site-specific basis will not occur until the model is firmly entrenched. In sum, barring a dramatic change of heart by the new EPA administrator, risk assessment is here to stay--at least until Congress returns to the issue in its inevitable third reauthorization of the program in 1991.

How troubled should we be by EPA's legally unauthorized but effective conversion of Superfund's decisionmaking process? This paper promised at the outset to be very troubled, and it is time to deliver on the promise. There are severe problems with EPA's hybrid model from the perspective of all the constituencies affected by the Superfund program. These problems, in turn, mean that relatively inappropriately substantive factors drive the decisionmaking process in the wrong context and at the wrong time. Before examining which factors drive the process in what way, it is worth establishing the negative implications of the model for the two legitimate constituencies of Superfund: (1) specific industrial defendants at Superfund sites and their national policymaking bodies and (2) waste site community residents and their national environmental representatives. (I will overlook for the purposes of this discussion the enormously complex schisms and divergences of opinion within these two groups.)

The downside of the risk assessment model from industry's perspective is that the remedial selection process is as mysterious as ever and can result either in extremely high cost or artificially deflated costs. The EPA's decisions are difficult to predict, affect, or challenge. Voluntary cleanup efforts are undercut because it is impossible to predict how the agency will react until it actually focuses on a site, and that process takes years to accomplish. The result is snail's pace cleanup, inordinately high transaction costs, and continuing terrible public relations both at specific sites and in general.

It must be acknowledged that most of industry would disagree with this paper's implicit premise: that the strong standards with waivers model is a better way to approach cleanup. Industry believes, probably correctly, that the strong standards model would result in more expensive cleanups and, for understandably self-interested reasons, opposes that result. I believe Congress assumed that the certainty that would evolve out of the faithful application of strong standards would compensate over the long run for the short-term expenses of meeting stringent standards. The reason for the assumption is that with certainty comes a dramatically increased ability to conduct voluntary cleanups at much lower cost.

As for waste site communities and their national representatives, the risk assessment model is regarded with extreme suspicion because it is so difficult to understand and because it is based on flawed and inadequate scientific evidence about health effects. Few members of this constituency believe for a moment that the model results in more stringent cleanups; most regard it as a bureaucratic fast shuffle designed to rationalize the convenient at any given site. Apart from these suspicions concerning how the process operates, there is the real issue of whether 1 in 10,000 cancer deaths--the high end of the risk range tolerated by EPA's version of the risk assessment model--should ever be acceptable as an overall standard for a Superfund cleanup. Most waste site communities and certainly their national representatives would reject this standard out of hand if given the opportunity.

So do these constituencies find the strong standards with waivers model more acceptable? In general, the answer is undoubtedly yes, although it would be difficult to achieve much consensus on the details of this approach. As mentioned earlier, there was a split between national environmental groups and grassroots community groups during the early Superfund debate, with the grassroots groups endorsing a background model and the national groups supporting the strong standards with waivers approach. If waivers were applied faithfully and the agency therefore was compelled to explain with more clarity what it was doing at a site, both groups probably would support this outcome, if for no other reason than it would afford an opportunity to challenge the ultimate decision more effectively.

But whatever the Superfund's two constituencies believe, there are even more subtle interests at stake here that could affect other epic battles they may have with each other over the next decade. Ultimately, the real social costs of the risk assessment model are likely to be an unexpected but devastating effect on industry's ability to site new facilities. And siting clearly is one of the most important environmental problems of the next decade.

The problem arises precisely because the risk assessment model has resulted in a further downturn in the Superfund program's credibility with waste site communities, which cumulatively include millions of Americans. This downturn has exacerbated the cynicism and distrust that in the past have given birth to and nurtured the so-called NIMBY (not-in-my-backyard) syndrome. At its most basic, the reasoning goes as follows: Superfund sites are dangerous, the government cannot address them effectively or rapidly, and therefore a community burdened with a waste disposal facility is sentenced to an indeterminate term. On a more sophisticated level, these fears boil down to a conviction that the government is more interested in justifying partial cleanups that do not offend the pocketbooks of industry than it is in having an honest dialogue with affected citizens. In either event, the system cannot be trusted to site safe facilities for the foreseeable future.

WHAT THE FUTURE HOLDS IN STORE

The controversy over EPA's implementation of Superfund's cleanup standards will persist in the years to come, and Congress undoubtedly will return to the issue in 1991, when the third reauthorization of the program is necessary.

Pressure also will build to develop clearer standards in other environmental contexts. For example, a major preoccupation of the banking and real estate industries these days is how to protect themselves from liability when they buy and sell land. So-called due diligence audits prior to sale transactions are becoming more and more common. But before a purchaser or seller can be confident that it is protected from liability, some yardstick of the degree and nature of the remedial action necessary at the site must be established. Without a coherent national policy toward ground water (and other) remediation, such audits are little better than shots in the dark.

Can we do better than either the Superfund state or the EPA risk assessment model in developing a rational decisionmaking process? I do not believe it is possible to answer this question unless and until we have actual experience in implementing the SARA strong standards with waivers approach. The health and technology standards SARA requires will continue to dog any cleanup decisions EPA makes, for there will always be an educated group of critics capable of comparing the agency's actual performance to the theoretical rigors of the statute. Until we have experience in rigorously attempting to apply SARA's strong, upfront standards and evoking and explaining the waivers that are the inevitable result of that cleanup approach, we will be unable to craft the standards needed to streamline and facilitate the process.

It is also true that the only antidotes to the public cynicism now plaguing this entire area are zealous environmental protection or a more honest admission that we lack the social consensus and therefore the economic resources to accomplish that result. The invocation of SARA waivers is a framework for that type of honest dialogue.

Zealous environmental protection may be the ultimate result as the pendulum pushed to one side by the last 8 years of conservative policy slowly begins to swing back, and there are many among us who would welcome that outcome. Those hoping for a moderate approach must explore the painful but promising possibilities of a more honest approach.

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10

Applying New Technologies: A Scientific Perspective

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INTRODUCTION

After only brief consideration of this topic, I have concluded that there is no purely scientific approach to the application of new soil and ground water decontamination technologies. Public opinion and the current regulatory climate, whether based on fact, fear, or finances, have greatly influenced technology development. There has been a justified reluctance by many consultants preparing remedial investigation/feasibility studies (RI/FS) to recommend new technologies. A recent survey of technologies recommended for ground water remediation at 36 Superfund sites showed that 87 percent would use standard pumping methods and rely on air stripping or carbon adsorption for contaminant removal (Haiges and Knox, 1988). Unreasonable or undetermined cleanup standards and the fear of liability have stifled creativity and limited the application of new ideas outside the laboratory.

It seems that a very arbitrary legal system often has demanded more control over subsurface events than can be provided reasonably. Indeed, the law, or its interpretation, has failed to grasp the complexity of contaminants that are randomly dis-persed under the influence of a much more absolute law of thermodynamics. Unfortunately, the technical community often has failed to inform policywriters of these absolute constraints. Technical overoptimism followed by the failure of many field demonstrations has set the stage for distrust. This paper offers a process of thought and action to improve our application of new technologies and to rebuild regulatory and public confidence in the remediation process.

PERIPHERAL VISION

Scientists and engineers often are criticized for their narrow focus and failure to take in the big picture when developing remediation technologies. As more field studies and cleanup actions are attempted, it is imperative that scientists and engineers exercise peripheral vision--that is, staying informed of others' experiences and constantly updating products to account for what others have learned. Far too many technicians have broadened their vision only enough to keep up with competing technologies and immediate regulatory pressures. Technology development that is driven by marketing strategies often becomes diluted by the "do-it-all" approach that fails to address a specific decontamination need adequately. Figure 10.1 illustrates the peripheral vision we should attempt to establish as individuals and technology firms.

Our vision also must extend beyond site-specific regulatory pressures to a more encompassing view of regulatory trends within EPA and state agencies and their impact on emerging technologies. Finally, technical experts should assume a more active role in law and policymaking. A consensus of facts should be presented formally to lawmakers, regulators, and citizen's groups. If these groups choose to ignore the experts and their facts, the scientists and engineers will go home with a clear conscience.

An important ingredient of peripheral vision is an ongoing search of engineering publications and proceedings of hazardous waste and ground water remediation conferences. Field studies, particularly those that have been evaluated by independent agencies such as universities, government laboratories, and professional organizations, should receive special attention. Evaluators without commercial interests are more likely to discuss problems and failures--information that is more valuable than Superfund Innovative Technology Evaluation (SITE)--move forward and more commercial cleanups are completed, the data produced by these technology demonstrations should provide valuable feedback that will stimulate ideas for new and improved technologies. These "lessons learned" will prevent much frustration and save time and resources when applying new remedial action technologies.

Evaluations of in situ technologies should discuss key issues, such as the removal of adsorbed or trapped contaminant residuals, undesirable side reactions that reduce aquifer permeability, and toxic by-products that may result from incomplete reactions.

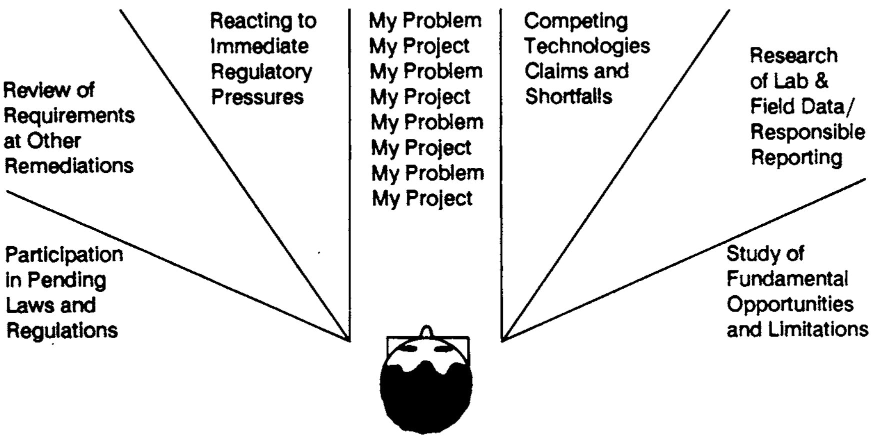

FIGURE 10.1 Peripheral vision.

Responsible documentation of above-ground soil and ground water decontamination will also discuss the mass balance of contaminants to account for volatilization and other passive losses. Costs should include the full cost of treatment and disposal of by-products, mobilization, and operating charges.

The creation of a central databank and a commitment to support its expansion could help to close the information gap. Standard documentation of all federally sponsored remedial actions would be an excellent beginning. Emerging technologies founded on a strong information base will draw funding support and opportunities for testing.

PERILS OF THE LABORATORY

Laboratory testing of soil and ground water decontamination methods is important for establishing and proving the principles of treatment. Bench-scale testing of chemical and physical reactions is the essential first step of technology development, and the importance of well-controlled experiments cannot be underestimated. Unfortunately, laboratory results too quickly have been translated into a "technology success." This overconfidence is particularly damaging when it is conveyed to the public without explaining the obstacles involved in full-scale field application. Laboratory panaceas often have led the public to expect far more than field engineers can deliver.

Two recent examples of laboratory overconfidence are worth sharing. The first example involved the testing of surfactant solutions for the removal of mixed hydrocarbons from soils. Soils from a site contaminated with waste oils, fuels, and solvents were placed in laboratory columns and repacked to simulate field conditions. After 14 pore volumes of a surfactant solution had passed through the soil columns, the concentration of contaminants remaining on the soils was measured. Hydrocarbon removals of 75 to 94 percent were achieved, with no significant decreases in permeability noted. Based on these positive results, a field pilot test of in situ soils washing was conducted on the site. Field results showed little or no correlation to laboratory results. The permeability of the soils was reduced by surfactant additions, and hydrocarbon removal was statistically insignificant (Nash et al., 1987). Simple laboratory experiments clearly failed to simulate a complex surfactant/soil interaction.

In situ biodegradation frequently is among the remediation options recommended for soil and ground water decontamination. Commercial firms applying this technology generally conduct laboratory "microcosm" studies to prove the feasibility of biodegradation at a specific site. Samples of site ground water and soils are enhanced with nutrients and oxygen to promote biodegradation of contaminants in laboratory flasks. After several weeks, microcosm studies generally result in the biodegradation of most hydrocarbons, and this information is used to scale up for field application.

Our experience has shown that a 250-ml flask has little or nothing in common with the contaminated subsurface and its response to nutrient and hydrogen peroxide (oxygen) additions. Permeability problems and poor oxygen distribution have been documented in the field with little warning from laboratory experiments (Downey et al., 1988). While microbiologists have proven the principles of biodegradation in the laboratory, engineers are having less success achieving a uniform reaction in heterogeneous aquifers.

Although laboratory experiments have serious limitations in predicting field response, these experiments can be designed to depict field conditions more accurately. For simulations of in situ treatment, well-preserved core samples should be placed in columns to better simulate subsurface soil structure and geochemistry. If possible, samples should be taken from a site proposed for future testing or from several sites with varying soil types. Other technologies that require excavation of soils and above-ground processing should ensure that laboratory experiments include a mass balance of all contaminants in the system and clearly identify by-products requiring further handling and treatment. Rigorous laboratory methods can be costly and time consuming, but shortcuts in the laboratory inevitably will yield embarrassment and waste in the field.

ON-SITE PILOT TESTING

In many respects every technology is a new technology when applied to a specific site. Regardless of past performance in the laboratory or at other sites, the tremendous variation in soil structure and ground water geochemistry dictates that an on-site pilot test be performed to validate a new or emerging technology. For in situ remediation methods, on-site pilot testing is an absolute necessity. As stated previously, it is virtually impossible to simulate actual ground water and soil conditions in the laboratory. This is particularly true of technologies requiring subsurface injections of treatment chemicals or relying on pumping of liquids or soil gas to remove contaminants from the soil. Above-ground soil and ground water treatment systems also will benefit from pilot testing, which can validate material handling techniques and treatment efficiencies at varying process rates using natural feed stocks.

The selection of an appropriate site for pilot testing is another critical step in technology development. If this is the first field test of the technology, the researcher should work closely with the sponsor to select a site that is "best case," with minimum known complications. Often, the site has been preselected by a sponsor or client, leaving the researcher little choice in the matter. Sites complicated by mixtures of organic and inorganic contaminants or nonuniform layered soils rarely produce useful test results and generate more questions than answers concerning technology performance.

Sites that are embroiled in controversy and regulatory confusion obviously should be avoided. Discussions with regulatory authorities well in advance of proposed testing and regulatory review of a draft test plan has proven very beneficial in securing their approval and cooperation. These authorities should be approached concerning cleanup standards and a realistic measure of success for your technology. In states with progressive environmental programs, regulators generally are supportive of new and innovative technologies that can help them solve their problems. My experience in several states has been that when regulators are considered partners rather than adversaries, they will assist you by reducing the red tape required for an on-site pilot test. Scientists and engineers should initiate these partnerships by offering to brief regulators on their laboratory findings and the concept of field operation at the earliest possible date.

Field testing is not exempt from the scientific method. A valid test must include untreated controls and adequate sampling and analysis to statistically confirm a result. Untreated controls are particularly important for in situ methods that rely on the pumping of ground water. Dilution of contaminants often is confused as treatment in many chemical and biological treatment methods. Likewise, soil treatment methods must be controlled carefully and sampled to account for losses owing to volatilization and leaching, that may not be associated with the treatment process.

Many pilot tests fail to produce defendable results because the budget did not allow adequate samples to be taken or the proper analytical method to be performed. Because of the great variation in soil and ground water contaminant levels, all pilot tests should begin with an extensive site characterization to establish both vertical and horizontal contaminant distribution (Cartwright and Schafer, 1987). The initial site characterization data and test plan should be reviewed by a statistician and geologist familiar with the vertical and horizontal variations in the soil. If necessary, the volume of soil or ground water to be treated should be reduced, or more samples taken, rather than sacrifice confidence in baseline data. Far too many field tests are completed only to discover later that the data cannot be interpreted.

Finally, pilot testing should identify and quantify by-products of treatment rather than focus on the primary treatment reaction with little regard for resultant wastes. This is particularly important for above-ground processes that may be required to meet Resources Conservation and Recovery Act (RCRA) delisting criteria before final disposal of end products. Often, additional technologies will be needed to destroy concentrated contaminants on site. If possible, these technologies should be tested side by side to observe problems with systems integration and to estimate total treatment costs. Successful pilot testing will produce solid documentation of treatment efficiencies and costs as well as problem areas to be addressed in full-scale design.

A CASE STUDY--RADIO FREQUENCY SOIL DECONTAMINATION

The Air Force Engineering and Services Center (AFESC) recently sponsored a successful pilot test of a radio frequency (RF) soil decontamination technology at a site contaminated with waste oils, fuels, and solvents. The development of this treatment method from bench-scale experiments through full-scale design provides a good example of how a new technology was applied to a specific contamination problem.

Radio frequency heating was first developed by the Illinois Institute of Technology Research Institute (IITRI) in the 1970s for recovering oil from oil shale and tar sand formations. As the energy crisis calmed, the developer sought out alternative applications for RF heating. After a review of several potential soil decontamination technologies, the Air Force selected RF heating for further development. In 1985 AFESC and EPA began a joint research project with IITRI to explore the use of RF heating for in situ soil decontamination. Because the majority of Air Force soil contaminants, including JP-4 jet fuel, have boiling points of less than 250°C , RF heating could be used to volatilize hydrocarbons in situ and remove them from the soil. The uniform removal expected with volumetric heating also was seen as an advantage over other in situ methods that had failed to provide uniform treatment.

Bench-scale laboratory tests were first used to demonstrate the thermal desorption of contaminants from soils in the RF temperature range of 100 to 150°C. Soils contaminated with 1,000 ppm perchloroethylene (PCE) and subjected to 100°C temperatures for 4 hrs produced a 98 percent PCE removal rate. During these preliminary tests, a variety of soils and moisture levels also were tested for their heating response to RF energy.

A series of 5-ft column tests next were performed to evaluate RF heating under conditions more closely resembling the field.

Initial attempts to use PCE-spiked soil in columns proved unacceptable. Volatile losses during column preparation were extensive, and initial contaminant concentrations could not be regulated. A decision was made to locate a suitable site for future pilot testing and to use samples of contaminated soil from the site for further column testing. After reviewing dozens of potential sites, an abandoned fire training area on Volk Field Air National Guard Base, Wisconsin, was selected. The sandy and relatively homogeneous soils represented a "best case" for technology demonstration, and site contaminants, waste oils, fuels, and solvents, were common to most Air Force sites. Preliminary discussions with the Wisconsin Department of Natural Resources (WDNR) were extremely positive, and base officials fully supported the proposed field test.

Contaminated soil was packed into columns and uniformly heated to simulate the expected RF temperature profile. Volatile hydrocarbons in off gases were monitored as was the effect of using water injection and resultant steam to enhance contaminant removal. These column studies showed that 99 percent of the hydrocarbons could be removed uniformly when soils were subjected to 150°C for 40 hrs. The tests also showed improved removal rates when additional water was provided. Based on these promising results and further discussions with WDNR, a decision was made to pilot test the RF technology at the Volk Field test site (Dev et al., 1988). Conditions for WDNR approval included the right to recommend changes to the test plan, a determination of whether soils were RCRA hazardous wastes, and adequate treatment and monitoring of gaseous and liquid by-products.

A 6 ft x 12 ft x 7 ft deep volume of soil was identified for treatment. Initial sampling included over 90 soil cores collected at three depths throughout the test volume. These baseline data then were analyzed carefully to ensure that the relative standard deviation of contaminant levels was small enough to permit meaningful evaluation of removal efficiencies.

Three rows of 13 electrodes were placed in the test volume, and a vapor barrier was placed over the heated area to collect escaping soil gas and to transport the gas to a vapor condenser for separating liquid hydrocarbons and a carbon bed to treat remaining volatile organics (Figure 10.2). The test volume and gas handling system was heavily instrumented to study soil temperature profiles and hydrocarbon concentration data at different points in the off-gas treatment system.

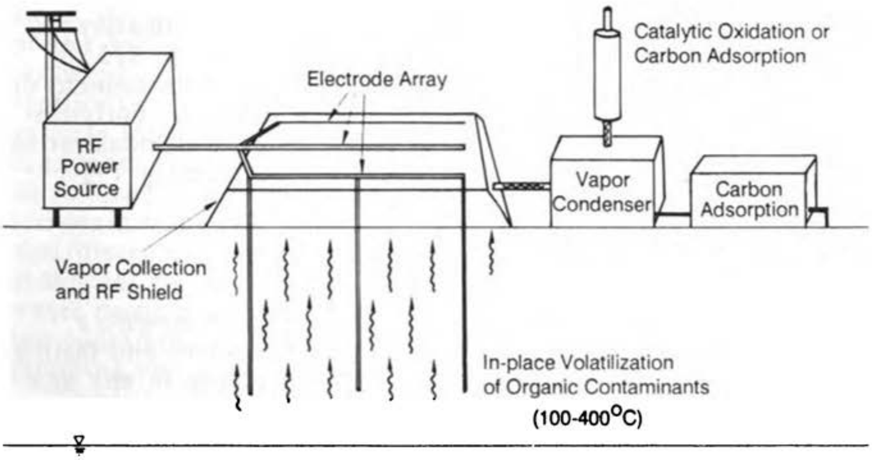

FIGURE 10.2 Radio frequency soil decontamination process.

Using a 40-kW RF power source, energy was applied to the soil over a period of 12d. After 8 d the 150°C target temperature was achieved throughout the test volume, and this temperature was maintained for a period of another 4 d. During this heating period, careful records were kept on the release of hydrocarbons and water vapor from the soil. At one point an inert tracer was injected into the soil outside of the treatment area to confirm that migration was into the heated zone and to estimate soil gas velocity. Power consumption also was monitored to determine the operating cost of this process. After 12 d power was turned off and the soil was allowed to cool prior to resampling.

The efficiency of the RF decontamination process was determined by a careful comparison of pretest and posttest soil samples. Samples were analyzed to determine changes in moisture, volatile aliphatics, volatile aromatics, and semivolatile aliphatics and aromatics. The results were impressive, with 94 to 99 percent removal of all classes of hydrocarbons. Close examination of the samples showed that contaminant removal at 7 ft also exceeded 95 percent. Problems were encountered when high-humidity soil gas fouled the activated carbon canisters, causing a loss of some organics and complicating the mass balance on soil hydrocarbons. Improvements in condenser efficiency or an alternate treatment method such as catalytic incineration is a consideration for full-scale design.

The total RF process had a power cost of approximately $35/yd^3$. Full-scale operating costs are estimated to be $75 to $100/yd^3$, which includes the cost of activated carbon disposal or regeneration. The Air Force has initiated a follow-on optimization study and full-scale design. A full-scale field demonstration of this technology on an Air Force site is scheduled for 1990.

SUMMARY

In today's skeptical regulatory and social environment, a carefully planned strategy for research, development, and testing is required to build technical and public confidence in any new remediation technology. This paper has outlined one possible approach for developing and applying more successful remediation technologies and building public confidence. In summary, key elements of this approach include the following:

- *Peripheral vision.* Literature review is not only the first step in the process but must continue throughout development and testing. A diligently maintained and accessible central databank describing federally funded remediation projects is needed to promote information sharing.
- *Laboratory testing.* However, laboratory success rarely equates to field success without extraordinary efforts to simulate in situ or on-site conditions.
- *On-site pilot testing.* Because every site presents unique technical challenges, this is always required for in situ technologies and is highly recommended for above-ground processes.
- If possible, a best-case hydrogeological site should be selected for initial pilot testing.
- Early discussions with regulatory personnel can simplify the approval process.
- The scientific method should be applied, including the use of untreated controls. Statistically adequate pretest sampling is critical.

• Responsible research and process development includes the reporting of shortcomings as well as the successes of testing.

FUTURE DIRECTIONS

Future technology development must focus on several frontiers. All ground water treatment must begin with the removal of the contaminant source--those residuals partially adsorbed or occluded in the soil. Because site remediation generally will require two or more technologies, more emphasis is needed on systems integration to impact the source and dispersed contaminants at minimum expense. The cost of soil treatment must be reduced significantly, particularly for soils contaminated with less-toxic fuels and solvents. Low-temperature thermal desorption/destruction technologies and above-ground chemical and biological treatments seem best suited for this purpose. Ground water pump-and-treat technologies should focus more on isolating contaminants from drinking water supplies though pulsed pumping and gradient controls.

Serious consideration should be given to point-of-use treatment for contaminated ground water rather than attempting to reverse the random movement of organic molecules at tremendous pumping and treatment expense. The pumping and treatment of billions of gallons of ground water to recover a few pounds of spilled solvent requires serious rethinking. Technology development should focus on how to economically and consistently surpass low part-per-billion treatment levels with a margin of safety required for potable water supplies.

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11

Policy Improvements To Encourage Soil and Ground Water Remediation

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The current need for environmental remediation evolves from many years of handling chemicals and wastes in a manner that, under today's standards, is not acceptable. Before discussing how to ensure that we address these current problems as expeditiously as possible, it is useful to consider briefly the various frameworks under which cleanups will occur and the myriad of requirements that will apply to these cleanups.

CLEANUP FRAMEWORKS

CERCLA

The most well-known cleanup program is that created by the federal Comprehensive Environmental Response, Compensation and Liability Act/Superfund Amendments and Reauthorization Act (CERCLA/SARA) statutory framework. Today, about 1,200 sites are scheduled for cleanup under that program, with many more expected in the future. While the rubric of Superfund exempts the on-site cleanup process from the administrative process of obtaining other environmental permits, Superfund cleanups must comply, in substance, with all applicable or relevant and appropriate environmental requirements. These substantive requirements include activity-based, location-based, and health-based standards from other federal laws. In addition, substantive state requirements must be met as well on site. If no relevant or appropriate standards exist, the Superfund program applies risk assessment to determine remediation goals.

RCRA

Under the 1984 amendments to the Resources Conservation and Recovery Act (RCRA) and Hazardous and Solid Waste Amendments (HSWA), a strong cleanup program was instituted for all hazardous treatment, storage, and disposal facilities. Whether they are operating facilities or facilities that intend to close, they must perform any necessary cleanup for the entire facility. This provision will result in facility-wide corrective actions at over 5,000 facilities. The magnitude of this requirement is very significant. A major manufacturing facility may have had a small RCRA storage tank on facility property. However, the corrective action provisions will require cleanup not only of the operating hazardous waste unit but also all solid waste management units on site; at some facilities this can amount to over 100 additional units. These cleanups will meet the same substantive requirements discussed above for Superfund cleanups. However, to the degree that permits are required under environmental statutes other than RCRA (such as the Clean Water Act), such permits are required before RCRA cleanups can proceed.

State Cleanup Programs

Individual states also have developed state Superfund programs. Many of the larger industrial states have identified over 1,000 such sites within their borders. These state cleanup programs are not exempt from obtaining Federally required environmental permits.

Voluntary Cleanups

The number of sites covered in the cleanup programs discussed above pales compared to the number of "voluntary" cleanups. The number of self-motivated voluntary cleanups also includes large numbers of cleanups required by lending institutions, insurance companies, property transfer laws, or as a buyer condition of sale. Moreover, the potential threat of future Superfund liability is a powerful motivation. In many of these situations, companies want to perform on-site treatment and/or disposal of waste. If the wastes involved meet the definitional requirements of a hazardous waste, two critical items are triggered. First, on-site storage, treatment, and disposal require an RCRA permit unless the waste/facility qualifies for an exemption. Second, in order to receive an RCRA permit, the facility must not only clean up the waste in question but also must clean up any other solid waste management units anywhere on the facility property. These two requirements also apply to facility owners who want to utilize mobile or transportable treatment technologies.

Permits of the type discussed here can take from 1 to 4 years to obtain. Moreover, a small cleanup of highly concentrated hazardous waste can require a facility to commit to extensive facility-wide cleanup of lower-concentration wastes. This presents society with a dilemma. On the one hand, we want all cleanup operations to be performed in an environmentally protective manner. On the other hand, we want to provide necessary incentives so that cleanups occur as expeditiously as possible, preventing additional contamination from occurring and reducing transaction costs.

The current statutory/regulatory/policy frameworks have been developed to emphasize environmental protectiveness and regulatory control. The purpose of this paper is to explore opportunities to expedite cleanup while still ensuring full protection of health and the environment. The paper provides examples of the types of statutory, regulatory, and policy changes that could prove helpful. In each case the paper provides insight on the current approach and suggests a proposed solution. The paper closes by exploring briefly more sophisticated databases and technology evaluation programs as well as the importance of developing a process that can achieve public acceptance of the cleanup remedy.

CHANGES IN STATUTORY STRUCTURE

Mobile Treatment Units (MTUs)

Mobile treatment units (MTUs) cover a broad range of technologies, including stripping of volatiles, solidification, chemical fixation, dewatering neutralization, and thermal destruction. MTUs are characterized by their ability to be moved to a site, set up in a reasonably short time to perform needed treatment, and to transport away. Some of these technologies reduce the toxicity of the waste so that it is no longer hazardous, whereas other technologies focus on volume reduction so that reduced reduction so that reduced volumes of remaining waste can be transported off site for final treatment/disposal.

The current statutory permitting scheme was designed to address stationary facilities. There are two problematic statutory provisions. First, the RCRA requires a public comment period and hearing prior to any permit issuance at a facility. RCRA regulations have defined "facility" to encompass the entire contiguous property at which a hazardous waste unit is located. Although this makes sense for a fixed facility, it can be highly repetitive and slow the process unacceptably for an MTU. It could easily take 180 days or more to get a permit for 1 or 2 days of MTU use. Taken to an extreme, an MTU would remain idle for much of the time, waiting for repetitive permit approvals. The second problem involves the corrective action provisions of HSWA. These provisions require that in order to get a hazardous waste permit for a facility, the facility must perform cleanup of all soil waste management units (SWMUs) on site. The MTU owner has no responsibility for these SWMUs, and the facility owner has more incentive to ship wastes off site rather than to bring MTUs on site if, when shipping off site, there is no need to commit to SWMU cleanup.

The needed fix would develop separate permitting requirements for MTUs. These would be national or state permits, but they would substitute one-time public hearings for site-by-site hearings. The new requirements would eliminate corrective action requirements other than those associated directly with the MTU itself. Facility-wide corrective action requirements for MTUs would be picked up more appropriately when--and if--generator corrective action requirements are developed. It might also be possible to develop "permits by rule" for some classes of MTUs.

Permitting Status for Voluntary Cleanups at Nonpermitted Facilities

This issue was discussed in the introduction. The permitting requirements and corrective action requirements applicable to voluntary cleanups are driven statutorily. This situation could be helped by the MTU suggested fixes, since MTUs undoubtedly will be used at many voluntary cleanups. Also, it might be possible to develop generic permits by rule or "class permits" covering certain types of cleanup situations. At a minimum, facility-wide corrective action should not be triggered by voluntary cleanups. To require it sets up a negative incentive to do any cleanup at all.

Clearer Links Between Decision Rules in Different Statutes

Different environmental statutes use different decision rules. For example, the Toxic Substance Control Act (TSCA), which governs the regulation of products, is an "unreasonable risk" statute, where unreasonable is determined by weighing risk against benefits. RCRA, which regulates wastes, is a "risk-only" statute. Thus, fertilizer products may be applied to the ground based on a risk-benefit assessment under TSCA. However, a future RCRA permit decision may require these same fertilizer levels to be cleaned up. Allowable levels of pesticides applied to the ground legally under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) may require remediation under RCRA if found at SWMUs. This has happened with piles of pesticide-treated grass clippings. Also, sludge may be land farmed based upon Clean Water Act regulations. However, RCRA may require cleanups at these same constituent levels.

The types of disconnects portrayed here should be identified carefully and reconsidered, both for environmental reasons and to ensure that proper incentives are created for pursuing cost-effective cleanups.

Definition of Land Disposal

Land treatment is defined in RCRA as land disposal since it involves placement of wastes on land. There are many promising biotechnology treatment technologies that would be prohibited by statute owing to the 1984 RCRA amendments prohibiting land disposal of untreated hazardous wastes. Before the wastes can be placed on the land, they must meet constituent-specific treatment levels. Thus, even though the waste may meet these levels at the *end* of the treatment period, the treatment would be prohibited from occurring on land (it could occur in a tank).

The simple fix to this problem is to redefine land disposal and omit land treatment from the definition. Alternatively, more complex fixes could be made to the land disposal restriction requirements in RCRA.

CHANGES IN REGULATORY STRUCTURE

State Adoption of RCRA Rules

Hazardous and Solid Waste Amendments is constructed so that regulations enacted under the statute are automatically effective in all states, authorized or not. On the other hand, non-HSWA regulations (regulations adopted under the pre-1984 version of RCRA) are not effective in authorized states until states repromulgate the national regulations. Moreover, states are not required to adopt federal regulations if the state regulatory framework is consistent with the federal regulatory framework and also is more stringent. The cut between consistency and stringency has never been a clear one. For example, if a presumably more stringent state regulation delays implementation of corrective action, one can reasonably question whether it is really more stringent from an environmental perspective. There are many current examples of this situation, and the MTU rule, the major/minor permit modification rule, research and development (R&D) permits under the codification rule, and the treatability study rule form a subset. These are situations where EPA has attempted to be responsive to streamlining cleanup but states have not agreed necessarily to adopt federal regulations.

There are two ways to address this problem. One approach is a statutory fix that requires states to adopt all RCRA rules. A slightly preferable fix would have EPA more clearly define the link between consistency and stringency, both generically and in each rule. Procedural streamlining always should be considered more stringent. State flexibility could be preserved by allowing states to adopt different procedural approaches if they meet the same timeliness and quality criteria.

Ground Water and Soil Monitoring Requirements

Currently, virtually all monitoring is tied to the ability to measure a constituent in the media of concern. If the measurement capability is available, the monitoring is required. This approach results in a lot of money being spent on monitoring, rather than flexibility to tailor monitoring frequency and comprehensiveness to location-specific considerations (slow-moving ground water).

Many examples can be provided that would reduce the time and money spent on cleanup without loss of environmental protection. Some of these include the following:

- Only require ground water or soil monitoring for constituents that are in the waste or the leachate.

- After performing initial comprehensive monitoring, develop tailored indicator parameters for routine monitoring based on chemistry and on risk.
- Allow reduced frequency in areas with slow-moving ground water.
- Recognize that soil or ground water cleanup levels should be tied to the most beneficial use of the resource in the foreseeable future. Thus, for example, soil cleanups in industrial areas should not need to reach the same levels as cleanups in residential areas.

Land Disposal Restrictions Rule (LDR)

Under the LDR, all waste ultimately will have to meet treatment standards before being disposed of in a land disposal unit (landfill, surface impoundment, Underground Injection Control (UIC) well, salt dome, land treatment facility). The only exception to this is the situation where a facility can demonstrate that there will be no migration of the waste from the unit for as long as the waste remains hazardous. EPA has chosen to define treatment standards on a waste code-specific basis, based on the treatability of a pure, high-concentration waste stream. EPA then uses the mixture "derived from" and "contained in" regulations to say that each complex waste stream must carry all underlying codes and meet all the underlying treatment standards for pure streams. EPA also states that waste disposed of pre-RCRA would need to be subject to the LDR treatment standards once that waste is removed from the ground for remediation.

The LDR rule creates two fundamental problems. The first set of problems is technical in that complex wastes, such as leachate, ground water, or soil/debris, often cannot meet the multitude of underlying pure waste code standards. While EPA has develop a treatability variance process, it is procedurally cumbersome and will result in significant cleanup delays. The second problem gets to the creation of disincentives for cleanup. Since the LDR limits the flexibility of treatment significantly, affected parties will have strong incentives to leave waste in place. For example, a facility owner likely would choose to close an old SWMU in place with an RCRA cap rather than incinerate the entire SWMU, given that both are allowable options. However, a better environmental outcome would be to stabilize the wastes before putting on the cap. Since stabilization is considered treatment, it would be precluded unless it could meet all treatment standards, an unlikely outcome. Thus, because a facility owner does not want to do a Cadillac treatment, he is precluded from doing any treatment. This same argument would tend to discourage owners from exhuming wastes that were not considered hazardous waste at the time of their disposal.

This is a very complex issue, and there are numerous regulatory fixes required. In short, considering these types of wastes as unique streams that warrant their own treatability standards is a major component of a fix. They should not carry standards for all underlying waste streams. Because of the variability of these types of streams, treatment standards should be defined either as technology-specific standards (such as waste water treatment with various treatment trains) or percent reduction standards but not as constituent-based absolute limits.

Other RCRA Regulations

Resources Conservation and Recovery Act regulations were developed to address newly generated waste. When they are applied to cleanup waste, problems occur. While some of these already have been identified earlier in this paper, the RCRA corrective action rules, the location standard rules, and the minimum technology standards all are important to mention. In each case these rules impose standards on cleanups that can be expected to provide owners with the incentive to leave waste in place.

An optional fix to this problem is to differentiate between requirements for newly generated waste and cleanup wastes. The more appropriate standards for cleanup wastes are comparative risk standards, similar those in the Superfund program. In such a scenario an owner would be encouraged to undertake an action if it were more protective than the option of leaving the waste in place. Less far-reaching regulatory fixes could be constructed, including waiver systems or exemptions for short-term waste placement. However, variances and waivers are difficult from a public policy standpoint because they always imply a "backing off" of the baseline stringent standards.

R&D Permits

At the present time, R&D permits are granted for 1-year time frames, with three 1-year renewals at most. R&D permits also are limited to nonland-disposal research methods and limited to small volumes. All of these conditions have the potential to significantly restrict important research initiatives. For example, biotechnology applications could be precluded because of the land disposal prohibition. Some research cannot be completed effectively in 4 years. The fix requires more case-by-case flexibility in granting these permits.

National Technical Permits for New Technologies

As discussed above, it can take many years to get a permit in place at one site, much less at multiple sites. While there may be legitimate site-specific issues that need to be addressed, the time could be reduced significantly if a single national permit could address the acceptability of a new technology. A single national review of technology also could improve the quality of the review, prevent technical concerns from being confused with "Not In My Backyard" (NIMBY) concerns, and expedite the introduction of new technology.

CHANGES IN POLICY

There is a fine line between policy or guidance and regulation. However, sometimes even when regulations may allow for certain outcomes, corporate culture or policy can preclude those actions. Policy changes can be implemented only if senior EPA decisionmakers are able to communicate the importance of these items to all levels of the organization. Examples of needed policy changes include the following:

- More flexible use of interim cleanup remedies that prevent risk during the immediate future. This allows resources to be spent on the biggest health/environmental problems first, and it also allows the time for the development of new, improved permanent technologies.
- Better up-front analysis of how site characterization data are going to be used to affect actual site remediation decisions. A lot of money is being spent to characterize sites when those data are not useful in differentiating between available remediation choices. In some cases these data confuse rather than clarify the decision and can result, at the very least, in very significant delays in conducting actual cleanup.

- The ability to evaluate different levels of uncertainty associated with different cleanup choices. All technologies should be evaluated at their expected value performance level where the expected value level considers the different uncertainties inherent in the different technologies. The current approach often compares best-case performance of one technology with worst-case performance of another technology.
- The need to provide some certainty that if voluntary cleanups are performed expeditiously and reasonably, state/federal agencies will not reevaluate these cleanups later and apply tougher standards unless these is a clear health or environmental risk.
- The need for agency personnel to be rewarded for making reasoned but quick decisions, with the understanding that the price to be paid for more decisions is some incorrect ones.

DATABASES

The common phrases "information is power" and "garbage in, garbage out" are important to remember in the context of remediation decisions. Good databases also can significantly reduce study costs and time as well as litigation costs. The following two suggestions are only a subset of possible activities that EPA could take to expedite remediation:

- Collect and disseminate data to determine what type of site situations lend themselves to particular technology/remediation strategies. Not only would such a database help to focus and limit preremediation studies, but it could serve to identify generic approaches to different kinds of sites. While EPA Records of Decision and RCRA permits would be one source of these data, it also would be helpful if trade associations could provide data from voluntary cleanups.
- Collect and disseminate data to determine how well selected technologies work in actual application over time. Also develop data on actual costs, implementation times, and failure modes.

PUBLIC ACCEPTABILITY

Even though everyone is in favor of cleanup, the community surrounding a cleanup site often is highly concerned about the risk associated with the cleanup implementation. Thus, these situations often turn into legal battles, with expert pitted against expert. While EPA has had a Science Advisory Board for many years, the board typically addresses generic science issues rather than site-specific decisions. The establishment of a set of scientific technical panels to review individual site remediation approaches and to address community concerns could increase credibility in the cleanup process and reduce public anxiety.

These same scientific panels could perform generic screens on the many new technologies. Without some effective screening process, both decisionmakers and the general public tend to stay with the status quo because they do not know what else to do. The number of new technologies is growing very fast, but they are not being utilized effectively in cleanup implementation.

CONCLUSION

This paper attempts to look at a set of disincentives that exist for completing effective, rapid soil and ground water cleanups. These disincentives have derived from a combination of statutory, regulatory, policy, information shortages, and public acceptability constraints. In each of these areas, there are important steps that can be taken to reorient the incentives and ensure that the balance between the pace and the thoroughness of cleanups results in maximal environmental protection.

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Making Science, Policy, and Public Perception Compatible: A Legal/Policy Summary, or Do We Want To Clean Up Hazardous Sites Or Just Scream and Yell at Each Other?

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Over the past several decades, Congress has passed a series of successively more specific and stringent statutes that require the cleanup of contaminated soil and ground water.[1] Despite wide popular support for the concept of cleaning up the environment, these statutes have been enacted without developing a consensus concerning the ultimate cleanup goals and without an accurate understanding of the scientific limitations of such cleanups.[2] EPA has attempted to provide a coherent strategy.[3] A coherent strategy, however, is not the same as nor is it a substitute for consensus. As a result, there is a vigorous, if not vitriolic, public debate under way concerning the adequacy of soil and ground water cleanups.[4]

More often than not, what is characterized as a conflict between science and policy is a conflict in value judgments, reflecting the lack of consensus on cleanup goals. The debate over soil and ground water cleanup policy has lacked a clear framework within which honest policy differences can be debated. This presentation is intended, in part, to (1) outline a clear framework for such a policy debate, (2) provide the factual background to place soil and ground water cleanup in the context of other federal health and environmental decision-making, (3) share the author's perspective on these issues as a former Superfund enforcement attorney and a current Superfund defense attorney,[5] and (4) propose some approaches for resolving the debate.

To answer the question of whether soil and ground water cleanup science, policy, and public perception are compatible, one must understand (1) the distinction between science and policy; (2) the source of the policy[6]; (3) the scientific evidence needed to support a soil or ground water cleanup policy *as a matter of law*; (4) the degree to which value judgment determines policy[7]; (5) the role of participants in the process, particularly the public; and (6) the policy options and their scientific and policy limitations.

THE DISTINCTION BETWEEN SCIENCE AND POLICY

Despite the inevitable tendency to blend science and policy, it is essential not to confuse a policy rationale with a scientific rationale for a cleanup decision. A policy includes the more detailed direction that an agency develops to guide its staff concerning how a statute is to be implemented.[8] To implement Superfund, for example, EPA must determine what degree of reduction in toxicity, volume, or mobility is "significant," when further reduction is not practicable, and how much weight to place on this preference compared to other factors, such as cost.

Science, on the other hand, is "accumulated and accepted knowledge that has been systemized and formulated with reference to the discovery of general truths . . . or the search for truth . . . ."[9] Science involves largely the "determination of what level of probability is needed to accept or reject a hypothesis."[10] Typically, scientists use a 95 percent to 99 percent confidence level in statistical tests to distinguish between a chance result and a result not caused by chance.[11] Scientists implicitly accept a risk of a false-negative by using such statistical criteria.[12] Statistical significance does not prove causation, however. Such proof ultimately involves scientific judgment.[13] Unless there is a consensus among scientists concerning this judgment, causation generally is not proven scientifically. Even when a consensus exists, individual scientists may possess conflicting or at least differing opinions.

Soil or ground water cleanup issues possess both scientific and policy components. For example, one must ascertain the degree to which each remedial alternative reduces the toxicity or volume of the hazardous substances at a site to determine whether the remedial alternative significantly reduces the toxicity or volume of hazardous substances at a site.

Unanimity on the scientific components does not determine the policy question. Ultimately, an agency must rely upon policy to justify its soil and ground water decisions, because few aspects of the soil/ground water process are scientifically certain.

THE SOURCE OF SOIL AND GROUND WATER CLEANUP POLICY

The Law: The Ultimate Source of Policy

Policy is not derived scientifically. Policy questions must be answered in light of the law involved. Laws may be based on emotional or other purely "political" factors.[14] As Justice Oliver Wendell Holmes once noted, "it [is] one of the glories of man that he . . . devotes a certain part of his economic means to uneconomic ends . . . ."[15] For example, Congress has decided that even a trivial risk must be regulated in food additives,[16] public preference must be considered in selecting soil and ground water remedies,[17] and underground injection regulations should not impede or interfere with the production of oil.[18] Ultimately, it is more important in a democracy that the public has the decisions it wants (even if the decision is wrong or irrational) than the scientifically "correct" decision be made.[19] Therefore, it does not invalidate a policy if a consensus of scientists disagrees with the balance struck in the law (e.g., the balance between the costs of implementing a cleanup versus the benefits).[20]

Scientific Limitations on Policy

This is not to say that science is irrelevant. For example, a policy that requires something physically impossible or that will worsen the situation is arbitrary and capricious.[21] Among the scientific realities that must be addressed by any soil and ground water cleanup policy are the following:

- Complete removal of chemicals from soil or ground water is physically impossible to achieve.[22]
- Soil or ground water cannot be cleaned up to levels below background levels.

- Cleanup of soil and ground water to detectable levels or background in most cases is impossible; even where physically possible, it is extraordinarily expensive.
- Six months of data collection is inadequate to characterize the hydrogeology of a site adequately for the purpose of selecting a remedial action.[23]
- Ground water cleanups take a long time--often decades.[24]
- The health effects, if any, caused by exposure to low levels of chemicals cannot be demonstrated scientifically; therefore, all health-based standards are based on health-protective assumptions.
- The residual risk and the risk from implementing excavation and incineration may exceed the residual risk and risk from implementing other less-permanent remedial actions, (e.g., the risk of excavation and incineration may exceed the risk of the no-action alternative).
- The cost of soil and ground water cleanups increases exponentially as the target cleanup goal decreases linearly.[25]

The Law Underlying Soil and Ground Water Cleanup Policy

Federal and state statutes relating to soil and ground water cleanups delegate the actual cleanup decision to administrative agencies. The statutes, however, provide little guidance concerning how to balance the statutory factors.[26] For example, Superfund lists a number of factors that must be considered, including a preference for permanent remedies, but includes no unique formula for balancing all of these factors.[27]

Generally, environmental and public health laws have been interpreted as providing agencies great latitude in making health-protective assumptions in areas on the "frontiers of science."[28] An agency may err on the side of overprotection rather than underprotection and may base its decisions largely on policy considerations.[29] Agencies need not wait until there is 95 percent scientific certainty before making decisions.[30] The government, therefore, may act before a problem occurs in order to prevent it.[31] These statutes give EPA significant, but not unlimited, discretion to develop a policy that fulfills the goals of the statute.

GROUND WATER AND SOIL CLEANUP POLICY: MYTHS, METHODOLOGY, AND MADNESS

The Options

The conceivable soil or ground water remedial actions options used, discussed, or proposed include removing and treating hazardous substances at a site to the following extent [32]:

- completely (i.e., there is zero residual risk or the cleanup level is defined by the detection limit or background levels);
- until the risk of the residual concentrations is acceptable (acceptable may be defined on a generic basis in national standards or on a case-by-case basis) [33];
- until the toxicity, mobility, or volume of the hazardous substances at the site are reduced, to the extent practicable or technically feasible, regardless of risk [34];
- to the extent determined by the local residents;
- to the level that such removal and treatment is cost effective or cost beneficial (determined either on a case-by-case basis or by national regulations); or
- to the level or extent required to protect the public health and by a balancing of the other factors discussed above, on a case-by-case basis (essentially EPA's policy).[35]

Zero Risk/Detection Limit/Ambient Background Levels

Zero Risk

Some people demand zero residual risk after implementation of soil and ground water cleanups. For example, it has been argued that maximum contaminant level goals (MCLGs) must be used as ground water cleanup standards in all situations,[36] even though MCLGs are zero for known or suspected carcinogens.[37] Such a cleanup standard is *not* required by federal soil and ground water cleanup laws.[38] Only when a statute is as rigid as the ban on carcinogens in food additives specified in the Delaney clause can a statute be interpreted as requiring no residual risk.[39] Rather, EPA must determine what is a significant risk.[40]

Furthermore, use of zero residual risk as a cleanup standard would (1) be infinitely expensive to attempt,

(2) provide little additional protection of human health or the environment or incremental reduction in the toxicity or volume of the hazardous substances compared to risk-based standards, (3) fail ultimately because it is physically impossible to achieve, and (4) undermine EPA's credibility further because it would raise false expectations.

Background or Nondetectable Levels

The general language in some state statutes prohibiting the discharge of chemicals at levels that would be injurious to health has been interpreted by some as requiring cleanup to the detection limit or background level (so-called nondegradation policies).[41] The primary "benefits" of such a policy are the strong negotiating position it provides for government officials, the perceived political advantage of not being required to state that any measurable level of pollution is acceptable, and the avoidance of the inherent tough decision concerning what is an acceptable level of pollution.

One of the greatest negatives to such a policy is its deceptive nature. In effect, these criteria are indirect methods of seeking zero residual risk. Cleanup to these levels generally is not physically possible. At the few sites where such levels theoretically may be achievable, it would be extraordinarily expensive to reach those levels. Furthermore, experience with permits, consent decrees, and other cleanup decisions in states that have adopted such draconian policies indicates that soil and ground water cleanup levels vary greatly, and few sites are cleaned up to background or the detection limit.

As a practical matter, this policy undermines the public's confidence in the stringent (perhaps even overly stringent) cleanup levels actually used, because the actual cleanup levels typically will be higher than the background level or the detection limit. Such policies also usually result in convoluted explanations of the reason why the government used or agreed to a cleanup level higher than background or the detection limit.

Site-by-Site Risk Assessments--EPA's Approach

Introduction

The critical issue in a soil or ground water remedial action is whether the residual concentration of chemicals remaining at a site is protective of human health and the environment (i.e., will the site be "safe" after the remedy is complete). This determination can be made on a case-by-case basis or by promulgation of risk-based national standards. Both approaches use the same risk assessment methodology that is used to determine acceptable concentrations of chemicals in our food, drinking water, surface water, air, and workplace.[42]

EPA's Policy

The policy of EPA establishes different degrees of protection for ground water based on its vulnerability, use, and value.[43] EPA's preference is to restore ground water to drinking water quality whenever practicable.[44] Ground water may be protected if it is (1) capable of yielding sufficient water to a well or spring to supply the domestic needs of a family (i.e., 150 gal/d)[45] and (2) not highly saline (usually containing greater than 10,000 mg/per liter of total dissolved solids) or "otherwise contaminated beyond levels that allow restoration using methods reasonably employed in public water treatment systems."[46]

The agency makes a case-by-case determination of whether the residual concentration remaining after cleanup adequately protects human health and the environment.[47] The residual soil or ground water concentration must be at or below an applicable or relevant and appropriate requirement (ARAR), such as an EPA drinking water standard.[48] For example, if the ground water contains benzene, the cleanup level would be 5 ppb.[49] The lifetime, upper-bound cancer risk attributable to drinking water containing this level of benzene for 70 years is 10^{-5}.[50] The EPA will clean up ground water to concentrations that correspond to a residual risk in the range of 10^{-4} to 10^{-7},[51] if there is no drinking water standard or soil ARAR or if the presence of multiple chemicals at the site would result in an *extraordinary* risk even though ARARs were achieved. This risk range is protective of human health.[52] Either a site-specific risk assessment or a comparison to a risk-based EPA advisory, such as EPA's water quality criteria, can be used to determine whether the risk is acceptable.[53] In effect, EPA drinking water standards have become national ground water cleanup standards. As drinking water standards for more chemicals are promulgated, there will be less need for chemical-specific ground water risk assessments, because most of the chemicals found at landfills will have drinking water standards.

There are no soil ARARs and few soil advisories. Therefore, most soil cleanups require a site-specific risk assessment. There are few widely accepted exposure measurements or assumptions for performing such soil cleanup level risk assessments; thus, setting a level presents many technical challenges. The final remedy is selected from among health-protective alternatives that reduce the toxicity, mobility, or volume of hazardous substances significantly at the site. EPA balances costs; the degree of the reduction in the toxicity, mobility, or volume of the hazardous substances at the site; the reliability of the remedial alternatives; the speed of cleanup; and community acceptance and enforcement considerations (e.g., preserving the case for litigation, while still providing a mechanism to encourage private parties to perform the cleanup).[54] ARARs must be met, unless an exception applies.

There is no explicit direction given in the statute or EPA's proposed Superfund regulations concerning whether such standards should be applied at the nearest point of use, at the landfill boundary, or directly underneath the site. This choice does not affect the health protectiveness of the remedy but rather the size of the portion of the aquifer that is restored to drinking water quality. If the drinking water ARARs (or other appropriate ARARs) are not met, EPA requires the use of institutional controls, such as water use and deed restrictions.[55]

EPA's Performance

Not surprisingly, a variety of ground water and soil cleanup concentrations have been selected at Superfund sites.[56] For example, the soil cleanup level for PCBs varies from 1 ppm to 100 ppm.[57] Benzene ground water cleanup levels vary from 0.1 ppb to 5 ppb.[58]

The EPA's Superfund cleanup decisions have been criticized as being "seat-of-the pants"[59] and "poorly documented."[60] There is much to criticize about EPA's implementation of the Superfund program. Some of the recent criticisms, however, are extreme, misdirected, not constructive, and based primarily on ideology. These critiques (1) fundamentally misapprehend the risk assessment process, (2) allege that the public near some sites is not being protected adequately, and (3) are indirect attacks on the risk levels that EPA finds acceptable. The following attempts to place EPA's remedy selection process in perspective.

The Risk Assessment Process

Part of the problem with EPA's site-by-site risk assessment approach is the common tendency to treat such risk assessments as medically certain predictions of health effects or as hopelessly underpredictive of the actual risk. On the contrary, the risk assessment process is deliberately overpredictive.[61] There is no scientific proof concerning whether or not very low concentrations of chemicals cause adverse health effects, and proof is unlikely to exist in the near future.[62] Even EPA's director of health and risk capabilities, an internationally respected scientist, doubts that health effects are caused by exposure to very low concentrations.[63] There are at least 50 health-protective policy assumptions used in the quantitative risk assessment process because of a lack of scientific certainty (e.g., that the dose-response curve is linear at low doses).[64]

A quantitative risk, therefore, is *not* a realistic prediction of the effect of exposure.[65] The true risk could be zero or perhaps as high as the upper-bound estimate provided in the risk assessment. EPA's particular risk assessment methodology results in estimated risks that are an order of magnitude or more higher than the risks estimated using the risk assessment methodology of other federal agencies, such as the Food and Drug Administration and the Centers for Disease Control.[66]

Furthermore, EPA makes extreme worst-case assumptions in determining exposure (e.g., assuming that a drinking water well is located in the middle of the worst part of the ground water plume). EPA's exposure assumptions at Superfund sites are considerably more stringent than those typically used in other national regulations.[67] As a result, the risk appears much higher than will ever occur.

Variations in Cleanup Levels--The Perception of Inequity

The Rosetta stone that translates the public health impact of a chemical at widely differing sites into one common denominator is risk--not concentration. The observed variation in EPA cleanup levels is inevitable given the variation in site-specific and chemical-specific factors that vary exposure by several orders of magnitude and given the variation in the level of acceptable risks used in regulatory decisions. The amazing thing is not that EPA's cleanup levels are so variable but that there is such a narrow range in such values.

For example, if ground water and soil cleanup statutes required everyone in the United States to be protected to the same degree (which they do not), the soil cleanup concentration for a potential carcinogen could vary by a factor of 10,000 to 100,000 because of additivity,[68] bioavailability[69], soil type, differences between residential exposures and industrial exposures, and other factors.[70] Federal regulatory agencies accept risks that vary over a range of 1,000. Therefore, an acceptable soil concentration could vary by a factor of 10,000,000 to 100,000,000 and still present acceptable risks and be consistent with the residual risks accepted in other regulatory programs. The much narrower variation in practice indicates that EPA has used substantial margins of safety at most sites.

The Adequacy of EPA's Superfund Risk Range

Some have criticized EPA's acceptance of a range of risks. The Superfund range of acceptable risks, however, is the same as the range that government agencies use in regulating chemicals in all other regulatory programs. In practice, federal agencies accept residual risks greater than 10^{-4} in one-third of the cases, particularly when small populations are exposed.[71] The average residual risk after regulation is 9×10^{-6}.[72] Residual risks at the 10^{-4} risk level are considered "safe."[73] Residual risks lower than 10^{-4} can be viewed as providing a larger "margin of safety." Superfund cleanups almost always involve small populations, yet EPA usually seeks a risk lower than the average residual risk for all regulations.[74]

The focus of attention on the variability in the soil and ground water concentrations ignores the real issue: of whether obtaining a greater margin of safety warrants the additional cost. Increasing the margin of safety for these low-level risks "can reach a point where, by absorbing resources and energy and impeding innovation and growth, it can do both individuals and society more harm than good. . .. The problem is how to know when to stop . . . how to know when prudence and care becomes over-reaction or paranoia."[75]

National Soil Standards

National standards are deceptively appealing because of the following:

- They are uniform and therefore easy to apply.
- They appear to eliminate the perceived inequities of a site-by-site cleanup decision because they specify one number for all sites.
- They conserve agency resources because cleanup levels would be determined once in the making of a rule.
- They may be given more credibility by the public because they were not determined in the messy and confusing context of a specific site.
- They would relieve the EPA regional staffs and state agency staffs from the need to decide what risk level is acceptable at a particular site (a difficult and inherently political task).

At this time, setting national soil cleanup levels presents an impossible scientific, policy, and practical task. There is no scientific consensus and little data concerning the facts that are needed to derive soil standards, such as the amount of soil typically ingested by children, the bioavailability of chemicals on different types of soil, and the biological half-life of chemicals on soil.[76] A national standard based solely on extreme worst-case assumptions would be 10,000,000 times more stringent than necessary in many situations. Furthermore, in most situations national soil cleanup standards would not be achievable.[77] Even where such national soil cleanup standards could physically be achieved, the costs of meeting these standards would be astronomical and without any clear benefit.

The only circumstances that might make soil standards workable would be to (1) limit such standards to surface soil that is freely accessible for residential or industrial use; (2) set different limits for soils at industrial sites and residential sites; (3) set such standards based on the amount of the chemical that is bioavailable (the milligrams of a chemical per gram of soil that is bioavailable per day), not on soil concentration[78]; (4) use the highest acceptable risk level rather than the 10^{-6} risk level; and (5) provide a broad exception for the many sites where a health-protective, risk-based soil standard cannot be achieved.

In sum, rigid national soil cleanup standards[79] do not provide equal protection to the public, are virtually impossible to derive in any reasonable manner, and will drive up cleanup costs astronomically.

Technology-Based Cleanups

A soil cleanup policy could require only those technologies that destroy virtually all of the hazardous chemicals in the soil (e.g., incineration of contaminated soil). Such a policy would ignore the risks created by excavation and incineration at many sites. This potential requires a site-by-site evaluation.

The cost of a cleanup is a function of the unit cost of the treatment technology, which can vary by orders of magnitude.[80] EPA seems to prefer incineration increasingly as a treatment technology. A policy of incinerating all contaminated soil at hazardous waste sites would be extremely expensive. Superfund grants EPA flexibility to choose innovative remedies at a particular site and even requires EPA to evaluate innovative technologies (i.e., the Superfund Innovative Technology Evaluation or SITE program).[81] In practice, EPA generally has been reluctant to use innovative, more cost-effective technologies at Superfund sites.

Cost-Based Cleanup Standards

Cost and cost-effectiveness are considered explicitly or implicitly in selecting soil and ground water remedial actions.[82] Protection of public health takes precedence over costs.[83] No one is proposing that cost be the sole or even primary factor in setting cleanup standards. The underlying question is "What level of risk reduction do[es society] . . . want, *at what cost?*"[84] In the context of soil and ground water cleanups, the key questions are (1) whether the increase in the margin of safety that can be achieved by choosing one acceptable or safe remedial alternative over another is worth the increased cost and (2) whether a small additional reduction in the toxicity, mobility, or volume of hazardous substances at the site is worth a substantial increase in cost.

The EPA estimates the present value cost of each remedial alternative in a Superfund feasibility study, but there is little EPA guidance concerning how to weigh costs. It is difficult even to determine the actual average cost of soil or ground water remedies pursuant to Superfund or any other soil and ground water cleanup statutes. One study indicated that the average cost of soil and ground water cleanup at a Superfund site would be $66 million if incineration of waste and soil were required.[85]

In addition to simply estimating average costs, the methods that were developed originally for evaluating the cost impacts of national regulations also could aid a decisionmaker in weighing costs versus benefits at individual hazardous waste sites. For example, the net benefit of an environmental or public health regulatory action is expressed in terms of the cost per cancer case avoided.[86]

The cost of federal regulation per life saved varies from $70,000 to $137 million.[87] EPA's cost per life saved has varied from $0.7 million to $2 million,[88] and EPA guidance suggests that a regulation is warranted if the cost per life saved is less than $1.5 million.[89] Most federal agencies now tend to regulate vigorously if lives can be protected at less than approximately $2 million per life saved but not if the cost is significantly higher.[90] One assessment of the net benefit of soil incineration at a particular site indicated that EPA would pay $160 million per cancer case averted.[91]

An analysis of the cost per life saved at every Superfund site could help place the remedial costs at individual soil and ground water contamination sites in the context of other regulations. If the cost per cancer case avoided by excavation and incineration is considerably higher than for other equally health-protective remedies (e.g., soil flushing) this fact might weigh against choosing such a technology, particularly if the cost substantially exceeds $2 million per life saved.

Other cost impacts, such as the impact on the cost of goods produced in the United States and the impact of these costs on the competitiveness of United States goods in the world market, and other societal impacts should be examined in regulation. Then (and only then) can policymakers in agencies and Congress engage in an informed debate about the appropriate cleanup policy and consider as appropriate the unanticipated, adverse economic side effects of various policy choices.[92]

Conclusion

The EPA's application of its cleanup policy is inconsistent but not underprotective of public health. In reality, few Superfund sites present an immediate significant risk.[93] The reason that these cleanups appear inconsistent is that (1) there is no generally accepted method for determining soil exposures, (2) EPA uses unreasonable, extreme exposure assumptions to justify remedies and enhance its negotiating position with potentially responsible parties, (3) most regional staff members are unfamiliar and uncomfortable with the risk assessment process, (4) professional judgment is required, (5) sometimes mistakes are made because of EPA's efforts to speed up the cleanup process, and (6) there is no peer review or quality control of the risk assessments.[94]

Additionally, the remedial investigation/feasibility study (RI/FS) and record of decision (ROD) often are used as the government's first proposal in negotiations. When used in such a manner, these documents may contain added frills and flourishes that are not really necessary, but are added solely to be bargained away. Most people reading these documents, however, do not know this.

Another reason that cleanup levels vary is that risk assessment is used to justify a lower cleanup level than the drinking water standards. For example, EPA enforcement attorneys may seek the lowest cleanup level the potentially responsible parties (PRPs) will agree to in a settlement, regardless of risk, because of the low costs of achieving such levels at a particular site. Unfortunately, the lowest level selected at any site has become the operative point of comparison (at least for some of EPA's critics). This obviously skews the comparison toward the levels that were selected for unique site-specific reasons.

In sum, EPA's failure in Superfund has not been a failure to protect public health but a failure to document and explain the protective nature of its cleanup decisions.[95] These cleanup decisions have resulted in very large margins of safety.

THE ROLE OF THE PUBLIC

Soil and ground water contamination raises public concerns about dangers to health and loss of property values. The important distinction between an actual prediction of injury and the results of a risk assessment usually are never explained to the public. The very fact that the federal government is spending billions to cleanup these sites is proof enough in many people's minds that there is an immediate likelihood of grave harm.

The public concern also stems from a growing societal fear of chemicals.[96] This fear is generated because such chemicals are invisible, and the true nature of the hazard is difficult to comprehend (even the names are alien).[97] Cancer and other diseases are more prevalent than most people commonly know;

therefore, people with diseases will exist around every hazardous waste site.

There is a belief that no method exists of predicting the behavior of these chemicals or controlling them once they have begun to migrate. The public's perception of risk focuses on the catastrophic potential, the dread associated with the risk, the equity and the involuntary nature of the risk,[98] as well as the absolute magnitude and probability of the risk.[99]

As a result, many local residents and national environmental groups insist that only zero exposure is acceptable.[100] This standard is impossible to meet. Excavation and incineration, the so-called cure for contaminated soil at many sites, can be worse than the disease (i.e., result in a greater risk than less draconian remedies or even the no-action alternative).

The public concern on this issue is felt deeply and cannot be dismissed, even if it is in large part an emotional reaction. Citizens in our society have demanded and obtained a role in environmental decisionmaking that is unique in the world.[101] For example, citizens (1) have a right to virtually all government documents through the Freedom of Information Act, (2) may intervene in the administrative process or in a judicial consent decree, (3) may sue directly to seek a cleanup, and (4) may express their preference for a remedy at the site (which EPA must at least consider in selecting the remedy).[102]

The EPA public comment process could provide meaningful public involvement, if implemented diligently and sensitively. There is a need, however, to better define what public participation means. It would be ludicrous to suggest that local residents "vote" to decide the direction of ground water flow. However, the present practice of presenting the public with a *fait accompli* after the RI/FS is completed or a consent decree[103] is negotiated seems destined to frustrate the public further and encourage opposition to the selected remedy.

The critical test of the process is not whether EPA chooses the remedy preferred by the public but whether the process is perceived as fair.[104] As William Ruckelshaus has noted: "Citizen participation is not the same thing as citizen victory . . . the right to be heard is not the same thing as the right to be heeded."[105] Currently, there is a public perception that the Superfund process is predestined and that EPA ignores local residents, particularly when the remedy is decided in a negotiation. Often the reality is that EPA selects or negotiates for more stringent remedies than are warranted from a purely scientific point of view in order to address public concerns.

THE ROLE OF THE EPA

Introduction

It is all too fashionable to bash EPA's handling of soil and ground water cleanups. The public distrusts EPA because the agency allowed the hazardous waste sites to be created in the first place and EPA will not respond to the "perfectly reasonable" demand that these hazardous waste site disappear immediately. Congress criticizes EPA because EPA has tried to interpret vague, poorly drafted statutes in a manner that takes into account widely varying site conditions and the potential to expend astronomical costs at one site with little public health or environmental benefit. The private sector (the author included) criticizes EPA because EPA (1) often takes an overly adversarial approach, (2) imposes draconian cleanup costs (e.g., incineration of soil) without demonstrating any commensurate public health and environmental benefits, (3) fails to consider the potential health risks associated with the implementation of some remedies (e.g., excavation), (4) avoids criticism at public meetings by throwing money at the problem rather than devising cost-effective remedies, and (5) overstates the risk at a site to provide a better negotiating position or to "justify" the remedy.

Many of the critics of EPA's soil and ground water cleanups, however, impose impossible, if not contradictory, standards. *It is time for a moratorium on the rhetoric from all sides.* In reality, soil and ground water cleanups present EPA personnel with heretofore undreamed of challenges in scientific areas, resource areas, public participation, and legal areas. The cumulative effect of these challenges and EPA's reaction to them has been to create unrealistic expectations and undermine EPA's ability to address even realistic expectations.

Who Makes the Risk Management Decision?

The type of decision to be made and who makes the decision in EPA's soil and ground water cleanup programs are significantly different from in prior EPA regulatory programs. The core decisions in any soil and ground water cleanup are whether the site is safe after the remedy is implemented and what price to pay for an increased margin of safety. This is an inherently more difficult question than determining what is the best available technology. Just as significantly, the ultimate risk management decision has been shifted from EPA headquarters to the EPA regional offices and state agencies. EPA regional and state agency staff members must decide what remedy is appropriate on a site-by-site basis[106] and then obtain meaningful public comment from the public on this decision.

Resources

The resources needed to implement these ground water and soil cleanup programs far exceed the resources necessary to implement prior environmental programs. Soil and ground water cleanup programs require an enormous number of site-specific, scientifically complex decisions. EPA, however, currently lacks a sufficient number of qualified and experienced experts knowledgeable in scientific disciplines necessary to make remedial action decisions (e.g., hydrologists, toxicologists, and modelers).[107] Also, EPA personnel generally are not trained adequately to utilize consultants to provide the regional staff this expertise. The situation is critical and likely to become worse.

Credibility

A public health agency needs to be considered trustworthy, or else its decisions will not be accepted publicly.[108] The consensus on environmental policy that once existed[109] has eroded. Over the years, a widespread public distrust of the public institutions that manage risks has developed.[110] EPA's credibility, in particular, was undermined as a result of the unpopular policies, positions, and rhetoric adopted by EPA's high officials in the early 1980s.[111]

The EPA, however, has undergone a complete change in policy-level personnel. A new president has appointed the head of an environmental group as the administrator of EPA. Even when trust was at its lowest, the vast majority of EPA personnel were dedicated public servants trying to perform a hideously complex task under difficult, if not impossible, conditions. The loss of credibility because of prior policies should no longer be a problem. Some of EPA's greatest achievements have been under Republican administrations,[112] and, therefore, EPA should now be accorded more trust.

Communication with the Public

The EPA is its own worst enemy. The agency usually will emphasize the toxicity of the chemicals at a site and overestimate the severity and the nature of the risk at the site in order to justify the action that may be necessary.[113] There is also an inherent reluctance among many EPA personnel to explain the extreme health-protective nature of the cleanup levels selected at a site because of concern that it might compromise later negotiations with the PRPs or a cost recovery action. Often, after literally years of fear and delay, EPA "suddenly" announces a remedy that often seems mild compared to the preceding rhetoric. It is no wonder that the public is disappointed, confused, outright hostile, or all three at public meetings.

The public participation process requires EPA scientists, engineers, and lawyers to explain the issues and justify their actions in a manner that can be judged by a lay audience. EPA personnel, however, are not trained to handle public meetings or to be sensitive to the public participation process. The existing limitations of agency personnel are symbolized in a quote from a Resources Conservation and Recovery Act (RCRA) permit writer concerning his view of risk assessment methodology: "ten-to-the minus-six is voodoo to me."[114] In sum, one of EPA's most important but least implemented roles is as a risk educator and communicator.

THE ROLE OF THE OTHER PARTIES

Introduction

Soil and ground water cleanup policy is neither developed nor implemented in a vacuum. In addition to EPA and the public, there are numerous other parties that have a role.

State Government

The role of the state in a soil and ground water cleanup often is unclear. Historically, Congress enacted federal environmental statutes because states lacked the resources and expertise.[115] Most states still possess even more-limited technical capabilities than EPA.[116] States also were perceived as susceptible to economic pressures caused by threats of plant closure or relocation.[117]

Many states have attempted to fill the vacuum created during the early 1980s by EPA's reluctance to launch an aggressive Superfund program. Superfund and EPA's proposed Superfund regulations (Proposed National Contingency Plan [NCP]) provide a significant role for the states in the remedy selection process.[118] The key question is does this role allow the 50 states to impose their 50 different cleanup levels and cleanup policies on EPA? If the states have unfettered control of these key decisions, there will be even greater differences between remedies and cleanup levels at sites across the nation. Additionally, unfettered control will provide the ultimate in separation between authority and accountability since the states would make the key decisions about how to spend the $8.5 billion in Superfund without any responsibility for recovering the money.

States are challenging EPA's Superfund remedies at an increasing rate.[119]2 There is a rivalry between EPA and state officials.[120] States often seek more draconian cleanup standards than EPA, simply under the presumption that any remedy accepted by EPA could not be adequate[121] or because it is politically unacceptable to call any level of pollution acceptable. Among the interesting, but as yet unanswered, questions that the proposed NCP raises is the question what happens if the two sovereigns, EPA and the State, disagree?

The proposed NCP provides an administrative procedure to resolve disputes between EPA and the states.[122] EPA, however, can select a remedy at a Superfund site even when the state does not concur in the recommended remedy.[123] A state must fund any additional remedial work it desires at a site if EPA or a court determines that additional remedies are not required by a state ARAR.[124]

All of the procedures and rights of states in a conflict with EPA are not clear yet. Continued litigation is likely until a uniform set of rules becomes apparent from the case law.

Consultants

Remedial action contractors are in a difficult position, for they are placed in the midst of the battles among EPA, the public, and the potentially responsible parties. Their role includes advising EPA on scientific issues, organizing the data at a site and evaluating (presumably neutrally) the remedial alternatives, serving as fact and expert witnesses in litigation, and actually implementing the remedies chosen by EPA. Increasingly, they may become the target of lawsuits themselves, particularly from frustrated local residents and others who may claim to be injured by releases during the implementation of the remedies.[125]

The EPA could not implement Superfund without these contractors, but contractors have been criticized for making policy decisions.[126] Obviously, contractors should not make the policy decisions, such as selecting ARARs or deciding the weight to be given to the remedy selection factors. Credibility in the Superfund process also is undermined when contractors slant their scientific opinion to appear to support a remedy actually being chosen as a matter of policy. There is a perception among potentially responsible parties that at least some EPA contractors abandon scientific objectivity and misuse science to support the policy preferences of EPA.[127]

Rather than reduce its use of contractors (as suggested by some), EPA needs to train its personnel how to manage these contractors. Furthermore, contractors should be given clear guidelines on which decisions are not appropriate for contractors.

Potentially Responsible Parties

The private sector produced and disposed of the chemicals that are now being cleaned up. These companies are portrayed as villains who care more about profit than public health. The line from the old Pogo cartoon is a more accurate assessment: "We have met the enemy and the enemy is us." Many hazardous waste sites are no more than old municipal landfills or locations where paint and common solvents were deposited. Between the time of disposal and the present, the legal rules have changed drastically. Furthermore, as a practical matter, the state of the art and the dissemination of that knowledge has increased at an accelerated rate. The moral outrage often expressed at the PRPs rarely is warranted.

It is not heartless nor unreasonable to want to protect the public health in a more cost-effective manner. In most situations private companies can apply more resources to a problem. They also have a more direct incentive to devise more cost-effective solutions. Obviously, money wasted in a cleanup at one contaminated site cannot be spent at the many other sites that require cleanup, since there is a finite amount of resources available to perform such cleanups. There are microeconomic and macroeconomic impacts on American industry to imposing unnecessary or wasteful costs. These impacts also need to be considered in setting an overall cleanup policy.

The soil and ground water contamination problems also cannot be addressed adequately on a national basis without voluntary efforts by industry. No conceivable enforcement budget is large enough to ensure the expeditious remediation of the existing sites across the nation. This national goal can be achieved only through voluntary efforts of industry and the internalization of the process through the real estate, insurance, and other "normal" business processes. The setting of impossible goals undermines the achievement of this goal.

Environmental Groups

Environmental groups have lobbied EPA, filed administrative comments, and, when necessary, sued EPA to take a particular regulatory action or interpretation. Often, these groups have served a valuable function as an early warning system, as prods to move the bureaucracy to take action more expeditiously, and as innovators.

Some of these groups now promote an overly adversarial attitude.[128] In the vacuum created by the loss of trust in EPA, the propositions advocated by such groups have been accepted unquestioningly. Environmental groups, however, advocate only one side of an issue and, therefore, their positions should be evaluated critically.

For example, some environmental groups opposed an EPA-commissioned study of the impacts of the Superfund program, including the economic impacts. This "hear no evil, see no evil" attitude toward determining the societal costs associated with the drastic increase in the margins of safety involved in soil and ground water cleanups has resulted in the elimination of this cost component from the study. It is one thing to argue that greater economic costs should be borne to obtain a greater margin of safety and quite another to deny to EPA policymakers and Congress relevant information on the economic impacts of this country's environmental policy.

Congress

Congress's primary role has been to respond to the public's unquestionable desire that more be done to clean up soil and ground water in an expeditious manner. Congress has passed a number of statutes with detailed technical requirements, specific deadlines, and self-actuating ("hammer") provisions to implement this public mandate. There are two dilemmas raised by congressional involvement in the details of such complex programs. First, Congress cannot repeal the laws of physics, (e.g., the processes governing the fate and transport of chemicals), by enacting legislation. Congressional mandates should be physically achievable. Second, congressional statutes (e.g., Superfund) are poorly drafted statutes that have limited legislative histories and ultimately do not resolve the policy conflicts.[129]

Congress's role in setting policy does not end with the passage of a statute. Increasingly in the last decade, Congress has used its oversight of EPA to ensure that the statutes passed by Congress are being implemented.

There also has been a decided shift in the attitude of Congress on environmental questions. In earlier eras some Congress members and senators would demand more stringent environmental controls, but they also would express their concern over the potential loss of jobs caused by such additional pollution controls. Closed and abandoned landfills, however, do not employ anyone. Soil and ground water remedial actions have become perceived increasingly as a boost to the local economy ("the pork barrel of the 1980s and 1990s"). Individual congress members and senators now are concerned about whether sufficient cleanup money is being spent in their individual district.

The Media

As with all public policy, the media have a significant role in framing the debate, informing the public, and influencing key decisionmakers (in Congress and within the agencies and private companies). The scientific complexities make this story difficult to cover in an even-handed manner. The emotional impact of the events tend to portray the agency and industry in an unfavorable light. Footage of mothers with infants in their arms crying as federal and state agency personnel an nounce the results of a health study or images of children playing at the feet of an EPA sampling team in "moonsuit" protective gear leave indelible images. Risk assessment is esoteric and too complex for explanation via nightly television "sound bites." Statements concerning costs of cleanups can be twisted into placing cost above health. Furthermore, neither EPA nor industry have made significant efforts to educate the media (or the public).

Not surprisingly, therefore, another motivation behind soil and ground water cleanup policy is concern about criticism from the press.

THE METHODS BY WHICH CONFLICTS CAN BE MINIMIZED

Introduction

There may be a conflict between "good science" and "good public policy" in many situations, although some conflicts are legally permissible as long as the policy reflects statutory mandates. There is a wide and growing chasm between public perception and science. The conflict between public (and to a great extent, congressional) perceptions and reality is the source of many of the so-called policy disputes.

It would be delightful if a simple list of suggestions prepared for a colloquium could solve all existing problems. Nothing, however, is simple about soil and ground water cleanups. As long as there are sharp value differences and an adversarial thrust to this nation's approach to environmental problems, many of these problems will persist.

Nonetheless, the following thoughts are provided for consideration (whether these steps can be accomplished in the real world is not addressed):

- Federal and state agencies, scientists, industry, and other participants in the regulatory process must devote significant resources to educating the public on the scientific limitations of policy, the policy alternatives available, and the trade-offs involved in soil and ground water cleanups.
- Federal and state agencies should obtain public input at the earliest point in the remedy selection process.
- Federal and state agencies should be trained in the skills necessary to obtain meaningful public participation.
- Federal and state agencies should clearly articulate and document the actual basis for the selection of the remedy in the ROD.

- Federal and state agencies should avoid raising false expectations among local residents. A large number of sites, particularly industrial sites, will never be cleaned up to the point where the soil is "edible" and the leachate is "drinkable".[130] EPA drinking water standards or soil cleanup standards cannot be achieved at many sites, and this should be stated clearly.
- Federal and state agencies would increase the credibility of their decisions by incorporating scientific peer review of (1) all contaminant transport models, (2) all risk assessments, particularly the exposure assumptions, (3) the physical constants and cost estimates used in decisionmaking, and (4) any other purely scientific components in the cleanup process.[131]
- EPA should have its Office of Policy, Planning and Evaluation perform a study of the full costs, benefits, and other impacts of soil and ground water cleanups (including an estimate of the cost per life saved).
- EPA should have some independent body study and evaluate all of the post-SARA RI/FS to determine whether some elements of the process are inconsistent (e.g., the cost estimates made for remedial alternatives, the assessment of risks from the implementation of alternatives, and so on).
- EPA should expand research on the bioavailability of chemicals in soils.
- EPA and Congress should clarify the role of local residents in cleanup decisions.
- EPA's new administrator should take the initiative in developing a consensus on soil and ground water cleanup policy.
- EPA should encourage the use of innovative technology.
- PRPs should be encouraged to implement the Superfund process under EPA's supervision at the earliest possible time[132] through reasonable settlement policies that encourage private cleanups.

A few of these issues warrant a brief additional discussion.

Lessen the Adversarial Nature of the Process and Educate the Public, Press, and Congress on the Nature of the Problem

Most regulatory decisions in this country are highly adversarial. However, that approach (1) usually consumes enormous amounts of resources, (2) is not a reliable method of obtaining a clear technical understanding of a scientific problem, (3) may not characterize and treat uncertainty adequately, and (4) does not produce consistent solutions.[133] Our national energies and resources are finite.

The EPA also cannot endure the endless second guessing accorded its soil and ground water policies. Some closure must be given to the process. The nation's resources would be better spent ensuring that cleanup adequately protects public health rather than cursing the lack of perfection and failure to achieve zero discharge.

It is not surprising that the public, press, and Congress are unfamiliar with the scientific constraints involved in soil and ground water cleanup policy given the complex scientific questions underlying these issues. An essential component of any attempt to lower the rhetoric is a massive effort to educate all of the participants in the process.

The present EPA budget for and emphasis on public communication and training are small. Special attention must be given to developing effective public information and involvement programs.[134] EPA must incorporate rewards for effective public communication and penalties for poor communication into the system by which EPA judges the effectiveness of its personnel. Instead of viewing community relations as a waste of money that could be better spent "putting remedies in the ground," the positive good of such an effort must be instilled at every level of the agency.

Clear distinctions should be made at sites between a present risk and a potential future risk hundreds of years in the future based on worst-case assumptions in order not to scare the public unduly. Furthermore, EPA personnel should understand that there are no perfect choices. Even when EPA picks the most draconian remedies (e.g., excavation and incineration of all soil at the site), someone still may object if he or she lives near the incinerator.

The best defense to criticism from the public is *not to throw money at the problem* but instead to (1) carefully consider all available information, including public comment; (2) choose health-protective yet cost-effective remedies; (3) clearly and patiently present the technical and other bases for the decision; and (4) answer the public's question, not pander to their fears. If the proper information is available and the right questions are asked, the public is likely to "understand [the] impact of spending tens of millions of dollars to add three minutes to two people's lives when the same resources used elsewhere could add years to the lives of ten thousand people . . . or save a critical wetland."[135]

Encouraging Innovative Legal and Technical Solutions

Many of EPA's policies discourage rather than encourage settlement. Other commentators have discussed the specific methods available to EPA to provide encouragement, so these methods will not be repeated here. Those suggestions boil down to demonstrating flexibility, bearing some of the costs of the cleanup, and evincing a desire to settle. The discretion granted EPA by Congress and the courts permits and should encourage settlement. This discretion bears with it a responsibility to be reasonable and fair. EPA's responsibility is even greater because of the high degree of discretion and the lack of pre-enforcement judicial review.

To date, EPA has not evidenced a great deal of constraint or consistency from industry's point of view. EPA's remedial philosophy also seems the exact opposite of what it should be. The agency often first addresses what to do about the source of the pollution (the most difficult, time-consuming, and costly issue) and lets the ground water plume continue to migrate into the community (thereby raising the concerns of local residents about exposure).

The remedial philosophy of EPA should be like the Hippocratic oath--first do no harm. Thus, the first priority should be the implementation of remedies that prevent immediate exposure (i.e., contain, collect, and treat the ground water plume). Then, the ultimate remedy can be selected after additional data studies, including field treatability studies, have been performed. Such a flexible approach has been supported by the courts.[136]

NOTES

1. E.g., the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or Superfund), 42 U.S.C. §§ 9601 et seq.,as amended by the Superfund Amendments and Reauthorization Act of 1986, Pub. L. No. 99-499 (Oct. 17, 1986) (SARA); Resource Conservation and Recovery Act (RCRA), 42 U.S.C. §§ 6901 et seq.; the Safe Drinking Water Act (SDWA), 42 U.S.C. §§ 300h-300h-7 (Underground Injection Program), 300i (emergency powers); Section 504 of the Clean Water Act, 33 U.S.C. § 1364; and Section 303 of the Clean Air Act, 42 U.S.C. § 7603.

2. The lack of political consensus is reflected in the contradictory, if not byzantine, legislative history of Superfund. Virtually every court opinion concerning Superfund starts off with the statement that Superfund has a "well-deserved notoriety for vaguely drafted provisions and an indefinite, if not contradictory, legislative history." *Dedham Water Co.* v. *Cumberland Farms Dairy, Inc.*, 805 F. 2d 1074, 1080 (1st Cir. 1986); see also, *Artesian Water Co.* v. *New Castle County*, 659 F. Supp. 1269, 1277 n.7 (D. Del. 1987). Statements of members of Congress can be found supporting virtually any point of view. See Statement of Congressman Dingell, 132 Cong. Rec. H9562 (daily ed., Oct. 8, 1986) and Statement of Congressman Lent, *ibid.*, at H9565. The courts have filled this vacuum by interpreting Superfund in light of its public health and remedial purpose. See *United States* v. *Mottolo*, 604 F. Supp. 898, 902 (D.N.H. 1985). The general lack of consensus on the issue of what constitutes an acceptable level of risk has been noted by numerous commentators. See The Council of State Governments, Risk Management & the Hazardous Waste Problem in State Governments 15, 35, 328, 461 (prepared for the National Science Foundation, May 1985) (CSG Risk Report). The assertion that the intent of Congress in amending Superfund was clear (see presentation of Rena Steinzor at this colloquium) is simply not supported by the plain language of the statute, the rules of statutory construction, or judicial interpretations of Superfund.

3. See National Oil and Hazardous Substance Pollution Contingency Plan, 53 Fed. Reg. 51,394 (1988) (proposed rule) (Proposed NCP).

4. See evaluations presented at this colloquium; Office of Technology Assessment, Are We Cleaning Up? 10 Superfund Case Studies--Special Report (1988) (OTA-ITE-362) (OTA Cleanup Rep.); Environmental Defense Fund, et al., Right Train, Wrong Track: Failed Leadership in the Superfund Cleanup Program--A Comprehensive Environmental-Industry Report on Recent EPA Cleanup Decisions (June 20, 1988) (Right Train); and Letter from J. Winston Porter, Assistant Administrator, EPA Office of Solid Waste and Emergency Response to Congressman Eckart (October 19, 1988) (responding to critiques).

5. The author was an EPA enforcement attorney from 1978 to 1986 and has been involved with hazardous waste cases since 1979. From 1980 to 1986, he was involved primarily in negotiating and defending in court the consent decrees specifying the remedies necessary for Occidental Chemical Corporation's Hyde Park and "S" Area Landfills. See *United States* v. *Hooker Chemicals & Plastics Corp.*, 540 F. Supp. 1067 (W.D.N.Y. 1982) (Hyde Park Landfill); *United* v. *States Hooker Chemicals & Plastics Corp.*, 607 F. Supp. 1052 (W.D.N.Y.) ("S" Area Landfill), aff'd 776 F. 2d 410 (2d Cir. 1985); *United States* v. *Hooker Chemicals & Plastics Corp.*, 641 F. Supp. 1303 (W.D.N.Y. 1986). Since June 1986, he has represented private clients in, among other things, Superfund cleanup actions. The conclusions expressed in this presentation are based on the author's experience in negotiating complex technical remedies at Superfund sites.

6. Society addresses issues, such as soil and ground water remediation, voluntarily or as a result of "legal" compulsion. Voluntary actions are motivated by a desire to enhance corporate goodwill, to reduce long-term costs, to avoid personal and property injury lawsuits, to meet insurance risk avoidance requirements, or to satisfy due diligence requirements in real estate or lending transactions. Legal compulsion includes those actions required through regulatory programs, such as Superfund or the RCRA corrective action program, as well as those actions required through private litigation. This colloquium addresses solely those soil and ground water remedial actions that are required by regulatory programs.

7. The entire cleanup process is heavily dependent upon value judgments. See CSG Risk Report, supra, note 2, at 388, 395-398, 420-22, 428.

8. Policy may be incorporated into regulations or through policy statements. A policy statement does not impose any rights or obligations and genuinely leaves the agency decisionmaker free to exercise discretion, but a regulation binds EPA as well as the regulated community. See *McLouth Steel Products Corp.* v. *Thomas*, 838 F. 2d 1317, 1320 (D.C. Cir. 1988).

9. Webster's Third New International Dictionary of the English Language Unabridged (P. Gove, ed., 1976).

10. Herring and Allee, Good enough for government work: Monitoring and modeling needs in mediation. In Symposium on Monitoring, Modeling, and Mediating Water Quality at 653, 654 (published by American Water Resources Association, May 1987). The definitions of science and policy are particularly difficult to develop. Ibid., at 653.

11. Ibid., at 654.

12. Ibid. (a type I error or a false-negative).

13. See Chemical Carcinogens; A Review of the Science and Its Associated Principles, February 1985, 50 Fed. Reg. 10,372, 10,378 (1985); Guidelines for Carcinogen Risk Assessment, 51 Fed. Reg. 33,992, 33,996 (1986); (EPA Cancer Guidelines).

14. Green, The Role of Congress in Risk Management, 16 Envt. L. Rep. 10,220 (August 1986) (summarizing the congressional risk management decisions in many of the major environmental statutes) (Congressional Risk Management).

15. Holmes, Law In Science and Science In Law; reprinted in Collected Legal Papers at 210, 212 (1952).

16. E.g., the Delaney Amendment, see Section 706(b)(5)(B) of the Federal Food, Drug, and Cosmetics Act, 21 U.S.C. § 376(b)(5)(B). Also see *Public Citizen* v. *Young*, 831 F. 2d 1108, 1113 (D.C. Cir. 1987).

17. Section 121(b)(2) of Superfund, 42 U.S.C. § 9621(b)(2).

18. Sections 1421(b)(2) and 1422(c) of the Safe Drinking Water Act, 42 U.S.C. § 300h(b)(2) and 300h-1(c).

19. Green, Limitations On The Implementation Of Technological Assessment, 14 Atomic Energy L.J. 59, 82 (1972).

20. There is a point where the expense is so extravagant and the benefits so minimal or nonexistent that the policy choice may be considered arbitrary and capricious. This presentation does not address where that line is drawn.

21. The most common standard of judicial review of agency decisionmaking is the arbitrary and capricious standard. See 5 U.S.C. § 701; *Citizens To Preserve Overton Park, Inc.* v. *Volpe*, 401 U.S. 402, 416 (1971); *Baltimore Gas and Electric Co.* v. *NRDC*, 462 U.S. 87, 103 (1983).

22. Committee on the Institutional Means for Assessment of Risks to Public Health, Commission on Life Sciences, National Research Council, Risk Assessment in the Federal Government: Managing the Process (1983) (National Academy Press) (NAS Risk Assessment Rep.); CSG Risk Report, supra, note 2, at 36; opening presentation of Robert Harris at this colloquium.

23. Hellman and Hawkins, How clean is clean? The need-for action (How Clean Is Clean.) In Hazardous Waste Site Management: Water Quality Issues at 98, 101 (Report on National Research Counsel Colloquium) (National Academy Press, 1988) (WSTB Colloquium Report).

24. Ibid., at 101-105.

25. Ibid., at 101-105 and Conway, Engineering workshop. In WSTB Colloquium Report, supra, note 23, at 186-191.

26. See Congressional Risk Management, supra, note 14, at 10,220.

27. Notwithstanding the assertions of some commentators that Section 121 of Superfund clearly defines how to select remedies, no plain meaning is discernible from the language or from the legislative history. See note 2, supra. Interestingly, there is no attempt to quantify the economic impact of including a preference for permanent remedies, no less the use of maximum contaminant level goals in the long legislative history of the 1986 amendments to Superfund.

28. *Baltimore Gas and Electric Co.* v. *NRDC*, 462 U.S. at 103; see Siegel, The Aftermath of *Baltimore Gas & Electric Co.* v. *NRDC*, A Broader Notion of Judicial Deference to Agency Expertise, 11 Harv. Envt. L. Rev. 331 (1987).

29. *Industrial Union Dep't* v. *American Petroleum Inst.*, 448 U.S. 607, 656 (1980) (a plurality decision). See also *Society of the Plastics Industry, Inc.* v. *OSHA*, 509 F. 2d 1301, 1308 (2d Cir. 1975).

30. *Ethyl Corp.* v. *EPA*, 541 F. 2d 1, 28 (D.C. Cir.), cert. denied, 426 U.S. 941 (1976); *United States* v. *Vertac Chem. Corp.*, 489 F. Supp. 870, 885 (E.D. Ark. 1980). See NAS Risk Assessment Rep., supra, note 22, for a description of the risk assessment process.

31. *United States* v. *Conservation Chemical Co.*, 619 F. Supp. 162, 192, 194 (W.D. Mo. 1985) (interpreting the Superfund statute); *Environmental Defense Fund* v. *EPA*, 598 F. 2d 62, 83 (D.C. Cir. 1978).

32. See WSTB Colloquium Report, supra, note 23; CSG Risk Report, supra, note 2, at 453-454; and the presentation of Rena Steinzor at this colloquium.

33. There are many methods of determining what is an acceptable level. See, e.g., Barth, et al., Establishing and meeting ground water protection goals in the superfund program. In WSTB Colloquium Report, supra, note 23, at 22-30 with Brown, Some approaches to setting clean-up goals at hazardous wastes sites. In WSTB Colloquium Report at 34-65.

34. This approach implicitly requires a consideration of costs because the terms such as practical, feasible, and the like are not unambiguously defined and usually imply a consideration of costs.

35. These factors are articulated explicitly in Superfund. See Sections 121 and 122 of Superfund, 42 U.S.C. §§ 9621, 9622 and the Proposed NCP, supra, note 3, at 51,428-32. As matter of policy, EPA is proposing to use these factors in other similar soil and ground water cleanup decisions because of their universality. See, e.g., Solid Waste Disposal Facility Criteria, 53 Fed. Reg.

33,314, 33,376-805 (1988), and Preliminary Draft of Corrective Action for Solid Waste Management Units (SMUs) at Hazardous Waste Management Facilities (the September 12, 1988, draft of proposed federal register notice). These factors are essentially the same factors articulated in the presentation of Rena Steinzor at this colloquium.

36. Right Train, supra, note 4, at 43-46; also see Hair, Executive Vice President, National Wildlife Federation, Risk Assessment: A Gamble or a Science?, presented at the 1986 Washington Conference on Risk Assessment (Washington, D.C., October 27, 1986) (NWF--Risk Assessment); see note 38, infra, for a brief review of the requirements of SARA.

37. National Primary Drinking Water Regulations; Synthetic Organic Chemicals; Monitoring for Unregulated Contaminants, 52 Fed. Reg. 25,690, 25,693-94 (1987) (final rule).

38. See Section 106 of CERCLA, 42 U.S.C. § 9606; Section 7003 of RCRA, 42 U.S.C. § 6973; Section 1431 of the SDWA, 42 U.S.C. § 300i; Section 504 of the Clean Water Act, 33 U.S.C. § 1364; and Section 303 of the Clean Air Act, 42 U.S.C. § 7603; Congressional Risk Management, supra, note 14, at 10,220. It is beyond the scope of this paper to "prove" that Section 121 of Superfund does not require the use of MCLGs for carcinogens. Given the controversy concerning this point, however, some comment may be helpful. Section 121(d) states that soil and ground water remedial actions should achieve "legally applicable or relevant and appropriate standard, requirement, criteria, or limitation" (called an ARAR), i.e., "a level or standard of control which at least attains Maximum Contaminant Level Goals established under the Safe Drinking Water Act and water quality criteria established under section 304 or 303 of the Clean Water Act, *where such goals or criteria are relevant and appropriate under the circumstances of the release or threatened release.*" Ibid. at § 9621(2)(A) (emphasis added). The legislative history is either unhelpful or contradictory, see note 2, supra. The question of what risk level to use at Superfund sites, therefore, has been delegated

to the discretion of EPA. This discretion must be exercised consistent with EPA's past practice and policy. The ARAR concept, however, has been EPA policy since 1984 (e.g., see memorandum from L. Thomas, assistant administrator for solid waste and emergency response, to deputy administrator [August 20, 1984]) and has been part of EPA's formal Superfund decisionmaking since November 1985 (see National Oil and Hazardous Substances Pollution Contingency Plan, 50 Fed. Reg. 47,912 (1985) [final rule]). EPA has consistently used MCLs, not MCLGs, or a site-specific risk assessment to determine the ground water cleanup standard for carcinogens. It is *not* appropriate (not to mention not feasible) to use zero as a cleanup standard. EPA does use MCLGs as cleanup levels for noncarcinogens because they are feasible and health protective. The concept of accepting some residual concentration of hazardous chemical in the environment is "deeply established in EPA's regulations." Underground Injection Control Program: Hazardous Waste Disposal Injection Restrictions; Amendments to Technical Requirements for Class I Hazardous Waste Injection Wells; and Additional Monitoring Requirements Applicable to all Class I Wells, 53 Fed. Reg. 28,118, 28,122 (1988) (final rule). Congress was well aware of the NCP and EPA's interpretation of Superfund and Congress did not explicitly change the statute. Congress at least has acquiesced in this interpretation. See generally *Young* v. *Community Nutrition Institute*, 106 S.Ct. 2360, 2364 (1986).

39. See *Young* v. *Community Nutrition Institute*, 106 S.Ct. 2360 (1986).

40. See NWF-Risk Assessment, supra, note 36; Proposed NCP, supra, note 3, at 51,438.

41. See Washington Department of Ecology, Final Cleanup Policy--Technical (1984) (Wash. Cleanup Policy).

42. See NAS Risk Assessment Rep., supra, note 22.

43. Proposed NCP, supra, note 3, at 51,433.

44. Office of Ground-Water Protection, EPA, Guidelines for Ground-Water Classification Under the EPA Ground-Water Protection Strategy at 39, 41 (Nov. 1986) (final draft).

45. Ibid., at 4.

46. Proposed NCP, supra, note 3, at 51,433.

47. Ibid., at 51,438, 51,441.

48. Ibid., at 51,441-43.

49. See 40 C.F.R. § 141.12(c).

50. See, National Primary Drinking Water Regulations; Synthetic Organic Chemicals; Monitoring for Unregulated Contaminants, 52 Fed. Reg. 25,690 (1987) (c.f. Table 1 at 25,694 to Table 2 at 25,700).

51. Proposed NCP, supra, note 3, at 51,441-43.

52. See ibid., at 51,426. There are five exceptions to the requirement to meet ARARs. See Section 121(d) of SARA, 42 U.S.C. § 9621(d).

53. EPA's water quality criteria documents do not select a water concentration that is acceptable. Rather, these documents perform a risk assessment and calculate the surface water concentration that corresponds to the 10^{-5}, 10^{-6}, and 10^{-7} risk levels, assuming bioconcentration of the chemicals in fish. These calculations must be converted to apply to groundwater.

54. See Section 121 of CERCLA, 42 U.S.C. § 9621.

55. Proposed NCP, supra, note 3, at 51,422-23.

56. See Baes and Marland, Oak Ridge National Laboratory, Evaluation of Cleanup Levels for Remedial Action at CERCLA Sites Based on a Review of EPA Records of Decision (ORNC-6479, Jan. 1989) (CERCLA Cleanup Decisions) (this is one of the few balanced reviews of the issue); Right Train, supra, note 4, and OTA Cleanup Rep., supra, note 4.

57. CERCLA Cleanup Decisions, supra, note 56, at 39, Table 17.

58. See Superfund Record of Decision, Geiger (C&M Oil) Site, S.C. (June 1987), and Superfund Amended Record of Decision, Rose Township, Mich. (September 1987).

59. Right Train, supra, note 4, at 43.

60. See ibid., at 43; CERCLA Cleanup Decisions, supra, note 56; OTA Cleanup Rep., supra, note 4.

61. See NAS Risk Assessment Rep., supra, note 22, and EPA Cancer Guidelines, supra, note 13. One recent report suggests that the one-hit model used by EPA may underestimate lifetime risk of exposure to low concentrations based on statistical analyses of animal bioassay data (see Bailar, Crouch, Shaikh, and Spiegelman, One-Hit Models of Carcinogenesis: Conservative or Not?; 8 Risk Analysis 485 [1988]). Other scientific studies have reached the opposite conclusion. For example, comparisons of epidemiology and animal data at high doses (exposure levels that correspond to a risk level of 25%) for 23 chemicals indicated that the animal data *overestimated* the human risk by an order of magnitude (see Clement Assoc., Investigation of Cancer Risk Assessment Methods. *Summary* [EPA/600/6-87/007a September 1987]). The significance of the Bailar study has yet to be determined.

62. Upton, Are there thresholds for carcinogenesis? The thorny problem of low-level exposure. In Living in a Chemical World: Occupational and Environmental Significance of Industrial Carcinogens, Annals of New York Academy of Sciences at 863 (1988); Ames, Six Common Errors Relating To Environmental Pollution, 7 Regulatory Toxicology and Pharmacology 379 (1987). Also see, presentation of Robert Harris at this colloquium for a list of sites where health effects may have occurred.

63. See Kimbrough and Simonds, Compensation of Victims Exposed to Environmental Pollutants, Brief Communication, 41 Archives of Environ. Health 185, 187 (May/June 1986).

64. NAS Risk Assessment Rep., supra., note 22. William Wallace in his presentation at this Colloquium argues that there is an unacceptable level of uncertainty in performing a risk assessment at Superfund sites. Yet, most of these uncertainties are no greater than in hundreds of other regulatory decisions.

65. EPA Cancer Guidelines, supra, note 13, at 33,998.

66. For example, see Cosmetics; Proposed Ban on the Use of Methylene Chloride as an Ingredient of Aerosol Cosmetic Products, 50 Fed. Reg. 51,551 (1985), which indicates that EPA's estimate of the risk from the same level of exposure would be 26 times higher than the Food and Drug Administration's estimate.

67. E.g., the definition of what is a hazardous waste uses a point of exposure 500 feet downgradient from the point of disposal, yet many Superfund cleanups use a point directly underneath the landfill. See Hazardous Waste Management System; Identification and Listing of Hazardous Waste; Notification Requirements; Reportable Quantity Adjustments; Proposed Rule, 51 Fed. Reg. 21,648, 21,666 (1986).

68. If one assumes that there are 10 carcinogens present, then the risk level for each chemical would be one-tenth the value if just one chemical were present.

69. The amount of chemical that comes off the soil and biologically interacts varies depending upon the chemical and soil type. This variation could be a factor of 100 or more. See Paustenbach, A methodology for evaluating the environmental and public health risks of contaminated soil. In Petroleum Contaminated Soils--Volume I: Remediation Techniques, Environmental Fate, Risk Assessment at 225, 236 (1988) (Contaminated Soils).

70. It is ludicrous to assume that a child lives in the middle of an industrial plant and eats the soil at the site. Industrial sites, therefore, use different exposure assumptions. E.g., see Contaminated Soils, supra, note 69, at 239.

71. See summary of acceptable risks in National Emission Standards for Hazardous Air Pollutants; Benzene Emissions From Maleic Anhydride Plants, Ethylbenzene/Styrene Plants, Benzene Storage Vessels, Benzene Equipment Leaks, and Coke By Product Recovery Plants, 53 Fed. Reg. 28,496, 28,515, 28,523, 28,547-49, (1988) (Proposed Benzene Regs.) (proposing to accept risks as great as one in one thousand, 10^{-3}); Rodricks, Wrenn, and Brett, Determination of Significant Risk in the Regulation of Chemical Carcinogens, ox. L. Rep. (BNA) 1337 (April 29, 1987) (Significant Risks); Travis, Richter, Crouch, Wilson, and Klema, Cancer Risk Management: A Review of 132 Federal Regulatory Decisions, 21 Env't Sci. Tech. 415, 419 (1987) (Review of Decisions) (a range of risks from one in one thousand, 10^{-3}, to one in ten million, 10^{-7}); Travis and Hattemer-Frey, Determining an acceptable level of risk, 22 Env't. Sci. & Tech. 873, 875 (1988) (Acceptable Level) (calculating a median residual risk after federal regulation of one in one hundred thousand, 10^{-5}).

72. Acceptable Level, supra, note 71, at 875.

73. Review of Decisions, supra, note 71; Significant Risks, supra, note 71; Acceptable Level, supra, note 71; Proposed NCP, supra, note 3, at 51,426.

74. Compare the EPA point of departure (10^{-6}) to Proposed Benzene Regs, supra, note 71.

75. Morgan, Risk assessment and risk management decision-making for chemical exposure. In Environmental Exposure from Chemicals, Volume II, at 107, 140 (CRC Press, 1985) (Risk Perception).

76. How Clean Is Clean, supra, note 23, at 7.

77. Ibid.

78. As far as the author is aware, there is no acceptable, reliable, and easily administered test to measure the bioavailability of chemicals on soils. Research has been accelerating in this area. Until such a test is developed, national soil standards would be infeasible. Therefore, EPA would need to develop soil standards on a case-by-case basis.

79. As a practical matter, EPA has adopted national standards for ground water by specifying that EPA drinking water standards (MCLs) must be met in ground water after the remedy is implemented. Proposed NCP, supra, note 3, at 51,441.

80. See EPA, PCB Sediment Decontamination--Technical/Economic Assessment of Selected Alternative Treatments (EPA/600/2-86/112 December 1986). The cost is also a function of the cleanup level since this determines the quantity of ground water or soil to be treated.

81. Proposed NCP, supra, note 3, at 51,427, and Section 311(b) of CERCLA, 42 U.S.C. § 9660.

82. E.g., Section 121 of Superfund, 42 U.S.C. § 9621.

83. Proposed NCP, supra, note 3, at 51,244, 51,438.

84. Ruckelshaus, Managing Environmental Risks: The Role of Trial Lawyers In Effecting Reform, 1 Tox. L. Rep. (BNA) 1192, 1193 (March 25, 1987) (Ruckelshaus).

85. Fullerton, Mangan, and Matey, Impact analysis of SARA on the CERCLA remediation program. In Superfund '88 Proceedings of the 9th National Conference at 598, 600 (The Hazardous Materials Control Research Institute, 1988).

86. E.g., see EPA, Guidelines for Performing Regulatory Impact Analysis (EPA/230/01-84-0003, 1983) (Reg. Impact Guidance), and presentation of Glenn Anderson at this colloquium.

87. Gillette and Hopkins, Federal Agency Valuations of Human Life, A Report to the Administrative Conference of the United States at 2 (July 7, 1988) (Agency Valuations).

88. Ibid., at 1.

89. Reg. Impact Guidance, supra, note 86.

90. Agency Valuations, supra, note 87, at 2-3; Review of Decisions, supra, note 71.

91. McKone, The Implicit Valuation of Environmental Cancer by United States Regulatory Agencies, 1 Tox. L. Rep. (BNA) 442, 446 (September 24, 1986).

92. See Stewart, *Economics, Environment, and the Limits of Legal Control,* 9 Harv. Envtl L. Rev. 1 (1985) (Limits of Legal Control), for a review of the unintended and unnecessary adverse economic impacts of the Clean Water and Clean Air Act. See particularly at 6-9.

93. This statement should not be misinterpreted as a dismissal or lack of concern for potential health effects from very low levels of exposure. There are sites where exposure levels have been at levels typically only used in animal studies. See Harris, et al., Adverse health effects at a Tennessee hazardous waste disposal site. In Andelman and Underhill, Health Effects from Hazardous Wastes Sites at 221 (1987) (Health Effects). Nonetheless, despite years of extensive research, there are few well documented studies demonstrating people that have been harmed by exposure to low levels of such chemicals. See Heath, Centers for Disease Control, Assessment of health risks at Love Canal. In Health Effects at 211, 219 (stating that there are no "striking increases in illness occurrence" among the residents who lived near Love Canal). But see Presentation of Robert Harris at this colloquium.

94. There is no doubt there is a public and congressional mandate to expedite soil and ground water cleanups. However, soil and ground water cleanups cannot be mass produced. More time--not less--should be taken to select remedies, perform field studies on treatment technologies, and gather adequate data upon which to base a remedial decision.

95. CERCLA Cleanup Decisions, supra, note 60.

96. NWF--Risk Assessment, supra, note 36, at 5.

97. F. Fields, General Counsel, St. Mary's Health System, Inc. Effective Risk Communications Strategies, at 9, presented at 1986 Washington Conference on Risk Assessment (Arlington VA, Oct. 27-28, 1986) (Fields Presentation).

98. Ibid.

99. Risk Perception, supra, note 75, at 136.

100. This demand has been made at virtually every landfill where public concern has been expressed.

101. Ruckelshaus, supra, note 84, at 1193, and Bachmann, Soil Cleanup Policy in the USA, Report of a Study Trip, February 1 to March 11, 1988 (July 1988) (German Marshall Fund).

102. 42 U.S.C. § 6973; Section 113 of Superfund, 42 U.S.C. § 9613; 40 C.F.R. § 300.67; 28 C.F.R. § 50.7; EPA, Community relations activities at Superfund enforcement sites--interim guidance. In Community Relations in Superfund: A Handbook at Chapter 6 (1985).

103. Office of Technology Assessment, Superfund Strategy 237 (1985); Quarles, The 1987 Airlie Superfund Conference of the Superfund Settlements Project, 2 Tox. L. Rep. (BNA) 820, 821 (December 23, 1987); Italiano, Staller, and Sullivan, Expediting Waste Site Cleanups by Initiating Citizen Settlements, 3 Tox. L. Rep. (BNA) 1062, 1064 (February 1, 1989).

104. Ruckelshaus, supra, note 84, at 1194; CSG Risk Report, supra, note 2, at 452 (citing Ronge).

105. Ruckelshaus, supra, note 84, at 1194.

106. Prior statutes, such as the Clean Water Act and the Clean Air Act, generally required the promulgation of national standards. These nationally applicable standards allowed EPA to focus its scientific resources and expertise on a one time effort to develop these standards. In the cool, relatively rational atmosphere of a rulemaking, all relevant factors, including costs, could be considered adequately. EPA regional offices and states implemented these programs by issuing site-specific permits. Most of the "hard" questions were resolved by the national standards. Even where "best professional judgment" permit conditions were imposed, these conditions typically involved determining what was technologically feasible.

107. General Accounting Office, Report to the Congress: Superfund Improvements Needed in Work Force Management (GAO/RCED-88-1 1987) (GAO Report).

108. McGarity, Risk and Trust: The Role of Regulatory Agencies, 16 Envtl. L. Rep. 10,198, 10,200 (August 1986).

109. Mintz, Agencies, Congress and Regulatory Enforcement: A Review of EPA's Hazardous Waste Enforcement Effort, 1970-1987, 18 Envtl. L. 683, 689-705 (1988) (EPA Review 1970-1987).

110. NWF--Risk Assessment, supra, note 36, at 7.

111. A remarkably broad spectrum of commentators acknowledges the faults of the Gorsuch/Burford EPA era. See Clark, Environmental protection under Reagan: What went wrong. In Protecting the Environment: A Free Market Strategy at 19 (Heritage Foundation, 1986) (for a conservative critique by a former associate administrator at EPA under the Gorsuch/Burford); Subcommittee on Oversight and Investigations of the Committee on Energy and Commerce, 98th Cong., 2d Sess., Investigation of the EPA, Report on the President's Claim of Executive Privilege over EPA Documents, Abuses in the Superfund Program, and Other Matters, (Comm. Print 1984) (for the congressional perspective); Wolf, Hazardous Waste Trials and Tribulations, 13 Envtl. L. 367 (1983) (an environmentalist's perspective); EPA Review 1970-1987, supra, note 108, at 715-743 (a relatively objective review by a law professor who formerly was an EPA enforcement attorney). Citations to these reports and articles should not be construed as agreement with all of the charges and accusations made.

112. EPA Review 1970-1987, supra, note 109, at 754-758.

113. Among the reasons for this distortion is the concern of EPA and the Department of Justice's enforcement officials that response costs may not be recovered fully if there are only trivial, remote risks presented by the site.

114. Office of Policy, Planning and Evaluation, Program Evaluation Division, Evaluation of Implementation of Risk-Based Decisionmaking in RCRA, Annotated Briefing at 17 (January 1987) (EPA RCRA Report).

115. Limits of Legal Control, supra, note 92, at 3; Office of Solid Waste and Emergency Response, State Participation in the Superfund Program, CERCLA Section 301(a)(1)(E) Study at 1-1 (December 1984) (the report required by Section 301(a)(1)(E) of Superfund, 42 U.S.C. § 9601(a)(1)(E)).

116. GAO Report, supra, note 107; International Ground Water Modeling Center, Holcomb Research Institute, U.S. EPA Ground-water Modeling Policy Study Group: Report of Findings and Discussion of Selected Ground-water Modeling Issues, at 5 (November 1986). EPA RCRA Report, supra, note 114, at 17.

117. Limits of Legal Control, supra, note 92, at 3.

118. Proposed NCP, supra, note 3, at 51,454-59.

119. See intervention motions filed in *United States* v. *Fairchild Industries, Inc.*, Civ. Act. No. R-88-2933 (D. Md. November 1988); *United States Shell* v. *Oil Corporation*, Civ. Act. Nos. 83-2386, 83-C-2379, and 86-2524 (D. Colo. July 5, 1988); *United States* v. *Akzo Coatings of America et al.*, Civ. Act. No. 88 CV73784-DT (E.D. Mich. 1989); *United States* v. *Texas Eastern Transmission Corporation*, Civ. Act. No. 88-1917 (S.D. Tex., filed August 11, 1988).

120. See Burger, State, Federal Conflicts During Negotiations of Site Remedies in CERCLA Injunctive Actions, 2 Tox. L. Rep. (BNA) 160 (July 8, 1987).

121. See Wash. Cleanup Policy, supra, note 41.

122. Proposed NCP, supra, note 3, at 51,457.

123. Ibid., at 51,458.

124. Ibid., at 51,511 (to be codified at 40 C.F.R. § 300.515(f)(3)).

125. It is beyond the scope of this presentation to explore the merits of such lawsuits. There are a number of potential defenses available to such contractors.

126. Office of Technology Assessment, Assessing Contractor Use in Superfund--A Background Paper (1989) (OTA-BP-ITE-51). Citation to this paper should not be construed as agreement with any of the conclusions or agreement with the accuracy of the review.

127. See Superfund Record of Decision, Liquid Disposal, Mich. Responsiveness Summary at 31-32 (EPA/ROD/RO5-87/051 September 1987) which cites an affidavit by Dr. James Dragun, a former E.C. Jordan employee, alleging that EPA and the state of Michigan ordered him to change the assumptions in an exposure assessment in order to justify a particular remedial action. EPA acknowledges that they instructed Dr. Dragun to change his assessment but denies that the rationale was to justify a particular remedy. Such "misunderstandings" also undermine EPA's credibility with the regulated community.

128. E.g., see Jorgenson and Kimmel, Environmental Citizen Suits: Confronting the Corporation (BNA 1988).

129. See note 2, supra.

130. The characterization of such sites as "national sacrifice" areas, although a catchy slogan, does not further the debate and simply flies in the face of reality.

131. See Note, Of Reliable Science: Scientific Peer Review, Federal Regulatory Agencies, and the Courts, 7 Va. J. of Nat. Res. 27, particularly 29 n.9 (1987) (authored by T. S. Burack).

132. Numerous other commentators have analyzed the concrete steps that could be taken. E.g., Krickenberger and Rekar, Superfund Settlements: Breaking the Logjam, 19 Env't Rep. (BNA) 2384 (March 10, 1989). It is beyond the scope of this paper to summarize those suggestions. A prerequisite to implementing any such reforms is a more credible and more innovative EPA.

133. Risk Perception, supra, note 75, at 141.

134. NWF--Risk Assessment, supra, note 36, at 6.

135. Fields Presentation, supra, note 97, at 15.

136. *United States* v. *Hooker Chemicals & Plastics Corp.*, 641 F. Supp. at 1311.

APPENDIXES

Appendix A

Biographical Sketches of Principal Contributors

RICHARD A. CONWAY, Chairman, received his B.S. in 1953 from the University of Massachusetts and an S.M. in sanitary engineering from the Massachusetts Institute of Technology in 1957. His expertise is in water treatment, aquatic fate processes, and hazardous waste management. Presently he is with the Research and Engineering Technology Department of Chemicals and Plastics Group of Union Carbide Corporation. Mr. Conway is a member of the National Academy of Engineering. He has authored book chapters and 30 technical papers related to pollution control technology.

GLEN D. ANDERSON is a senior economist of the Environmental Law Institute in Washington, D.C. Currently, he is conducting research on the use of market mechanisms to address nonpoint pollution concerns and on a variety of Superfund issues. He recently prepared papers on Superfund remedial action research needs and a classification system for underground storage tank regulations. Dr. Anderson's other professional duties include serving as associate editor for the *Journal of Economics and Environmental Management* and as a reviewer for *Land Economics, American Journal of Agricultural Economics, Coastal Zone Management Journal,* and the *Marine Resource and Economics Journal.* He received a B.A. in economics from the University of Washington in 1977 and his M.A. in 1980, and Ph.D. in 1981 in agricultural economics from the University of Wisconsin. Dr. Anderson also has taught graduate resource and environmental economics courses at George Mason University since 1986.

LARRY W. CANTER received his B.A. in civil engineering from Vanderbilt University in 1961; his M.S. in sanitary engineering from the University of Illinois in 1962, and his

Ph.D. in environmental health engineering from the University of Texas, Austin, in 1967. Dr. Canter currently is Sun Company Professor of Ground Water Hydrology, School of Civil Engineering and Environmental Science, and the director of the Environmental and Ground Water Institute, University of Oklahoma. He is also codirector of the National Center for Ground Water Research (Consortium of University of Oklahoma, Oklahoma State University, and Rice University). Dr. Canter has been a consultant to several U.S. and international industries, governmental groups, and engineering firms since 1967.

CHRISTOPHER J. CORBETT currently is the technical coordinator for the Hazardous Waste Management Division, U. S. Environmental Protection (EPA), Region III (Pennsylvania, Delaware, Maryland, Virginia, West Virginia, and the District of Columbia). He is responsible for the development and implementation of the division's Technology Transfer Program. He was previously a project manager in EPA's Superfund Program. Before joining EPA, Mr. Corbett was an assistant to the chief of the Environmental/Natural Resources Division, Department of the Army, at Fort Dix, New Jersey. He began his professional career as a geophysicist with the Gulf Oil Corporation in Midland, Texas. Mr. Corbett holds a B.S. in earth science from the State University of New York at Stonybrook.

DOUGLAS C. DOWNEY is a senior research engineer assigned to the Air Force Engineering and Services Center Laboratory, Tyndall Air Force Base, Florida. He is a 1977 graduate of the U.S. Air Force Academy and attended Cornell University where he received an M.S. degree in civil and environmental engineering in 1981. Mr. Downey is responsible for the development and testing of soil and ground water decontamination technologies for the cleanup of contaminated sites at over 200 Air Force facilities. His most recent projects include field demonstrations of enhanced biodegradation, in situ soils washing, radio frequency thermal soil decontamination, and soil venting. In addition to his Air Force duties, Mr. Downey is a registered professional engineer practicing in the state of Florida.

ROBERT H. HARRIS is cofounder of the Environ Corporation and a graduate of West Virginia University. He received his M.S. degree in environmental health engineering from the California Institute of Technology and a Ph.D. in environmental sciences and engineering from Harvard University. Dr. Harris has over 20 years of experience in the area of environmental health, with a particular specialty on water and air pollution issues. Dr. Harris was a presidential appointee to the Council on Environmental Quality. He also has served as a consultant to the U.S. Department of Justice, the National Science Foundation, and the National Research Council. He has written and lectured broadly on the topics of water pollution, health, and the environment, and he has offered expert testimony on these subjects before the U.S. Senate and House of Representatives.

DAVID R. LINCOLN obtained his Ph.D. in biochemistry from the University of Oregon Health Sciences Center and his B.A. in chemistry from the University of California, San Diego. Currently, he is assistant discipline group director for fate and effects for CH2M Hill's environmental sciences discipline. He specializes in the application of risk analyses and management techniques to chemical contamination investigations. His broad technical background includes chemistry, biology, biochemistry, environmental science, and simulation modeling. Dr. Lincoln has been involved extensively in the development of a new approach, the observation method, for the remediation of hazardous waste sites. He has served on several government advisory committees, including one advising the development of an industrialized county in Pennsylvania. Dr. Lincoln served on the Washington State Science Advisory Board to advise the Department of Ecology on technical issues related to hazardous waste site remediation. He has been a member of the environmental release subcommittee of the EPA's Biotechnology Science Advisory Committee. Dr. Lincoln also is a member of the American Association for the Advancement of Science, American Association for Artificial Intelligence, and the Federation of American Scientists.

DOUGLAS M. MACKAY is an assistant professor in the Environmental Science and Engineering Program at the University of California School of Public Health's Division of Environmental and Occupational Health Sciences. Dr. Mackay was a research associate in the Department of Civil Engineering, Stanford University, for 5 years, managing two interdisciplinary research projects on ground water contamination and bioreclamation. Dr. Mackay received his M.S. and Ph.D. in civil engineering from Stanford University in 1973 and 1981. He has served as an expert witness at hearings held by the U.S. House of Representatives on the B.K.K. Hazardous Waste Facility in West Covina, California, and by the Senate on EPA's proposed hazardous waste land disposal restrictions. Dr. Mackay is a member of the International Technical Advisory Committee of the International Water Modeling Center at Holcomb Research Institute (Butler University). Dr. Mackay's research focuses on field studies of transport and fate or organic chemicals in ground water and ground water decontamination technologies.

PERRY L. McCARTY obtained his Sc.D. in sanitary engineering from MIT in 1959. He has been a faculty member of the Department of Civil Engineering at Stanford University since 1962, and from 1979 to 1985 he was departmental chairman. From 1962 to 1967 he was an associate professor, from 1967 to 1975 he was a professor, and since that time has served as Silas H. Palmer Professor of Civil Engineering. He has been involved with ground water recharge and water quality studies for several years in California and elsewhere. Dr. McCarty is a member of the National Academy of Engineering and has either chaired or been a member of many National Research Council boards and committees.

GLENN PAULSON received a B.A. in chemistry from Northwestern University in 1963 and his Ph.D. in environmental sciences and ecology from Rockefeller University in 1971. He is currently director of the Center for Hazardous Waste Management at the Illinois Institute of Technology. Dr. Paulson's technical areas include hazardous waste management, environmental chemistry, environmental toxicology, and environmental policy. He is author or coauthor of numerous journal articles, book chapters, and encyclopedia references in his areas of expertise and has been a member of several National Research Council study groups.

RENA I. STEINZOR is a counsel to the Washington, D.C., law firm of Spiegel & McDiarmid. Ms. Steinzor's practice concentrates in the legislative and environmental areas. She is the project manager for an *Environmental Compliance Manual* written by Spiegel & McDiarmid and the engineering consulting firm of R. W. Beck & Associates for the American Public Power Association. She advises the National League of Cities regarding pending legislation and represents the Environmental Policy Institute in EPA's proceedings to withdraw the state of North Carolina's authority to enforce the Resource Conservation and Recovery Act. Ms. Steinzor is a 1976 graduate from Columbia Law School and a 1971 graduate of the University of Wisconsin.

WILLIAM A. WALLACE is the director of hazardous waste management for CH2M Hill. He is responsible for the direction of the firm's hazardous waste management business nationwide. He also is a member of CH2M Hill's Board of Directors. Mr. Wallace holds a B.S. in chemical engineering from Clarkson University and a M.S. in management from Rensselaer Polytechnic Institute. He has over 20 years of professional experience, including 13 years with the public and private sector in hazardous and solid wastes. He has testified on hazardous waste policy matters before four subcommittees of the U.S. House of Representatives and the Colorado State General Assembly. He served on the U.S. Congress Office of Technology Assessment Advisory Panel for the report "Superfund Strategy" and now heads the Technical Standards Committee of the Hazardous Waste Action Coalition. Mr. Wallace has presented numerous papers and lectured at more than 20 seminars for industry and government.

WILLIAM J. WALSH is a partner in the Washington, D.C., office of Pepper, Hamilton & Scheetz. He has represented clients at Superfund sites, in permit proceedings, and in toxic tort litigation. Mr. Walsh has had extensive experience in placing novel or complex scientific issues in the relevant legal context; leading multidisciplinary teams of lawyers and experts in negotiating innovative and health-protective, yet cost-effective, remedial actions; and in understanding and using the risk assessment process. From 1978 to 1986 (when he joined the firm), he worked as an EPA attorney in the Office of Water Enforcement, on the Hazardous Waste Task Force, and in the Office of Enforcement and Compliance Monitoring--Waste. He was lead EPA counsel on the four precedent-setting lawsuits involving hazardous waste: the Love Canal, Hyde Park, "S" Area, and 102nd Street landfills. He became chief of the National Projects Branch, with overall responsibility for these and other matters. He graduated cum laude from Manhattan College in physics in 1968 and received his law degree and membership in the Order of the Coif in 1978 from George Washington University School.

STEPHEN R. WASSERSUG currently is the acting deputy regional administrator, EPA, Region III. Mr. Wassersug's responsibilities include management of the region's hazardous waste, water, air, and environmental services programs. He has served as the director of the Air Division, Water Division, Enforcement Region III and is currently a member of numerous agency-wide councils and committees. Prior to joining EPA in 1970, Mr.

Wassersug spent 4 years as both a commissioned officer with the U.S. Public Health Service and a regional air pollution control director with the U.S. Department of Health, Education, and Welfare. He has served also with local and state environmental agencies since 1964. He is currently an adjunct professor at Temple University and has recently published "European Study on Risk and Public Policy," resulting from a fellowship with the German Marshall Fund.

MARCIA E. WILLIAMS is divisional vice-president of environmental policy and planning for Browning-Ferris Industries. She is responsible for environmental planning and evaluation, regulatory analysis, and liaison with state environmental agencies and other environmental organizations. Ms. Williams is also vice-president of environmental and regulatory affairs for CECOS International, Inc., the BFI subsidiary responsible for hazardous waste treatment, storage, and disposal. Ms. Williams holds a B.S. in math and physics from Dickinson College.

Appendix B

Colloquium Attendees

GLEN D. ANDERSON, Environmental Law Institute, Washington, D.C.
CHARLES ANDREWS, S. S. Papadopulos & Associates, Inc., Rockville, Maryland
WILLIAM S. BIVINS, Federal Emergency Management Agency, Washington, D.C.
CHARLES BOHAC, Tennessee Valley Authority, Chattanooga, Tennessee
EDWARD J. BOUWER, The Johns Hopkins University, Baltimore, Maryland
BRUCE BOWMAN, American Petroleum Institute, Washington, D.C.
MARILYN BRACKEN, Metcalf and Eddy, Chevy Chase, Maryland
EDWARD BRYAN, National Science Foundation, Washington, D.C.
STEPHEN J. BURGES, University of Washington
LARRY CANTER, University of Oklahoma, Norman
RICHARD CASIAS, Kennedy, Jenks & Chilton, Bakersfield, California
DONALD L. CHERY, JR., U.S. Nuclear Regulatory Commission, Washington, D.C.
JACK CHRISTOPHER, Bureau of Reclamation, Denver, Colorado
RICHARD A. CONWAY, Union Carbide Corporation, South Charleston, West Virginia
CHRISTOPHER J. CORBETT, U.S. Environmental Protection Agency, Philadelphia, Pennsylvania
STEPHEN R. CORDLE, U.S. Environmental Protection Agency, Washington, D.C.
SHEILA D. DAVID, National Research Council, Washington, D.C.

ROBERT DAY, Renewable Natural Resources Foundation, Bethesda, Maryland
RODNEY DEHAN, Department of Environmental Regulation, Tallahassee, Florida
DOUGLAS C. DOWNEY, Tyndall Air Force Base, Florida
CHRIS ELFRING, National Research Council, Washington, D.C.
LOIS EPSTEIN, Environmental Defense Fund, Washington, D.C.
GERALD FEDER, U.S. Geological Survey, Reston, Virginia
MARY GEARHART, Geraghty & Miller, Inc., Denver, Colorado
JENNIFER HALEY, U.S. Environmental Protection Agency, Washington, D.C.
ANITA A. HALL, National Research Council, Washington, D.C.
CLINTON W. HALL, U.S. Environmental Protection Agency, Ada, Oklahoma
WILLIAM HANSON, U.S. Environmental Protection Agency, Washington, D.C.
JAMES P. HEANEY, University of Florida, Gainesville
R. KEITH HIGGINSON, Department of Water Resources, Boise, Idaho
JOEL HIRSCHHORN, Office of Technology Assessment, Washington, D.C.
PATRICK HOLDEN, U.S. Environmental Protection Agency, Washington, D.C.
MICHAEL C. KAVANAUGH, James M. Montgomery Consulting Engineers, Oakland, California
HOWARD C. KUNREUTHER, University of Pennsylvania, Philadelphia
DAVID R. LINCOLN, CH2M Hill, Bellevue, Washington
DOUGLAS M. MACKAY, University of California, Los Angeles
G. RICHARD MARZOLF, Murray State University, Kentucky
PERRY L. McCARTY, Stanford University, California
ROBERT R. MEGLEN, University of Colorado, Denver
WENDY MELGIN, National Research Council, Washington, D.C.
JAMES W. MERCER, GeoTrans, Inc., Herndon, Virginia
VERNON MYERS, U.S. Environmental Protection Agency, Washington, D.C.
EDGAR H. NELSON, U.S. Department of Agriculture, Washington, D.C.
BETTY H. OLSON, University of California, Irvine
FRANK OSTERHOUDT, U.S. Department of the Interior, Washington, D.C.
MELIH OZBILGIN, James M. Montgomery Consulting Engineers, Walnut Creek, California
STEPHEN D. PARKER, National Research Council, Washington, D.C.

BRENT PAUL, U.S. Department of the Interior, Washington, D.C.
GLENN PAULSON, Center for Hazardous Waste Management, Chicago, Illinois
P. SURESH CHANDRA RAO, University of Florida, Gainesville
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JOSEPH V. RODRICKS, Environ, Inc., Washington, D.C.
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WILLIAM J. WALSH, Pepper, Hamilton & Scheetz, Washington, D.C.
C. H. WARD, Rice University, Houston
STEPHEN R. WASSERSUG, U.S. Environmental Protection Agency, Philadelphia, Pennsylvania
DAVID L. WEGNER, Bureau of Reclamation, Salt Lake City, Utah
HEATHER WICKE, Environmental Law Institute, Washington, D.C.
MARCIA E. WILLIAMS, Browning-Ferris Industries, Inc., Washington, D.C.
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