Technical Report IRRP-93-1
June 1993

US Army Corps of Engineers
Waterways Experiment Station

Installation Restoration Research Program

Army Groundwater Modeling Use and Needs Workshop

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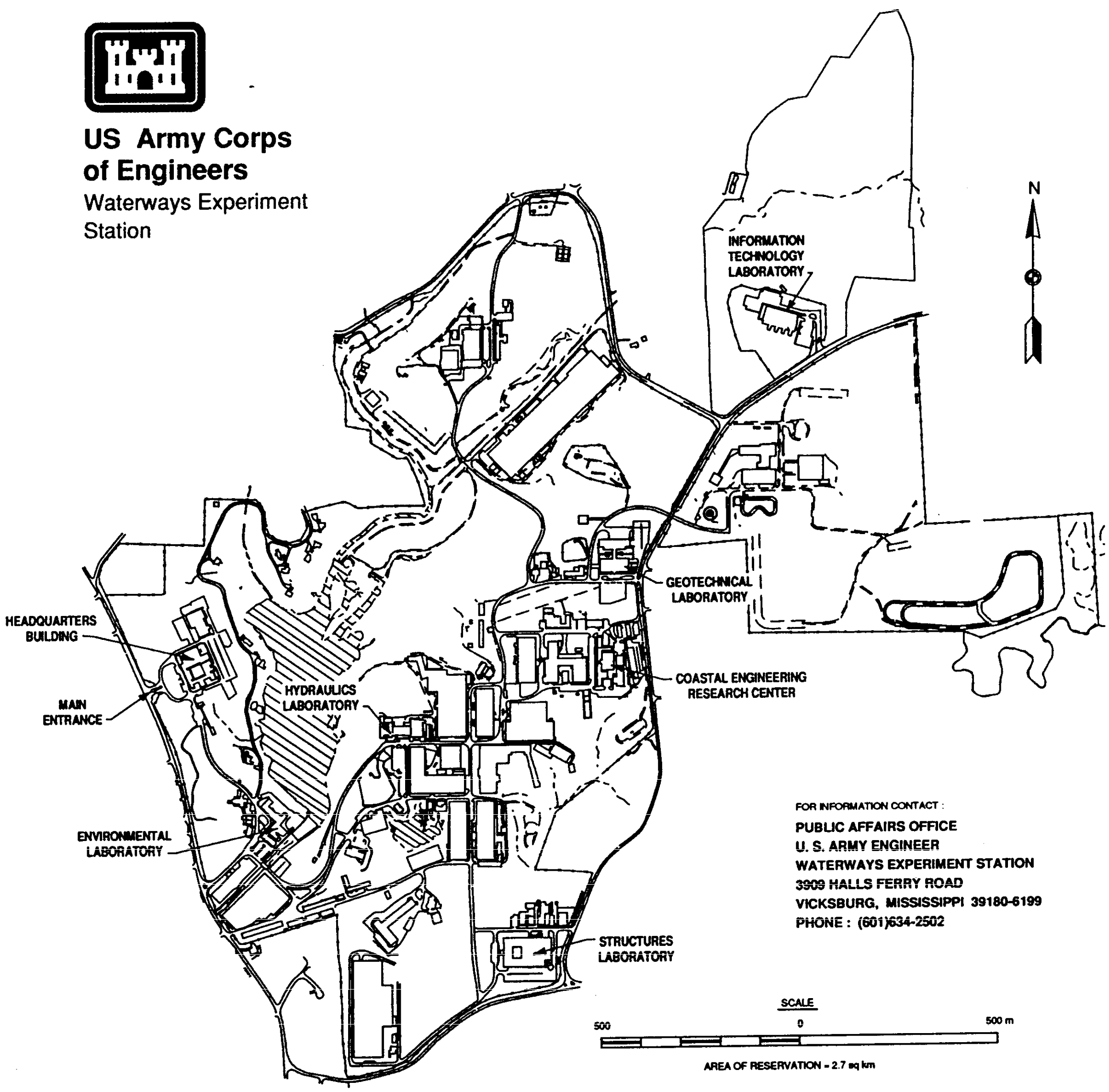
US Army Corps of Engineers
Waterways Experiment Station



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Contents

Preface

The U.S. Army Engineer Waterways Experiment Station (WES); the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE); and the U.S. Army Environmental Center (AEC; formerly the U.S. Army Toxic and Hazardous Materials Agency) cosponsored the workshop that resulted in this report. The workshop, held in Denver, CO, on 30 March-1 April 1992, included a technical tour of Installation Restoration (IR) activities at the Rocky Mountain Arsenal (RMA). USACE gratefully acknowledges the support of the Commander, RMA, and his staff throughout the course of this workshop.

The workshop objectives were to determine the following: (a) the extent and specific nature of groundwater flow and contaminant transport models in Army hazardous and toxic waste site remediation work; (b) requirements for enhanced transfer of groundwater modeling technology within the Army; and (c) needed research and development in groundwater modeling systems. As in any short-duration workshop of practitioners, the focus of the individuals attending was on how to improve the state of practice and do the most professional job possible. The attendees concentrated on making things better, and not much time was spent on recognizing what is already being done well. Thus the tone of the meeting and of this report, which attempts to be faithful to what took place at the workshop, leaves the reader with an incomplete and perhaps biased picture. Problems were identified but no time was taken to celebrate successes.

The report of the workshop was written by Mr. Ira May of AEC; Ms. Tomiann McDaniel of HQUSACE; and Drs. P. F. Hadala and D. K. Butler, Geotechnical Laboratory, WES; J. Cullinane, Environmental Laboratory, WES; and J. P. Holland, Hydraulics Laboratory, WES. In addition to these individuals, the following contributed to the planning and organization of the workshop: Mr. Tony Dardeau, Ms. Cheryl Lloyd, Dr. Paul R. Schroeder, Mr. Mark E. Zappi, Mr. Christian J. McGrath, and Dr. Carlos Ruiz, Environmental Laboratory; and Ms. Dorothy L. Staer and Dr. James H. May, Geotechnical Laboratory.

The workshop was conducted as a part of the Installation Restoration Research Program under HQUSACE-sponsored RDTE Work Unit Groundwater Model Assessment AF25-GW-0001. The preconference questionnaire and its analysis were sponsored by the Directorate of Military Programs. The

AEC technical monitor was Mr. Ira May; the USACE technical monitor was Ms. Tomiann McDaniel.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

Summary

The findings of this investigation are based upon two major activities: a groundwater model users needs questionnaire sent from the U.S. Army Engineer Waterways Experiment Station (WES) to the Corps of Engineers elements, certain installations, and the U.S. Army Environmental Center (USAEC) major elements involved in the Army's environmental restoration programs in February 1992; and a workshop sponsored by WES; the Directorate of Military Programs, Headquarters, US Army Corps of Engineers; and USAEC on 30 March-1 April 1992 in Denver, CO. Of interest is that although the responders to the questionnaire and the attendees at the workshop were not identical, the outcomes of both exercises were quite similar. This summary, which reviews the results of the questionnaire and the workshop, is divided into two areas: summary of the activities, and recommendations for future research and development needs for the US Army Corps of Engineers.

The questionnaire was developed to solicit Army needs for, use of, and experience with groundwater flow and contaminant transport modeling tools in support of contaminated site characterization and remediation. Responses were received from 77 individuals representing installations, USAEC, and 17 different Corps of Engineers districts and divisions. These responses suggested the following:

a. The primary contaminants of concern at Army study sites are organic solvents, petroleum hydrocarbons, and explosives. Heavy metals were also cited as a concern at many sites.

b. Limited in-house Army expertise is available in groundwater modeling.

c. A dramatic increase in the amount of groundwater modeling is expected in the next 5 years.

d. Training and guidance in the use, applicability, and limitations of groundwater models were almost universally stressed.

e. In-house technical assistance in the Army is needed, although the exact form of that assistance was not recommended.

The workshop gathered together the individuals involved in the use of groundwater models in support of Army environmental programs. Major

objectives of the workshop were to determine the extent and specific nature of the use of groundwater flow and contaminant transport models in hazardous and toxic waste site identification and remediation efforts; and to provide Army researchers with user recommendations for required research and development in groundwater modeling systems. Ninety individuals attended the workshop, representing USAEC, various Corps of Engineers offices, universities, consultants, and other Federal government entities. The workshop participants suggested the following (though not necessarily in order of importance):

a. Complexity of the modeling effort should be a reflection of the complexity of the problem and the objective of the modeling effort.

b. The absence of adequate data for modeling is not a good reason for refusing to attempt the modeling process. Adequate data that are needed for a model are generally also needed to define the problem and the geologic system being studied. The need for modeling and the data to support the modeling effort should be based on the degree to which the modeling effort can improve the ability to make decisions about the project.

c. Groundwater modeling is the best possible mechanism to synthesize and analyze large amounts of geologic, geochemical, and hydrogeologic data available, and therefore should be used throughout the remedial investigation/feasibility study process. A state-of-the-art modeling-based approach to the site characterization and cleanup will result in predictable and decreased remediation costs and verifiable results.

d. In-house institutional knowledge is essential. The Army needs an in-house capability to evaluate and assess groundwater model results and their uses, and to provide technical assistance to individual practitioners.

e. Training and guidance in the use of groundwater models is the users' most pressing need. This guidance is needed for all levels of potential model users, from the field level practitioners to upper level management.

f. Geostatistics represents the best methodology currently available to rationally account for uncertainty and geologic heterogeneity.

g. Many problems with groundwater modeling studies are not technical in nature, but rather involve initial constraints, miscommunications, regulatory requirements, etc.

h. A formal mechanism is needed to provide technology transfer to the practitioners in the field. These mechanisms could include future workshops, newsletters, etc.

i. Many good modeling studies have been conducted during the course of the Army environmental restoration program. The state of practice of

Army modeling is, in general, the same as that in all Superfund related work. However, the state of practice is not close to the state of the art in groundwater modeling in academia and Federal research and development agencies.

Research and development needs as identified by the workshop and the questionnaire (again, in no particular order of importance) included the following:

a. Optimization methods for design of remedial actions need development and should employ sensitivity analysis of site parameters.

b. Better understanding of contaminant transport mechanisms and processes, especially of Army specific compounds, is needed in order to improve modeling capabilities.

c. Procedures for parameter sensitivity analyses and for understanding and quantifying uncertainties need to be developed.

d. New procedures to make use of fundamental geology in site conceptualization are needed.

e. Research needs to be conducted in multiphase flow in groundwater systems, in the vadose zone, and in fractured systems, and in flow in frozen soils.

f. Capability needs to be increased to evaluate a variety of transport processes including diffusion, sorption, biodegradation, etc.

g. Existing models need to be improved, with orientation toward input requirements and output displays. Graphical User Interfaces should be developed for the models.

h. Interfaces between groundwater models and geographic information systems and environmental databases are needed.

1 Introduction

Background

The U.S. Army has significant responsibilities and numerous actions underway to define the extent of and then remediate groundwater contamination by hazardous, toxic, and radiological wastes in its (a) Installation Restoration (IR) Program, (b) Formerly Used Defense Sites (FUDS) Program, (c) Base Realignment and Closure (BRAC) process, (d) Superfund work undertaken in support of the U.S. Environmental Protection Agency (EPA), and (e) incidental support to some Civil Works (CW) projects.

The scope of the groundwater contamination problem is large and the contaminants present are numerous (see Appendix A). There are 97 Department of Defense (DOD) sites on the EPA's National Priorities List (NPL). The top ten of the Army's NPL sites have contaminated groundwater as their major problem.[1] The estimated cost of groundwater cleanup is \$2-\$6 billion. The Army's focus is contaminated site cleanup as a means of reducing the risk of harm to human health and the environment. Groundwater modeling is used by the Army as a tool to help meet this goal by helping to reduce remediation cost, increase its speed, and assess potential risks.

The correction of a groundwater contamination problem begins with its definition. This definition process is called site characterization or, more commonly, remedial investigation (RI), as shown in Figure 1. With respect to groundwater, the objectives of an RI are to define the sources and current state of contamination, and predict the future movement of and changes in the contamination, especially off installation. The direction, rate of movement, and concentration of contaminants are largely controlled by the direction and rate of movement of the groundwater, which is, in turn, largely controlled by the regional and site geologic profiles, the regional hydrology, the biochemistry of the aquifer, and the inherent chemical makeup of the contaminant(s). Much effort is expended in the RI phase on geologic reconnaissance, geologic mapping, borings, geophysics, observation wells, water quality sampling wells, data collection, and chemical and data analyses to understand the subsurface conditions and model conceptually (and oftentimes numerically) the flow of

[1] Report to Congress on the Defense Environmental Restoration Program, February 1991.

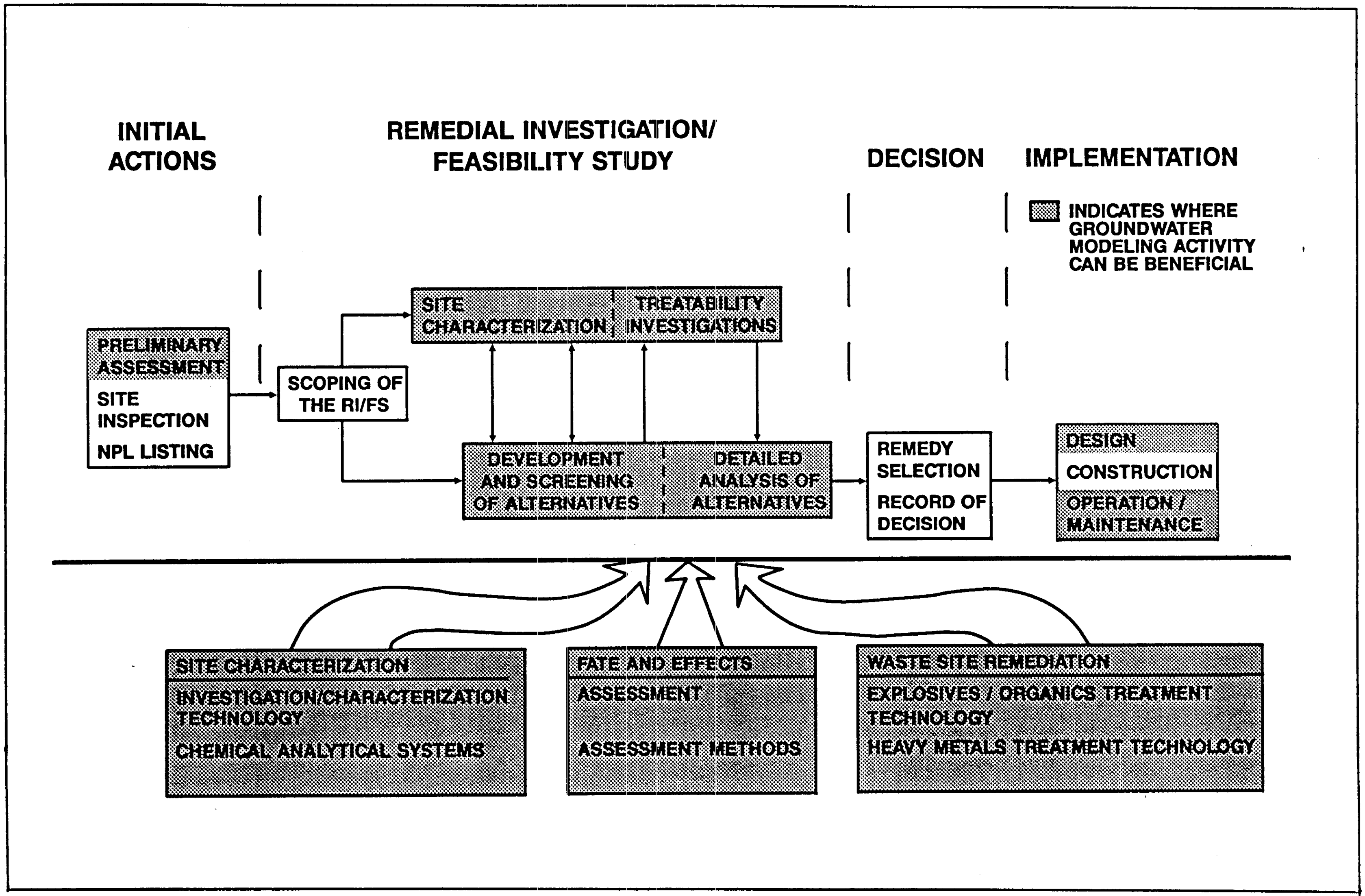


Figure 1. Installation Restoration Program

groundwater at a site. Groundwater flow and transport modeling is used to assess the risk of future contaminant arrival at critical locations under known or postulated hydrologic conditions.

The feasibility study (FS) phase compares proposed contaminant containment and remediation alternatives for effectiveness, timeliness, cost, and reliability. Since all of these are possible future events, prediction is required; and prediction of effectiveness as a function of time inherently requires modeling of groundwater flow and contaminant transport in one fashion or another. In the implementation or remediation phase, the design of the remediation requires evaluation of the effectiveness of a variety of physical treatments (liners, slurry walls, caps, pumping scenarios, etc.) and biochemical treatment options. Groundwater modeling can assist with these determinations. During the operational phase, time-dependent owner-controlled activities such as rates and durations of pumping and evaluations of data taken to assess effectiveness of remedial measures can benefit from groundwater modeling to predict, albeit imperfectly, the course of future events should certain alternatives be adopted.

Purpose

The U.S. Army Engineer Waterways Experiment Station (WES), in conjunction with the Directorate of Military Programs, Headquarters, US Army Corps of Engineers, and the U.S. Army Environmental Center (USAEC), sponsored a workshop on 31 March-1 April 1992 in Denver, CO, to determine the following: (a) the extent and specific nature of use of groundwater flow and contaminant transport models in Army hazardous and toxic waste site remediation work; (b) requirements for enhanced transfer of modeling technology to Army users; and (c) user recommendations for research and development in groundwater modeling systems. As the title of this report and the workshop indicates, the sponsors were interested in determining future needs in order to identify deficiencies and the research to overcome them. The workshop succeeded in this purpose, and as subsequent parts will indicate, also defined a need for immediate significant technology transfer effort to bring the current state of practice closer to the current state of the art.

Scope and Format

This report is intended to be a record of the workshop. This record is backed up by a nearly verbatim transcript taken by a court reporter and copies of all Vugraphs and slides presented, which are on file at WES. Abstracts of all presentations are included in Appendix A. The workshop was organized so that the experts from Government agencies, academia, and industry and users at USAEC, U.S. Army Engineer districts, and Army installations held the floor for most of the meeting. The Corps of Engineers research and development laboratories concerned (i.e., WES and Cold Regions Research and Engineering Laboratory) were represented but were primarily in a listening and facilitator capacity. The workshop was deliberately planned as a users meeting. The agenda of the meeting is given in Appendix B. In the first session, after an overview of the subject and purposes by representatives of the sponsoring agencies, the result of a preworkshop survey (Appendix C) on Army groundwater model use was presented (Chapter 2 of this report).

In the remaining sessions, four panels discussed the following subjects:

Panel	Topic	Chapter in This Report
1	Groundwater Problems, Users Needs and Model Uses	3
2	Model Use in Remedial Investigations	4
3a	Model Use in Remediation, Part 1	5
3b	Model Use in Remediation, Part 2	6

Each panel had one to three invited speakers and several other members representing a mix of Army users and non-Army experts and users. The panel (a) discussed questions posed by a moderator, (b) reacted to the panel speakers, and (c) fielded questions from the floor. Planning materials from each panel furnished to each attendee, given in Appendix D, better describe the scope of the panel's activities and list the panel members.

Rocky Mountain Arsenal (RMA) sponsored a field trip for workshop attendees to their installation where the scope of their investigation and remediation of groundwater contamination was presented and the workshop attendees saw pump and treat operations in action.

Ninety individuals, of which 60 were Corps of Engineers employees, participated in the workshop. The complete list of attendees is given in Appendix E.

2 Summary of Responses to Questionnaire on Army Use of Groundwater Models

In early February 1992 a questionnaire (Appendix C) was developed at WES that solicited information on Army use of and experience with groundwater flow and contaminant transport modeling tools in support of contaminated site characterization and remediation. The questionnaire also sought user input on the research and development requirements for future model development. The questionnaire was mailed to 22 Corps of Engineers district and/or division offices, generally to specific individuals designated by Directorate of Military Programs, Headquarters, US Army Corps of Engineers, personnel. Forty-seven responses from 17 Corps of Engineers offices were received. Responses were obtained from 28 users at USAEC, representing seven USAEC elements, and from two Army installations (Aberdeen Proving Grounds, MD, and Fort Richardson, AK). While only two installations were polled directly, USAEC representatives provided input for all other known uses of groundwater models at Army installations. Thus, it is believed that a significant majority of potential Army groundwater model users doing modeling in support of contaminated site cleanups received questionnaires.

Analysis of Questionnaire Responses

An analysis of the questionnaire responses is presented in the following paragraphs. The results of this analysis are presented in the forms of graphs, tables, and simple statistics (such as percentages) for each question posed. This document seeks to present a snapshot of where the Army finds itself relative to groundwater modeling at this time.

This part of the report is arranged by section for each survey question. Following these sections, additional analysis of the global survey is provided, along with a summary.

Question 1. What percentage of the hazardous and toxic wastes (HTW) problems you are encountering at military or Superfund sites is associated with

___ Petroleum Hydrocarbons
___ Organic Solvent Liquids
___ Explosives
___ Metals
___ Other (please specify) ____________

The responses to this question are given in Figure 2, with an overall response (Figure 2a), and a breakdown for the Corps and USAEC/installation responses (Figures 2b and 2c, respectively). The designation of "high," "medium," or "low" was developed based on these criteria:

a. High: response greater than 33 percent

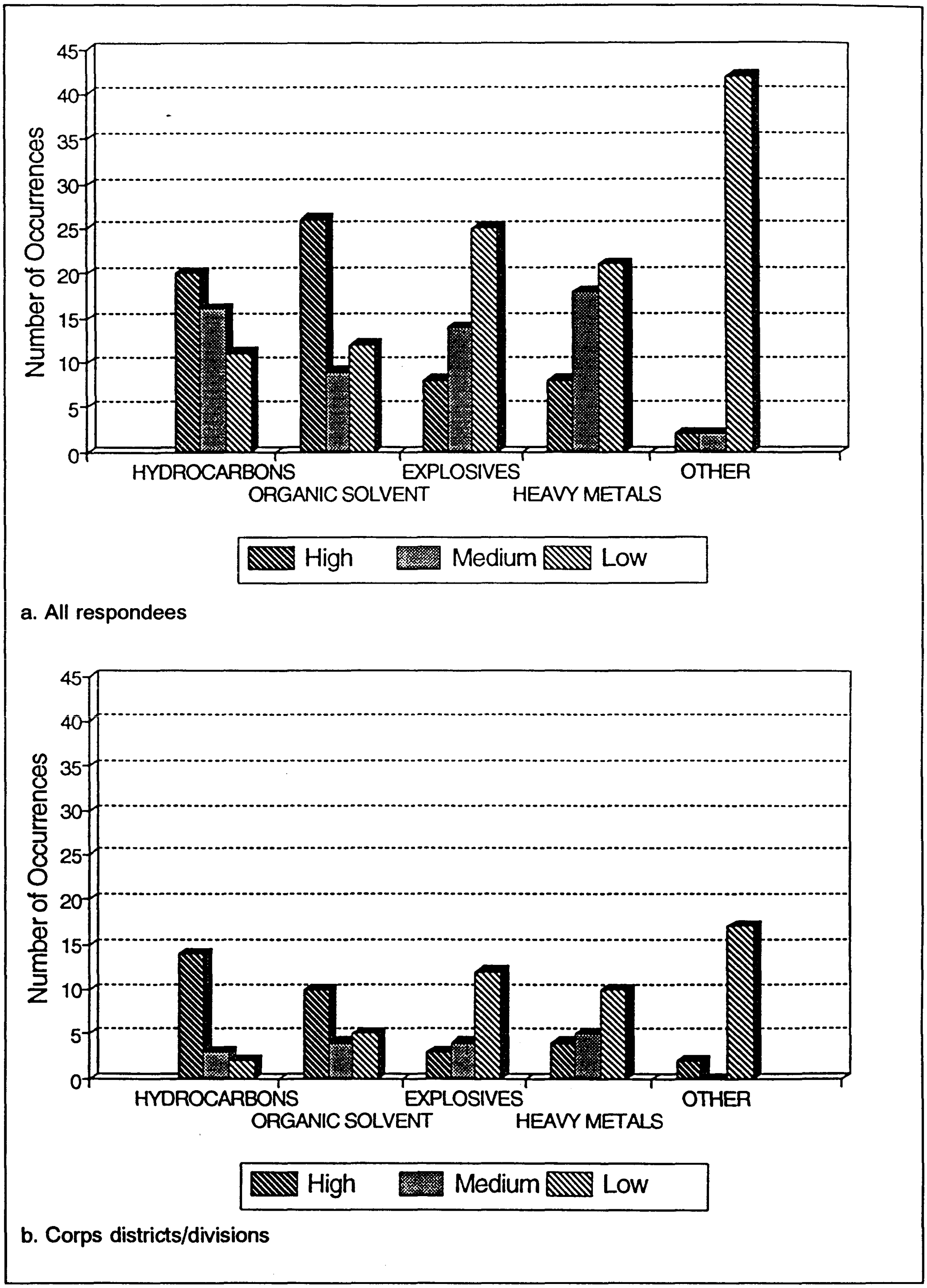
b. Medium: response between 10 percent and 33 percent

c. Low: response less than 10 percent

As shown, the Army is most strongly concerned about hydrocarbons, organic solvents, and explosives cleanup. A concern with metals appears to be growing as well, given the elevated "medium" vote cast for this class of containment. The "other" category contained several things including pesticides, polychlorinated biphenyls (PCB's), radionuclides, and herbicides. Note also that, other than a slight change of order of priority, very little difference was found between the Corps responses (Figure 2b) and the USAEC/installation responses (Figure 2c).

Question 2. For the sites referred to above, how many of them are, or are projected to be, involved with the cleanup of contaminated groundwater resources for both saturated and unsaturated conditions? ___(military) ___(Superfund) What percentage of the total number of your HTW sites is this number? ___(military) ___(Superfund) The responses to this question were very difficult to analyze due to relative incompleteness of the responses. Of the information that could be analyzed, over 60 percent of the respondents said their HTW sites had contaminated groundwater as a principal concern, with military and Superfund sites both receiving significant representation. This number, however, is probably low. Communication with multiple USAEC personnel and several Corps offices indicated that over 85 percent of all Army RI sites investigated to date have groundwater contamination as a point of prime concern (given that a concern is registered at all).

Question 3. How many of your groundwater-related cleanup studies (over the last ten years) contained, or are projected (over the next five years) to contain, a groundwater modeling effort? ___ If this number is zero, skip to Question 10. Respondents listed 127 groundwater modeling studies that had been conducted in the last 10 years, or were projected over the next 5 years. Additional analysis of the information provided in Table 2 of



a. All respondees

b. Corps districts/divisions

Figure 2. Army contaminants (Continued)

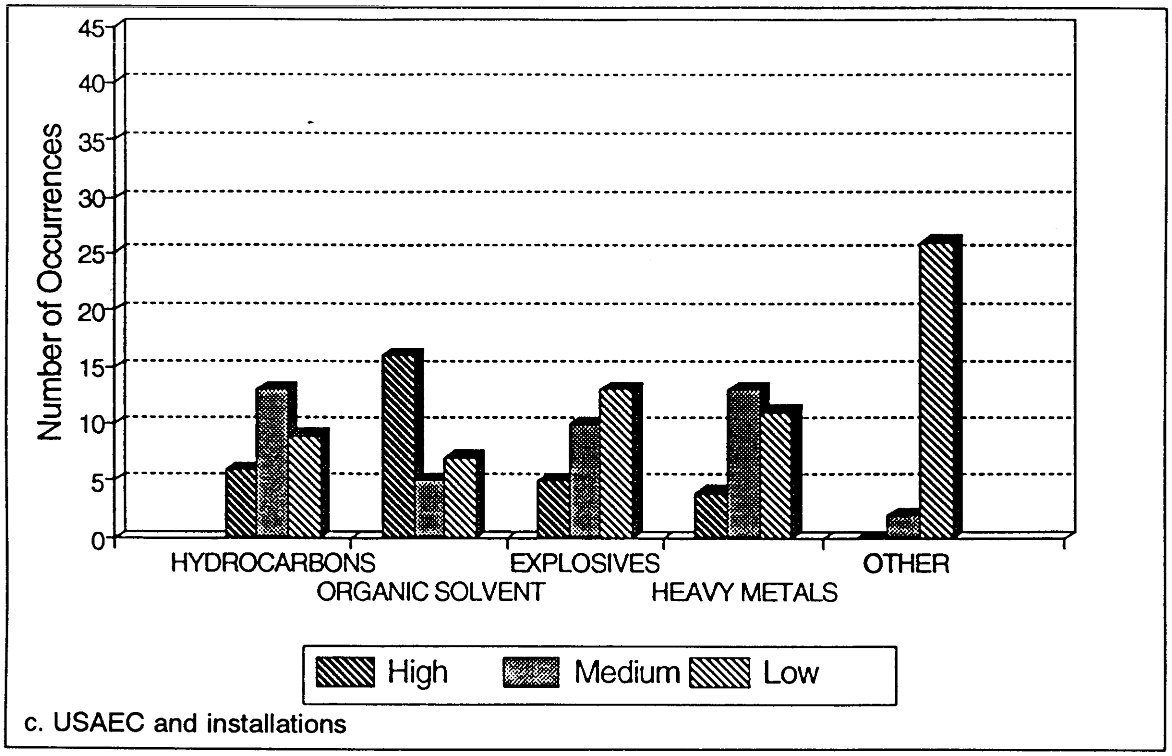


Figure 2. (Concluded)

the questionnaire (Appendix C) revealed that 61 of these studies were ongoing or completed, with the remainder planned. Note also that 11 of the respondents to the questionnaire had no ongoing, completed, or planned groundwater modeling studies at this time. Six of these respondents were from USAEC and five were from the Corps.

Question 4. For each groundwater modeling study planned or executed, please provide the information requested in the attached Table 1. Please reproduce additional sheets as needed. (See Table 1 in Appendix C.) An enormous amount of information was derived from Table 1. The analysis of this information was constrained to those responses for which the model studies were either ongoing or completed (based on information provided in Table 2 of Appendix C). This was deemed most appropriate given the types of information requested in Tables 1 and 2. As stated previously, this amounted to analysis of 61 ongoing/completed studies.

As shown in Figure 3, 36 of these studies (59.0 percent) were for military installations; 10 (16.4 percent) were for combined military/Superfund sites; 7 (11.5 percent) were for Superfund sites; 6 (9.8 percent) were FUDS; and 2 (3.3 percent) were of the "other" category (1 civil works project and 1 "no response").

Figure 4 provides the models employed for the ongoing/completed model studies. The model cited with the greatest number of applications is the

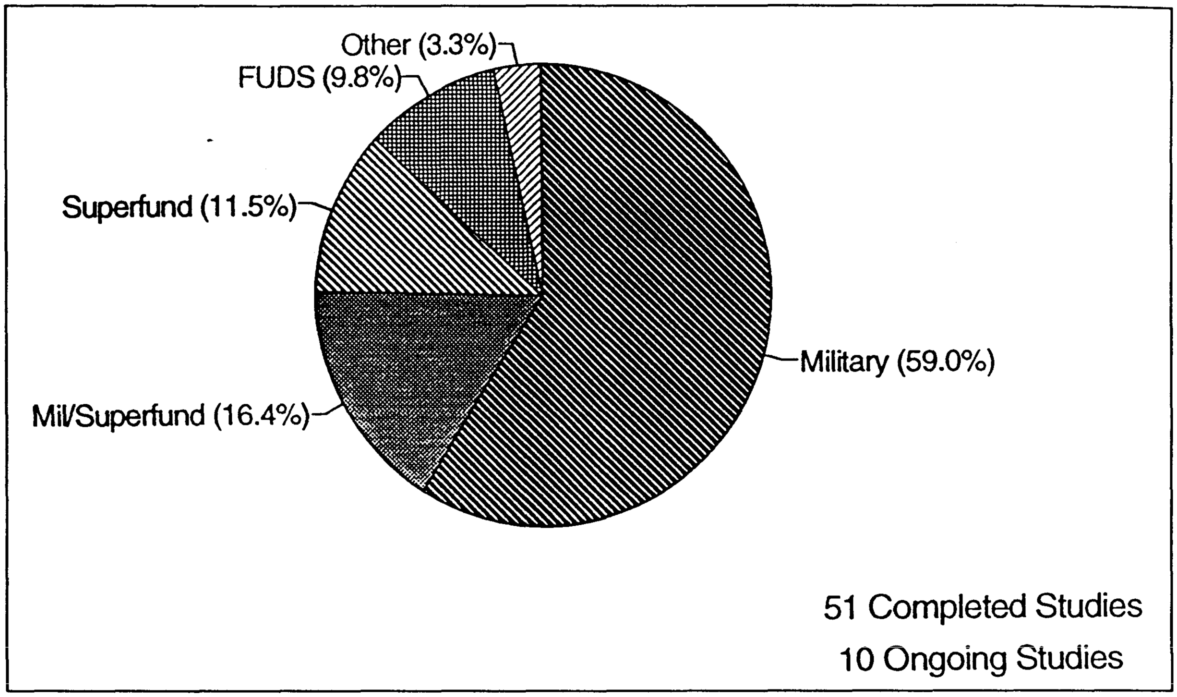


Figure 3. Distribution of sites with completed/ongoing modeling studies

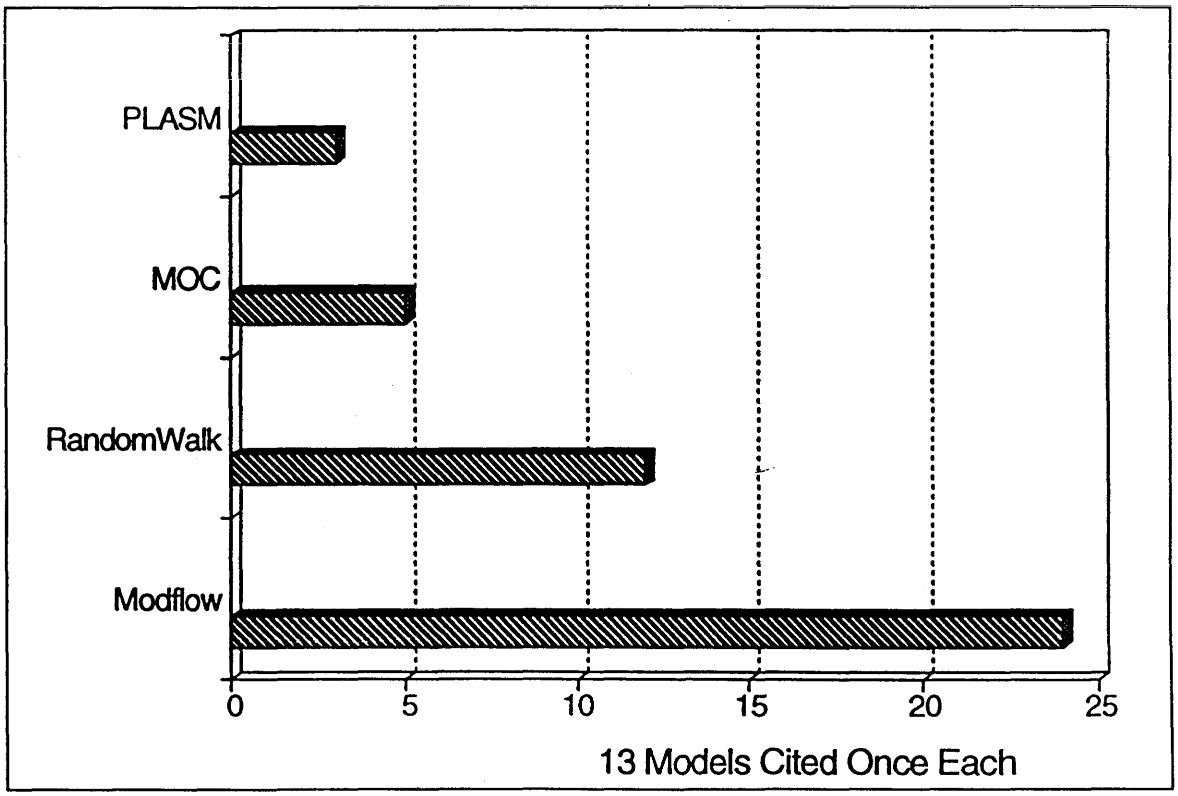


Figure 4. Number of uses of cited models in Army groundwater cleanups

MODFLOW model, with 24 of 61 total responses. This is of little surprise, given that the model is currently among the best models available that is executable on multiple (personal computer to supercomputer) computing platforms.

As shown in Figure 5, most of the Army's model studies to date have been two-dimensional (2D) or three-dimensional (3D). These studies have been for both steady-state and transient conditions (Figure 6) in generally saturated environments (Figure 7). This latter point is of importance because, to date, most of the cleanup concerns requiring modeling have been related to whether or how fast a contaminant will travel through the saturated zone to a domestic water supply (given present or possible future hydrologic conditions) as part of a risk assessment. This also explains the multidimensionality of a significant majority of studies, given the basic heterogeneous nature of the soil matrix and the potential for movement along multiple axes.

Figure 8 provides responses for the phases of study during which the Army has conducted the ongoing/completed groundwater modeling. Note that the majority of these modeling efforts have been conducted in association with RI, followed by remedial treatment, design/operation (RE), and FS.

As illustrated in Figure 9, the majority of ongoing/completed groundwater model studies have entailed the execution of both flow and transport models (in either a coupled or uncoupled mode). Forty-two of the 61 respondents gave this response, followed by 18 "flow-only" responses. These results point toward the often nonconservative[1] nature of the contaminants simulated numerically in Army-sponsored studies, which require the more rigorous modeling associated with transport simulation. However, most of the 18 studies citing "flow-only" responses listed a variety of nonconservative contaminants as those of concern in connection with the modeling. This is, hopefully, an artifact of the requirement often expressed by regulatory agencies that the Army simulate "worst case" conditions. These conditions usually entail simulation of flow only as an expression of conservative[1] contaminants that neither lag behind the flow of water, become attached to or trapped by soil particles, nor biodegrade. This achieves, in theory, the strongest contaminant concentration that reaches a location of concern the fastest. If this result is not an artifact of regulatory conservatism, it represents a misunderstanding of the kinetics of the contaminants being modeled. Note, also, that this result again points toward the idea that the majority of Army modeling has probably been in support of a risk analysis, with the use of modeling as part of a remedial design being a secondary factor (as shown in Figure 8).

Figure 10 provides one last snapshot of the modeling the Army is doing. As shown, the Army has been simulating a number of contaminant classes, most notably solvents. The lack of modeling emphasis on explosives and hydrocarbons is in contrast with the prevalence of these materials in

[1] Conservative contaminants are biochemically nonreactive. Nonconservative contaminants are chemically and/or biologically reactive.

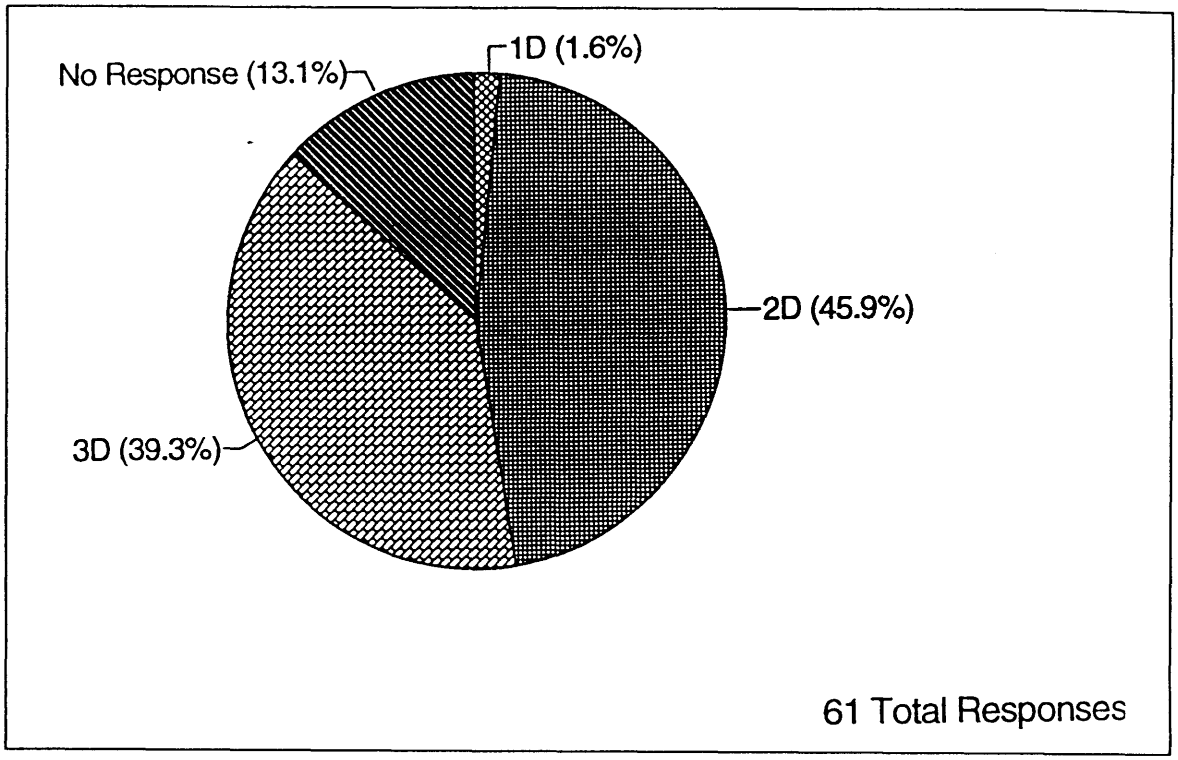


Figure 5. Cited dimensionality of model applications

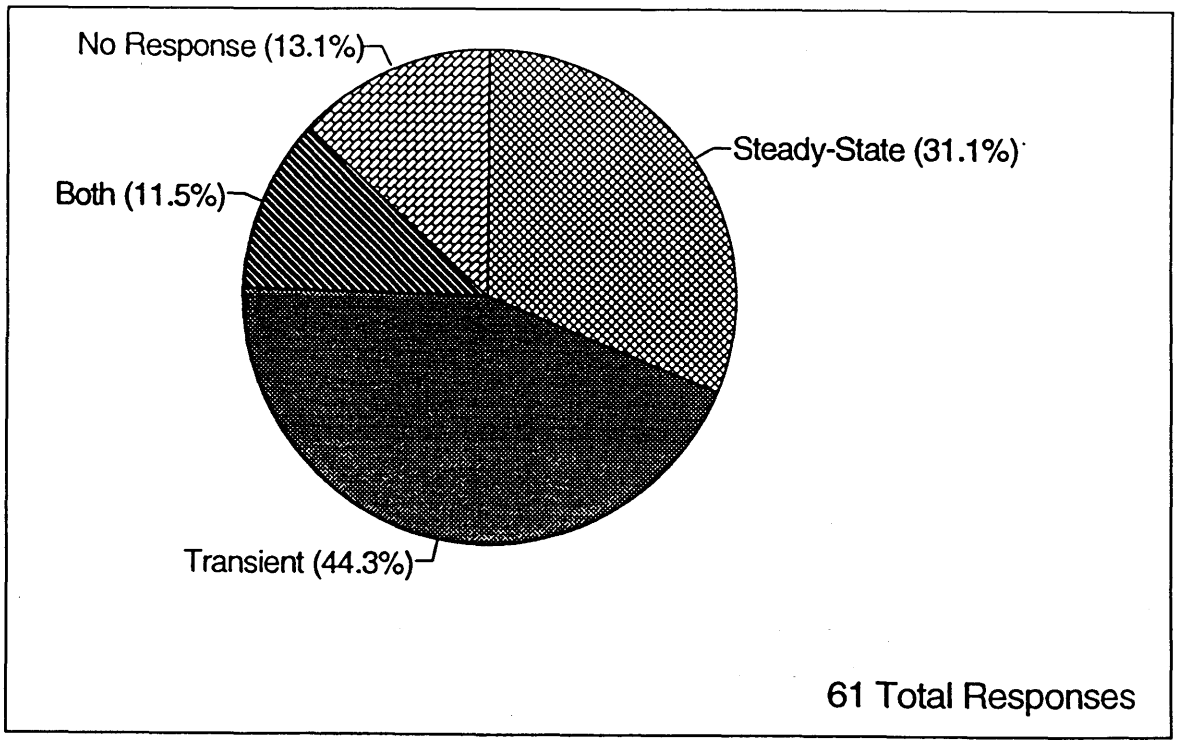


Figure 6. Steady-state versus transient applications

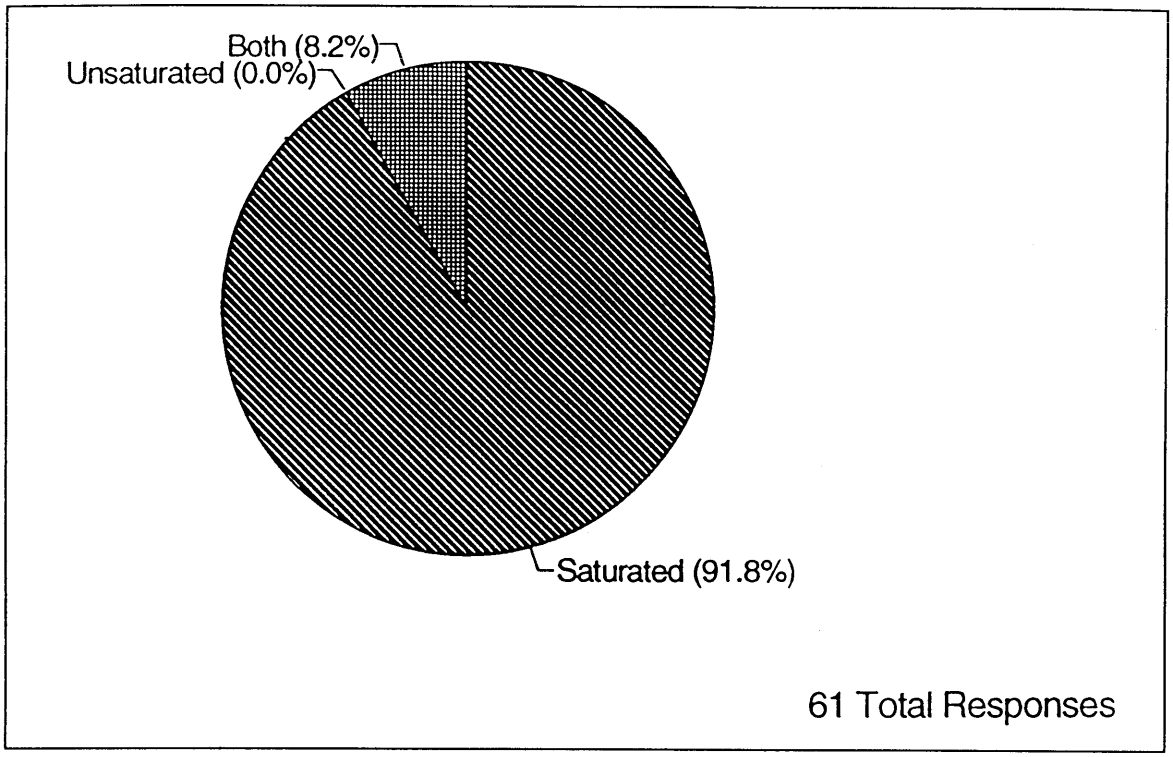


Figure 7. Type of application cited: saturated or unsaturated conditions

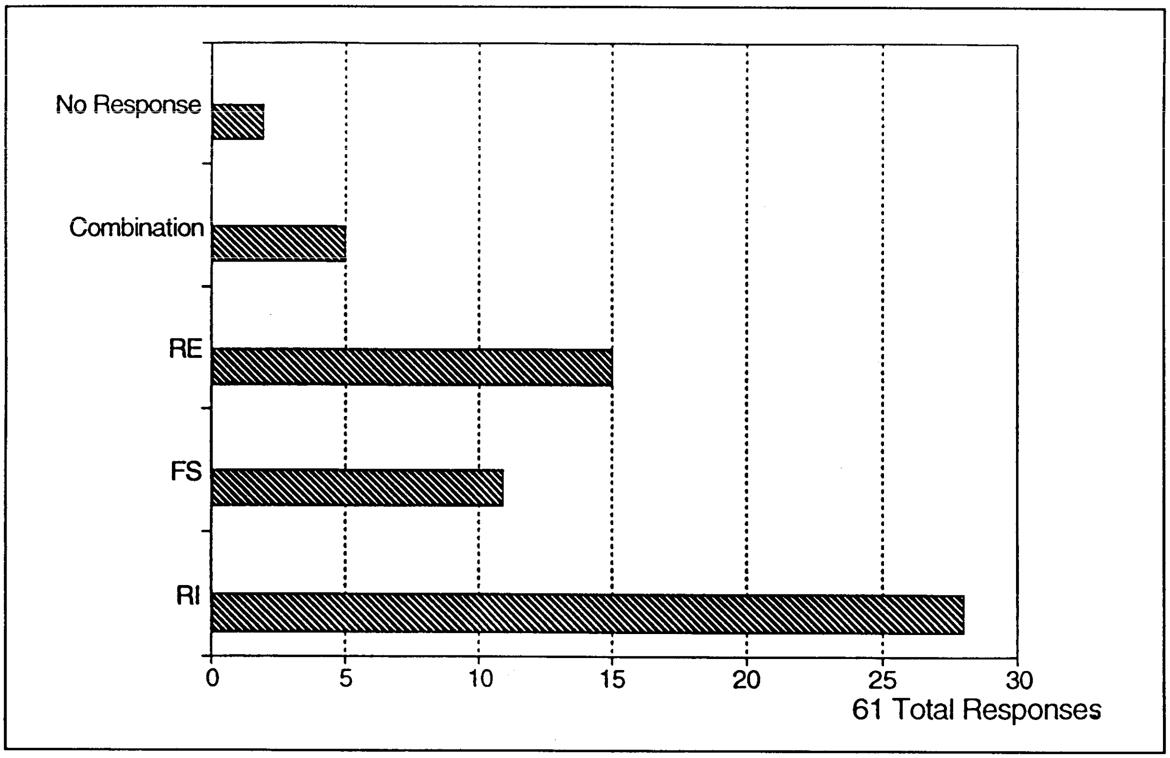


Figure 8. Phase of study employing groundwater models

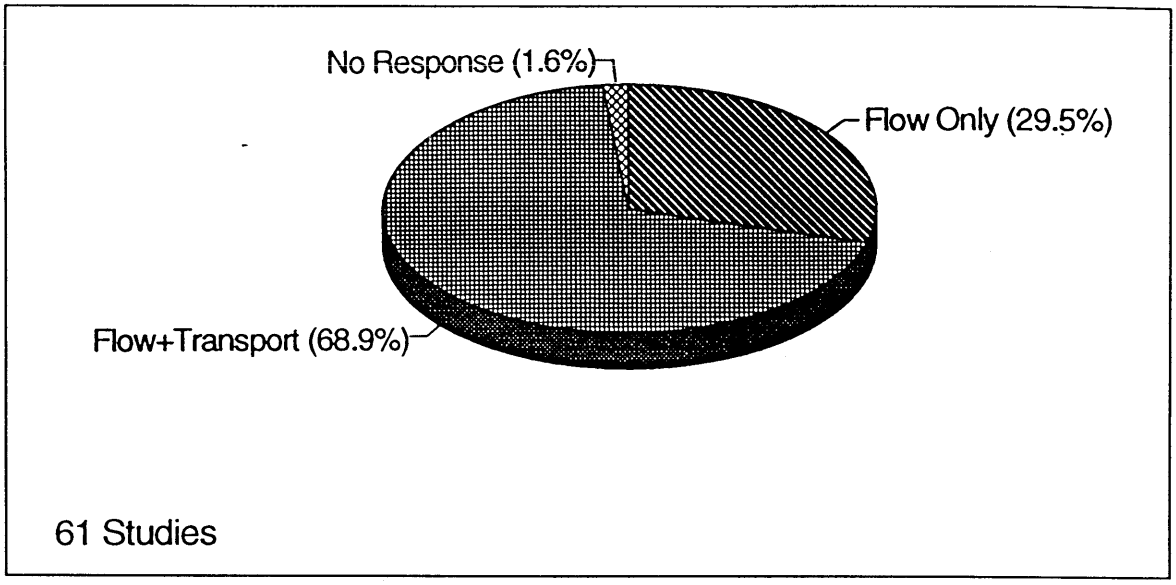


Figure 9. Flow or flow and transport modeled for ongoing/complete studies

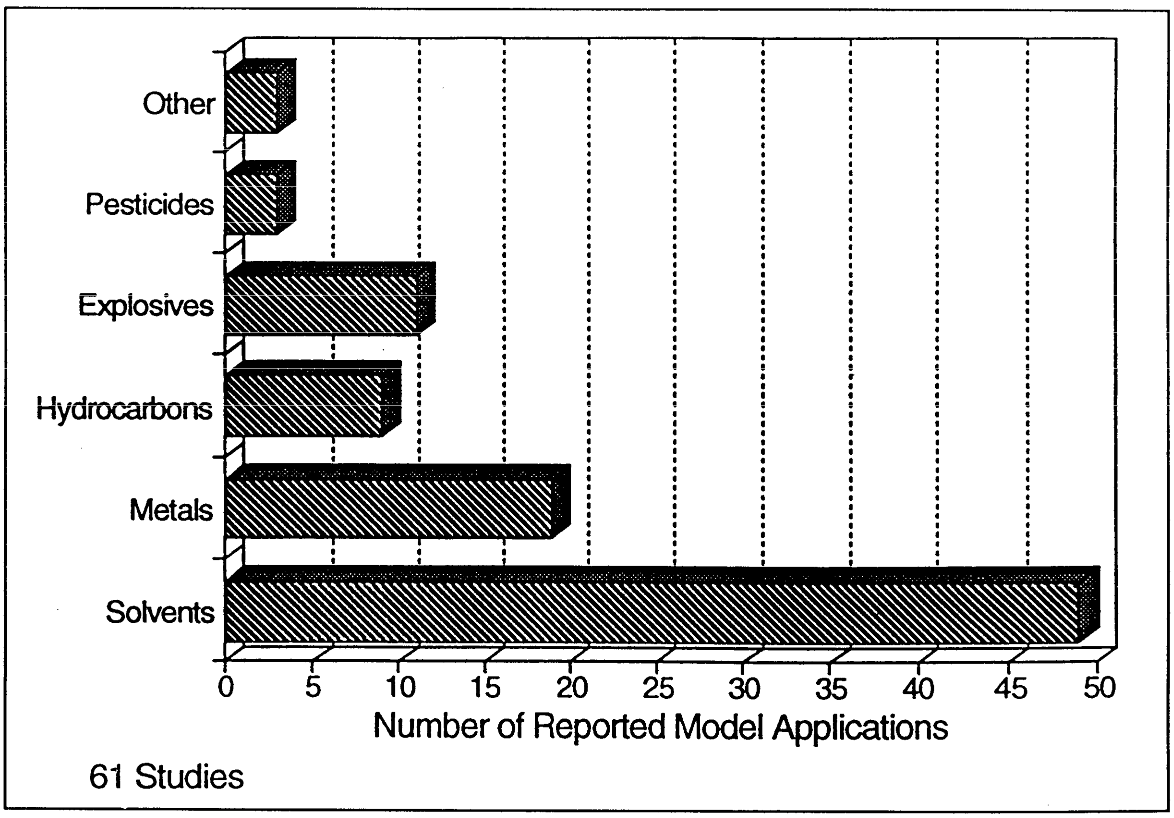


Figure 10. Contaminant types being evaluated with groundwater models

groundwater at Army installations shown in Figure 2. Alternatively, the result most likely represents a lack of experience or confidence with the modeling of explosives and hydrocarbon transport by either the Army, its contractors, the regulatory agencies, or all three.

A final piece of information requested in Table 1 had to do with the types of computing hardware on which groundwater models were being run. A significant majority of those who did respond to this question listed the personal computer environment as the one they were currently operating within.

Question 5. For each groundwater modeling study listed in Table 1, please provide the information requested in the attached Table 2 on a sheet per study basis. Please reproduce additional sheets as needed. (See Appendix C for additional detail.) Figure 11 shows that, of the 61 studies listed as ongoing or completed, only about one-half of them were felt to be successful. The remaining studies were listed as a combination of marginal, unsuccessful, and no-response. Approximately 80 percent of these 61 studies were contracted. Figure 12 shows the relationship among successful, unsuccessful, and marginal studies and whether said studies were contracted, done in-house, or done as a combination of the two. As shown in the figure, there is no bias associated with who does the studies; all study agents succeed or fail with equal ease.

Figure 13 provides some insight into why respondents thought their modeling studies were marginal or unsuccessful. Eleven of 39 respondents (28.2 percent) listed poor or incomplete site characterization as the prime reason for less-than-successful modeling applications. The additional answers are noteworthy as well. Seven respondents said that technical gaps in the state of modeling precluded their successful use in their applications. Five responses listed poor study documentation as proof of a marginal or unsuccessful study. Coupled with four responses each that listed a lack of contractor expertise and a lack of in-house analysis expertise as prime contributors to lessened study success, this strongly suggests the need for increased in-house expertise (through training, technical assistance, and hiring). Such expertise should greatly reduce the likelihood of poor contractor selection, and would improve study monitorship through heightened technical interaction, statement of in-house expectation of contractor products, and in-house review of contractor results.

Question 6. Are groundwater models overly expensive or difficult to use for your applications? ___ If the answer is no, please continue to Question 7. If the answer is yes, please check the following that supports your answer:

___ **Models typically require more cost or effort than the information gained from them is worth.**

___ **User manuals or other instructions for using the individual models are inaccurate, incomplete, and/or out of date.**

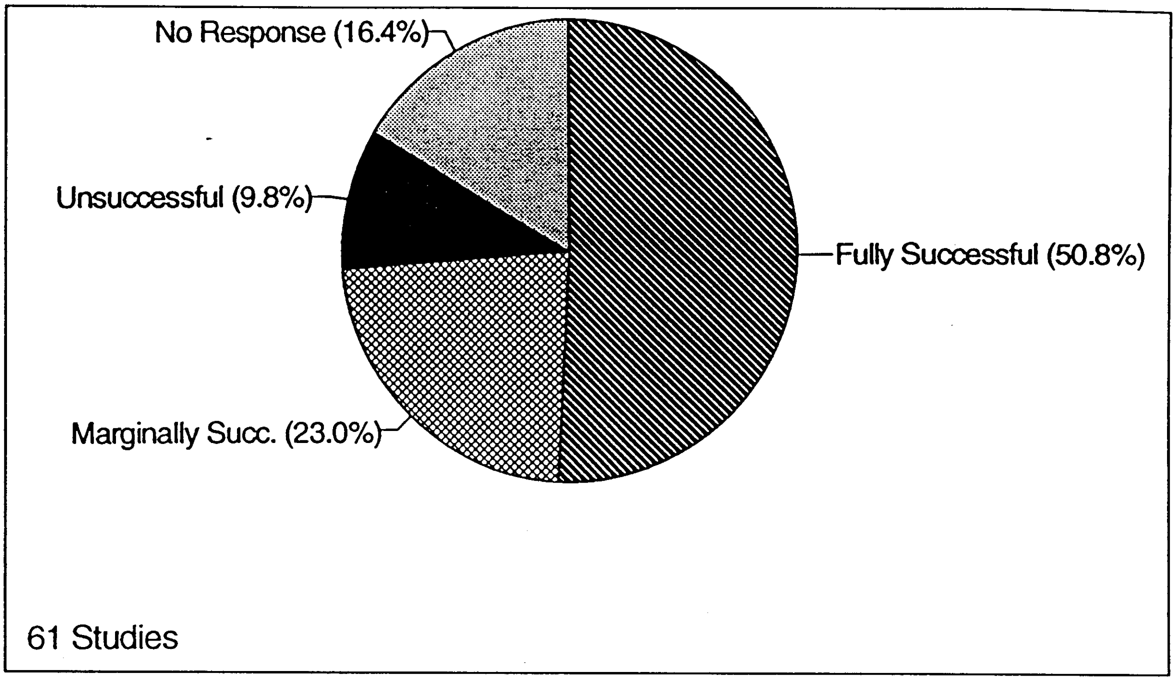


Figure 11. Evaluation of relative success of ongoing or completed studies

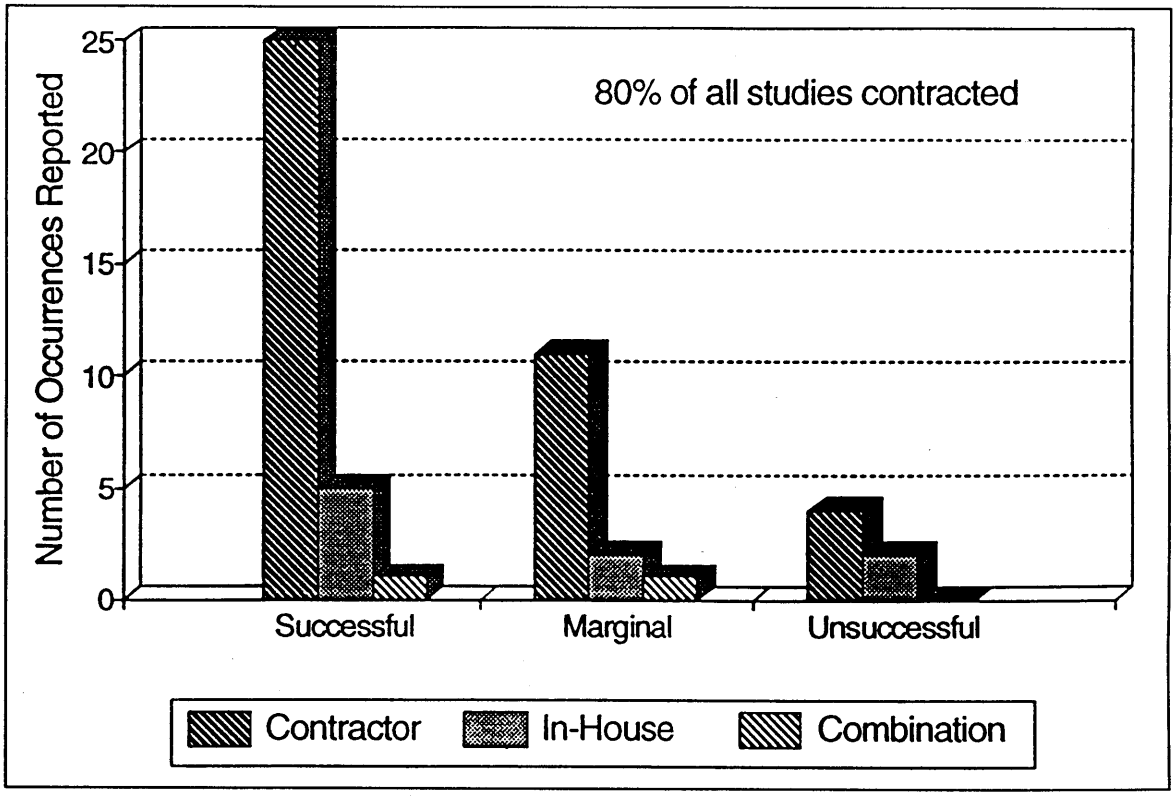


Figure 12. Relative success of modeling as a function of who performs the modeling

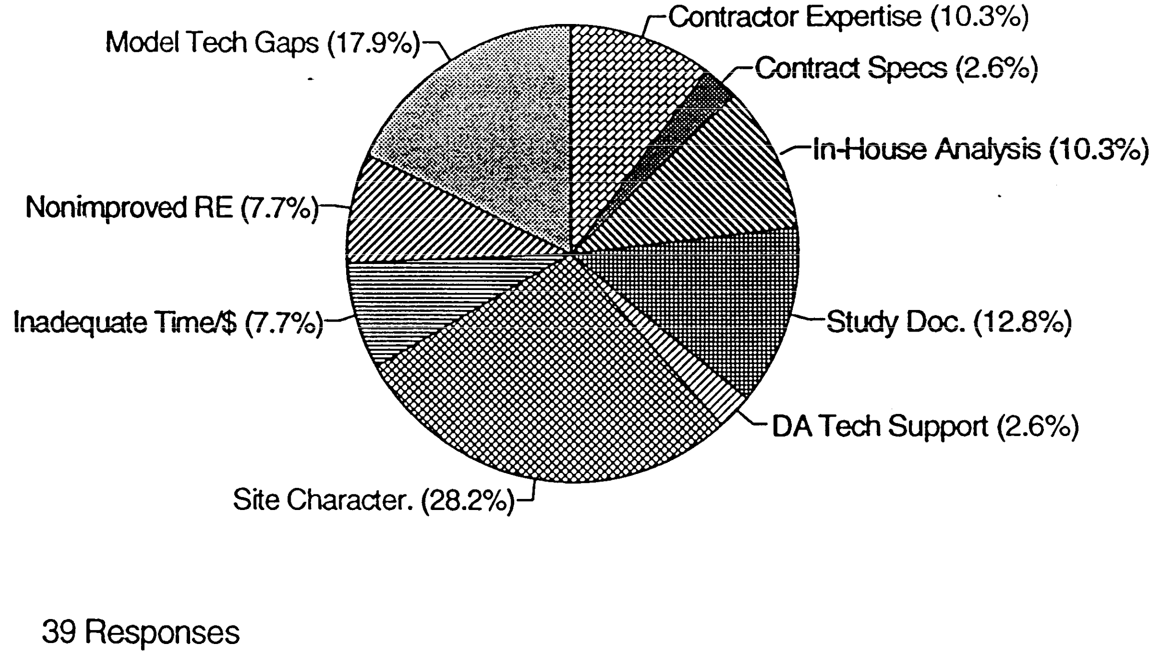


Figure 13. Reasons for marginal or unsuccessful studies

___ **Too much labor and/or time is required to compile the field data needed to define the problem to be modeled.**

___ **Too much labor and time is required to put results of model analyses in a form that is useful for making engineering decisions.**

___ **Other; please explain.** ______________________________
____
____

There were a total of 47 responses to this question; their distribution is given in Figure 14. Respondents were split on this question.

As shown in Figure 15, those responding yes to Question 6 felt that the costs of getting the data required to execute a groundwater model effectively were excessive. This is of some concern because the same data required to execute a model are, in general, those required to conduct a thorough site characterization. Additional respondents cited the effort to conduct the modeling as a contributing reason for their answer. Presumably, the intensity of this effort, including data collection, parameter estimation, model calibration, and analysis was deemed too high by the respondents. When coupled with concerns about analysis costs, be they associated with time or labor usage, or concerns about poor model documentation, the reasons respondents thought groundwater models were too difficult or too expensive to operate suggest a few ideas: (a) the time model users have in the RI/FS process to conduct any

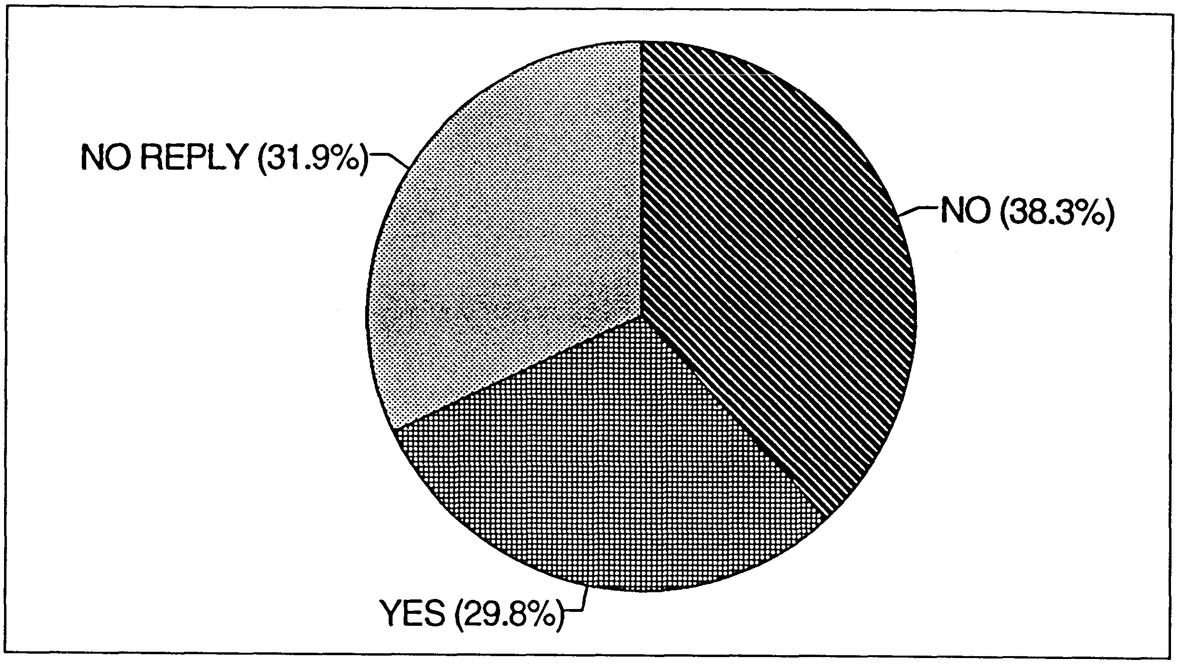


Figure 14. Are groundwater models too difficult or expensive to use?

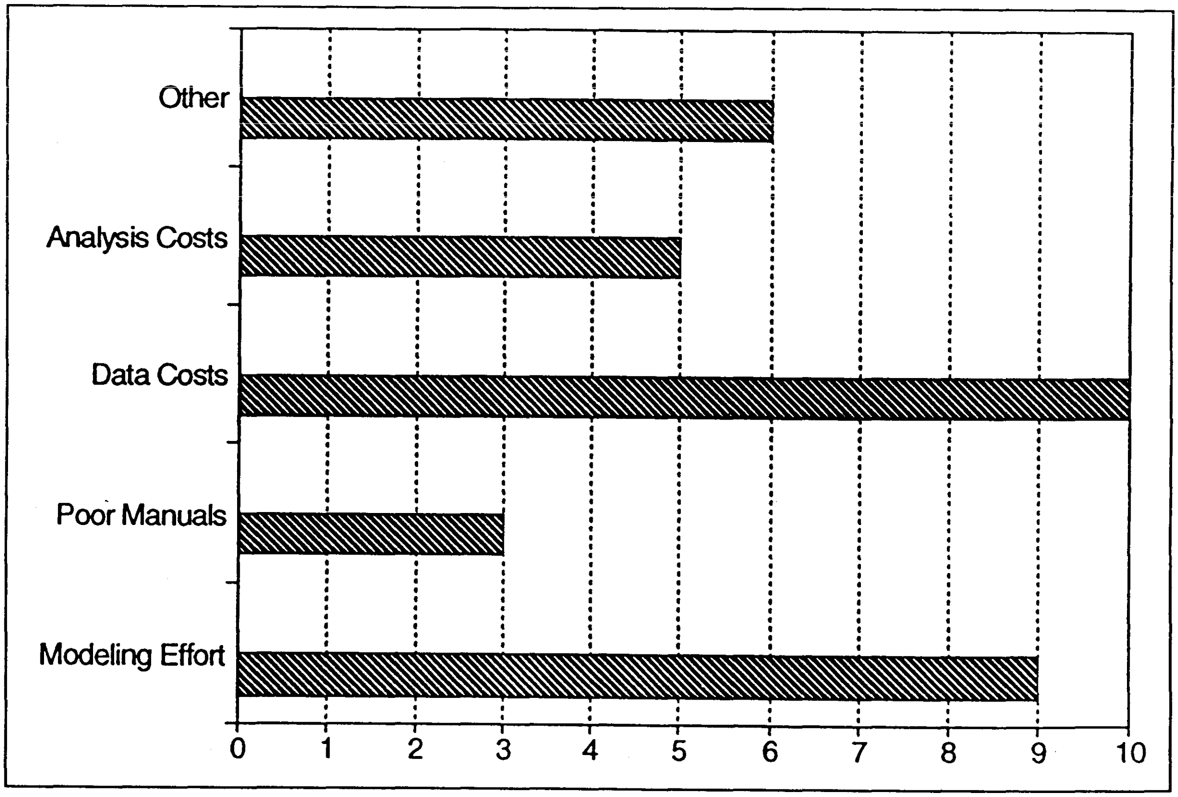


Figure 15. Reasons why groundwater models are felt to be too difficult/expensive

model studies, whether elaborate or simple, is short; (b) the groups presently doing site characterization consider data collection to support numerical models to be outside the scope of data they normally collect for adequate site conceptualization; and (c) the difficulties present users have in implementing models, as exemplified by model documentation concerns, when coupled with the other two concerns, may be great enough to discourage more extensive use of groundwater models in the Army.

It is interesting that nearly one-third of the respondents to Question 6 gave no response to the question. An analysis of the overall questionnaire responses from this group is shown in Figure 16. All of the respondents in this group cited, in one way or another (i.e., the group had only five ongoing or completed studies, and these were all contracted), a lack of in-house groundwater modeling experience as the primary reason for their lack of response to Question 6. As will be discussed in a later section, this finding is extremely important because of its potential impact on future studies, and on the quality of in-house review of future contractor studies.

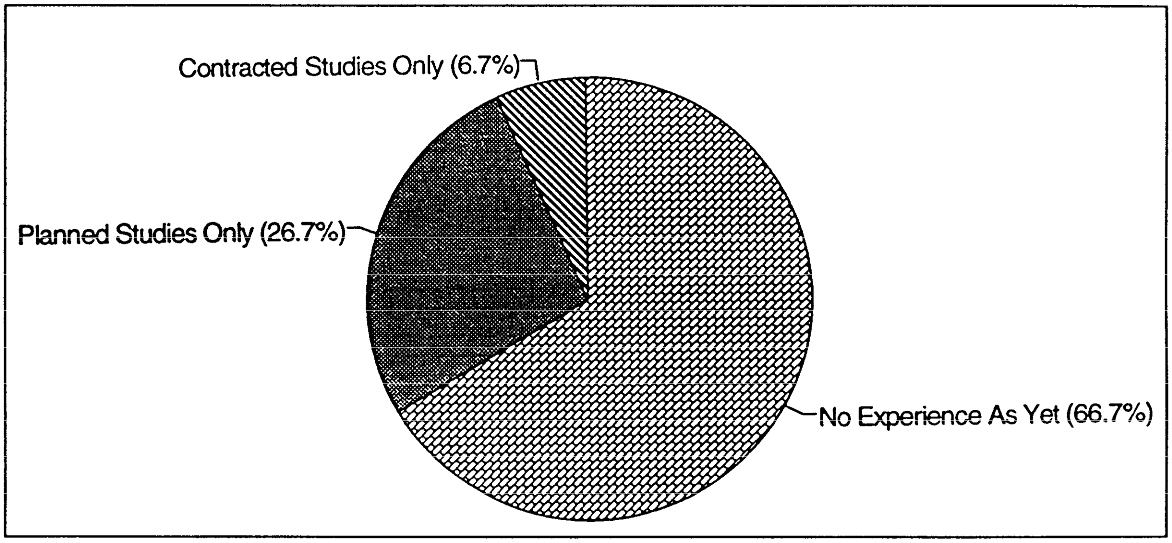


Figure 16. Reasons for nonresponse to question on model difficulty/expense

Question 7. Was your answer to Question 6 based on your own experience, discussions with contractors, or both? __________ Continuing with examination of the experience base of the Army modeling community, the results to Question 7 are provided in Figure 17. The "minimal experience" group (that is, the group that gave no response to Question 6) has been discussed in the preceding paragraph. Now the three other groups listed in Figure 17 will be examined.

In an effort to analyze the Figure 17 responses, a set of criteria were established relative to the overall experience base of Army model users.

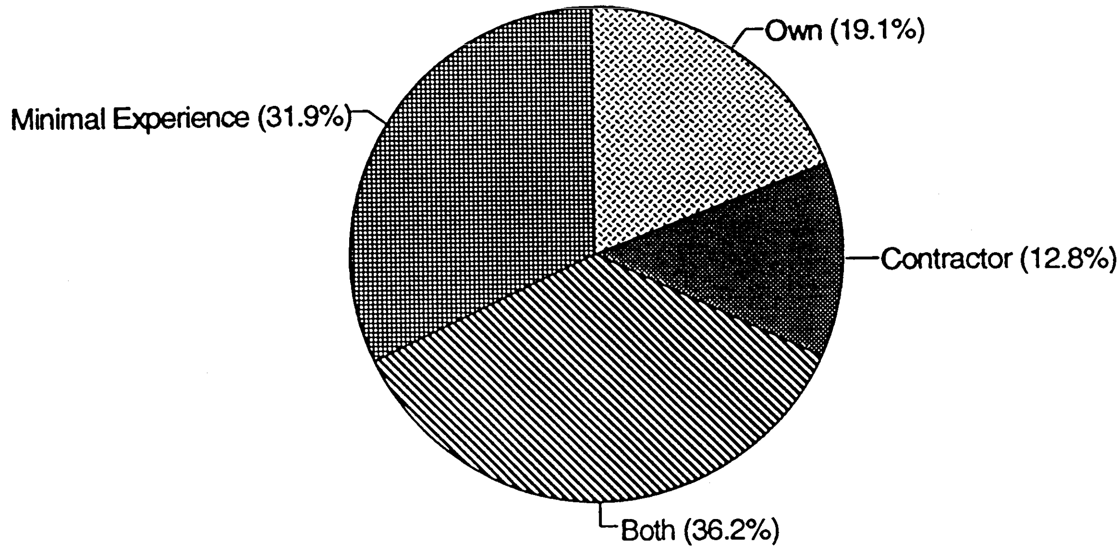


Figure 17. Experience basis for answer to question on model expense/difficulty

Required in this analysis was that the respondent have ongoing or completed modeling studies rather than just planned studies alone. This resulted in the size of the "experienced" group being reduced from 32 (those answering yes or no to Question 6) to 21. Any trends in responses based on the respondent's answer to Question 7 were then investigated. Analysis of an additional variable, whether the model studies to date have been done in-house, by contract, or as a combination of both, failed to produce any obvious trends.

Nine "experienced" Army modelers said that groundwater models were overly difficult or overly expensive to use (Question 6). Twelve said no. Of the "yes" group, all cited their own experience, or a combination of their own and contractors', as the basis for their response to Question 6. One of the "no's" cited their own experience; the remaining 11 cited a combination of their own and contractors', or just contractors', as their experience basis.

Now return to the group of 32 original respondents to Question 7, removing for a moment the experience criterion. Analyzing these data further, of the nine respondents who listed the basis for their answer to Question 6 as their own experience, seven said that models were overly difficult or overly expensive to use. One said no, and one had no response to Question 6. Eight of the nine in this group were listed among the "experienced" modelers as discussed in this section. Conversely, of the six modelers who listed contractor experience as their basis for answering Question 6, all six responded that models were not overly difficult or expensive to use. This group had only seven studies planned or executed among the six of them, and four of the six were listed among the "experienced" group.

Finally, 17 respondents to Question 7 listed both contractor and in-house experience as the basis for their answer to Question 6. Ten of the 17 said that models were not overly difficult or expensive to use.

From this analysis, it would appear that those modelers having in-house experience in modeling generally thought that groundwater models were overly difficult or expensive to use. Further, those thinking the converse were generally using solely contractor, or a combination of their own and contractor, experience to justify their answer. While this is a bit of a mixed bag, the result does again support the need for additional in-house training and expertise in groundwater modeling tools. It is obvious that the level of Army in-house experience is greatly impacting the answers given to Question 6.

Question 8. In your experience, are groundwater models comprehensive enough to account for the major details of real field problems? ___ Alternatively, do you believe your organization generally collects data sets comprehensive enough for groundwater model use? ___ Figure 18 illustrates the responses to this question. Again, there is no clear trend in these answers. It is interesting that eight of ten Corps district/division respondents to this question said models were comprehensive enough; two-thirds of USAEC respondents said no. The responses to the data set question were

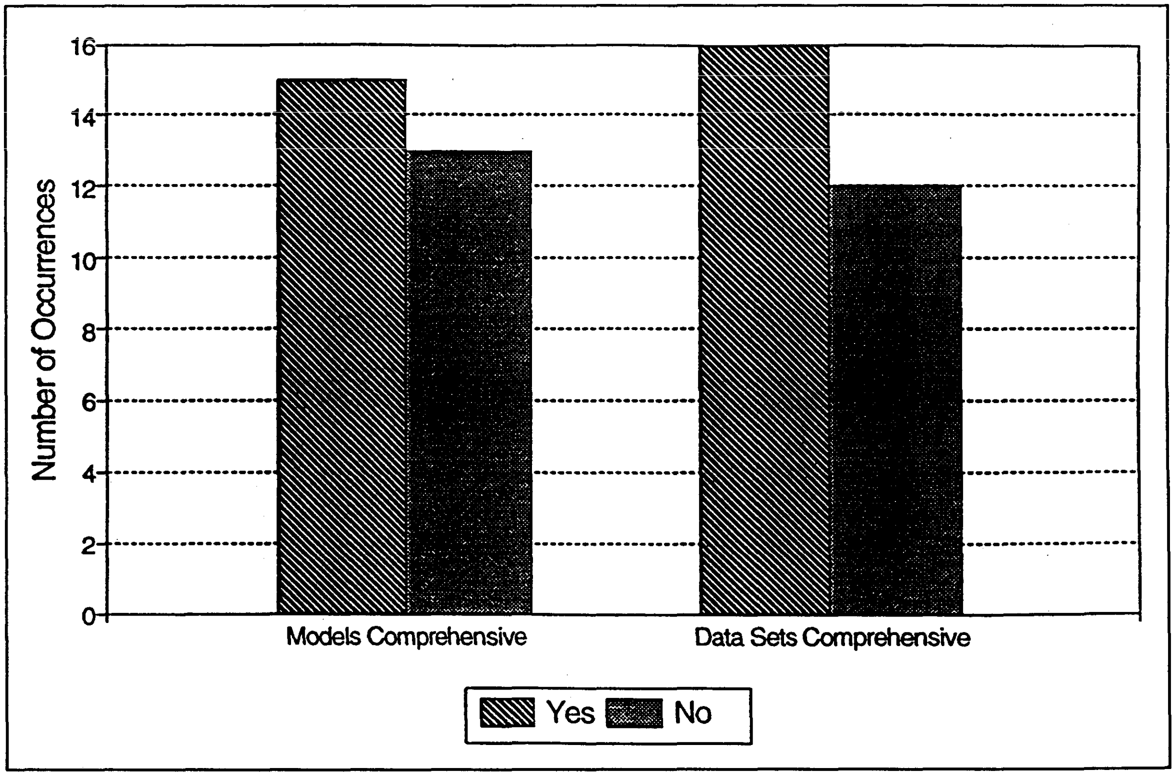


Figure 18. Are groundwater models and data sets comprehensive enough?

mixed. Additionally, 12 "experienced" modelers said models were comprehensive enough; eight said no (one did not respond). It is not clear what this trend suggests. It is entirely possible that many of the questions the Army is currently facing, especially in Corps district/division offices, can be answered with better packaging of existing technology. However, the results also suggest that the need is recognized by a sizeable portion of the user community for improvements to both models and data gathering techniques.

Question 9. Rank the following items by assigning them a High (H), Medium (M), or Low (L) importance in making groundwater models more useful tools for your site applications. Note that the abbreviation for each item appears at the end of said item.

___ **software for personal computers (PCs) or work stations with a graphical user interface that enables easier input of data to groundwater models (PCGUI)**

___ **software for PCs or work stations with a graphical user interface to aid in visualizing groundwater model results (PC Visuals)**

___ **software that would aid in extracting information from model results in the form of tables and plots similar to those now used to evaluate field data (Extraction)**

___ **interfaces that would couple groundwater models to CADD and GIS software (Interfaces)**

___ **a data base of typical geophysical and biochemical parameter values for specific soil types and contaminants (Par. Dbase)**

___ **a data base that would provide citations to pertinent published information on groundwater models (Cit. Dbase)**

___ **a probabilistic modeling capability that includes measures of uncertainty in geologic conditions, aid in parameter estimation, and theoretical limits of modeling reliability (Prob. Model)**

___ **guidance on the use and limitations of existing groundwater models for site characterization, feasibility studies, and remediation operation (Guidance)**

___ **an expert system to aid users in the selection of appropriate groundwater models. The system would also provide users with recommendations for model parameter selection (Expert Sys.)**

___ **groundwater modeling systems that have remedial alternatives integrated fully within their flow and transport models (Rem. Sim.)**

___ **Army-wide standardized groundwater modeling tools that have obtained EPA approval for use (Std. Mod.)**

___ **Army technical support personnel to assist in model choice and application (Tech Supp.)**

The results of this question are given in Figure 19. The trends in these results again illustrate the users' desires for improved methods for the use of existing models, as illustrated by the high marks for personal computer-based graphical user interfaces for existing models, and by the call for visualization and guidance on model use. From these three items, a second group, made up of extraction methods, expert systems, probabilistic models, general interfaces to a Geographic Information System (GIS), and standardized modeling tools, was bunched together in importance. These items point toward a combination of development for existing tools and the creation of new research products. Army technical support, integrated remediation simulation tools, parametric databases, and a citation database were the lesser desired products of those mentioned in the survey, in that order. It is interesting that the Army technical support item scored below the median line for all items in contrast to the general tone of responses to questions elsewhere in the questionnaire, which were quite positive on this point. Additionally, it may be possible that the ordering of all but the three items in the highest grouping reflects, again, the level of experience of the users at this time. The responses may more accurately reflect the field's overriding desires to do better with existing tools than any focused priority for the development of improved tools.

Question 10. If you are not using groundwater models for your groundwater cleanup studies, please indicate why (check each that is appropriate):

___ **Generally insufficient time for model usage within normal project schedules**

___ **Insufficient funding or time to learn the use in-house of most groundwater models**

___ **Insufficient in-house manpower to apply groundwater models**

___ **Insufficient time to contract groundwater modeling efforts**

___ **Insufficient funds to pay for contracted modeling efforts**

___ **Current groundwater models have insufficient levels of credibility for decision making**

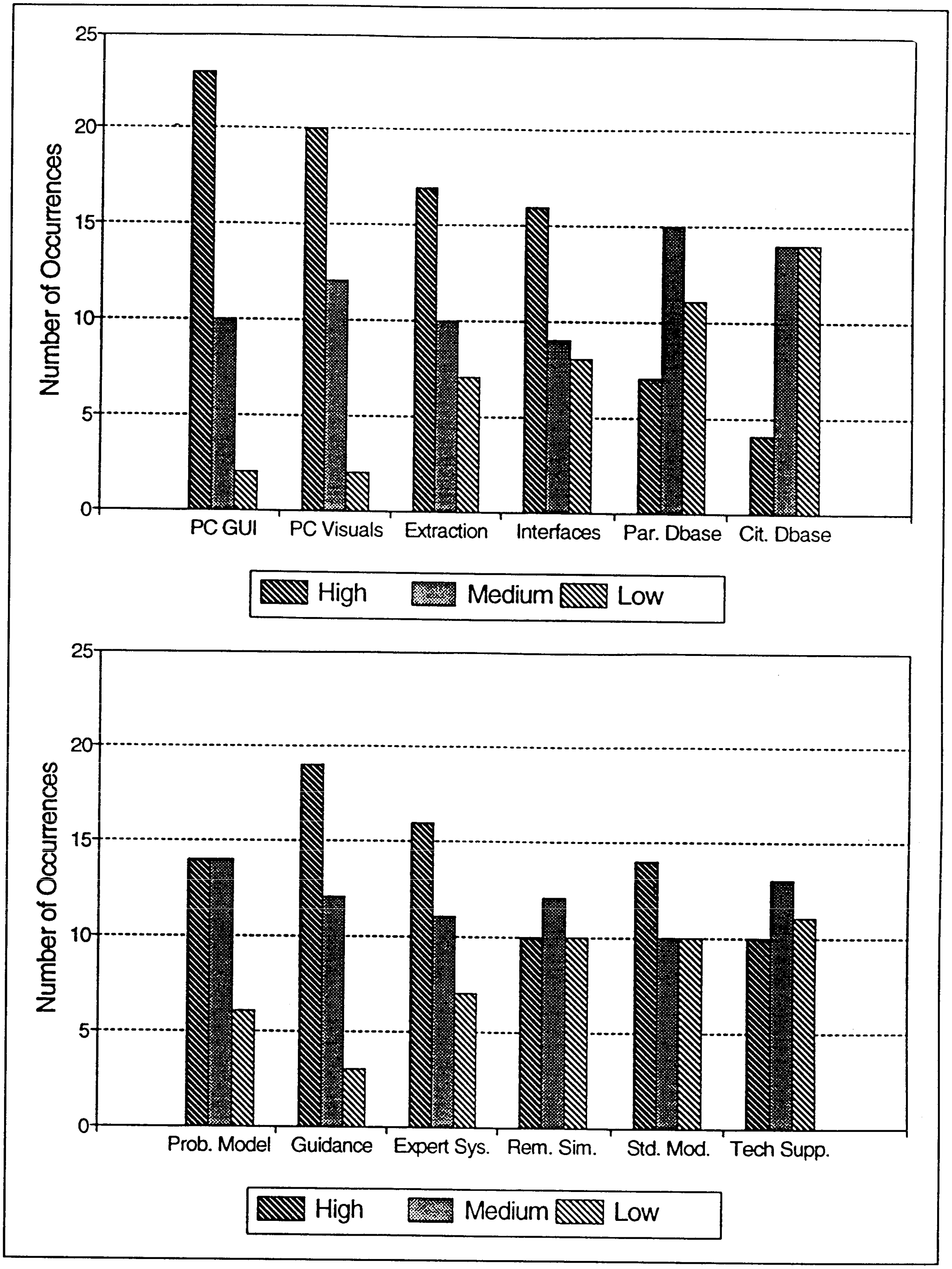


Figure 19. User ranking of potential modeling R&D activities

___ **Typically an insufficient amount of site data exists to warrant groundwater model use**

___ **No groundwater modeling was deemed necessary. Please explain the rationale for this decision** ______________

____

___ **Other; please explain.** ______________________

____

The most frequent responses for this question are given in Figure 20. Inadequate site data was the reason for not using modeling in remediation and site characterization studies. This is quite disconcerting, for it seems a complete site characterization or remediation scheme design would, in general, require the same data, or nearly so, as a modeling investigation.

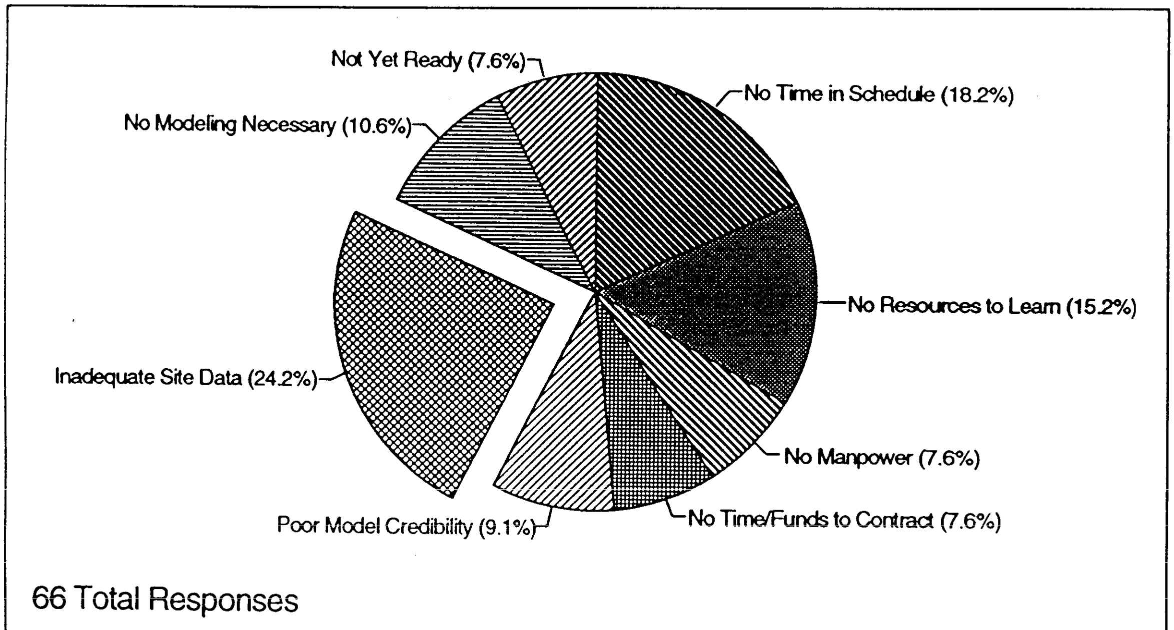


Figure 20. Reasons for groundwater model nonuse

The remaining responses illustrated in Figure 20 can be divided into two basic groups: (a) "Our schedules are so tight that we do not have the time, manpower, or funds to do an adequate job of modeling"; and (b) "We are not ready for modeling yet, or modeling is not ready for us." The lack of in-house experience discussed in many previous sections again comes into play in these answers. However, a second concern appears. Several respondents seem to be saying that the site characterization/remediation process itself, either through regulatory or Army rigidity, does not provide for ample time to do a concerted, complete modeling study. One must wonder, if this is indeed the case, how a concerted, complete site characterization or remediation design is effected.

Question 11. Would you employ models more often if the items above in Question 9 were available? ___ If the answer is yes, please be sure you ranked the items in Question 9. Of the 47 responses to this question, 19 said yes, 15 gave no response, and 13 said no. This leads one to ask what these results really suggest, given the distribution of the responses. The intent of the question was to ascertain if the conduct of the research and development discussed in Question 9 would induce more effective use of groundwater modeling tools. Taken at face value, it appears that some of the respondents to Question 11 would not make more effective use of groundwater models regardless of the development proposed. However, it may be that the question was framed too ambiguously to provide really usable results. For example, some of those answering no to Question 11 might believe that they were then using, or had already planned to use, groundwater models effectively prior to any proposed research and development. On the other hand, those answering no could be averse to groundwater models under any circumstances. Given the plausibility of each of these postulates, it may be advisable to discount the overall worth of the responses to Question 11.

Question 12. Do you have any access in-house to additional groundwater models that are not listed in Table 1? [See Appendix C.] **If so, please provide the names of those models below and whether they are run on personal computers (designate PC and class of PC; i.e., 286, 386, etc.), workstations (designate WS with workstation name) or mainframes (M with machine name):**

MODEL NAME	COMPUTER
____________	____________
____________	____________
____________	____________

Ten models, or direct variations thereof (usually associated with graphical interface extensions to the original model), were listed. The MODFLOW model (McDonald and Harbaugh 1984) led the way by far, followed by PLASM (Prickett and Lonnquist 1971), RANDOMWALK (Prickett, Naymik, and Lonnquist 1981), and SUTRA (Voss 1984). Several additional models were mentioned in individual responses. None of the in-house models were being housed on a supercomputer by the Army user community. In fact, all of the respondents stated that their models were operating on personal computers or workstations except two, who listed VAX hardware as their computing platform. The models listed, and the computing platforms mentioned, are very important in that they indicate a general requirement for personal computer modeling tools in the near future. The questions of what level of personal computer on which to conduct development (i.e., 286, 386, 486), and what level of development is appropriate given the changing hardware world will require additional review and discussion between Army model users and developers. However, there can be no question that the current computing platform of choice of the Army user community is the personal computer.

Question 13. When evaluating groundwater modeling proposals presented by contractors, which of the following is generally the <u>deciding</u> factor in contractor selection? (Check one please)

___ **Quality of proposal based on in-house technical review**

___ **Quality of proposal based on external technical review. Who generally conducts this review? ______________**

___ **Known reputation of contractor**

___ **Other; please explain ______________________**

Thirty-six responses were provided to this question as shown in Figure 21. The importance of this question, and the next one, is tied directly to the level of in-house experience the Army has in groundwater modeling. Recall that 80 percent of all ongoing or completed Army groundwater model studies have been contracted. Further, recall that one-third of respondents to this

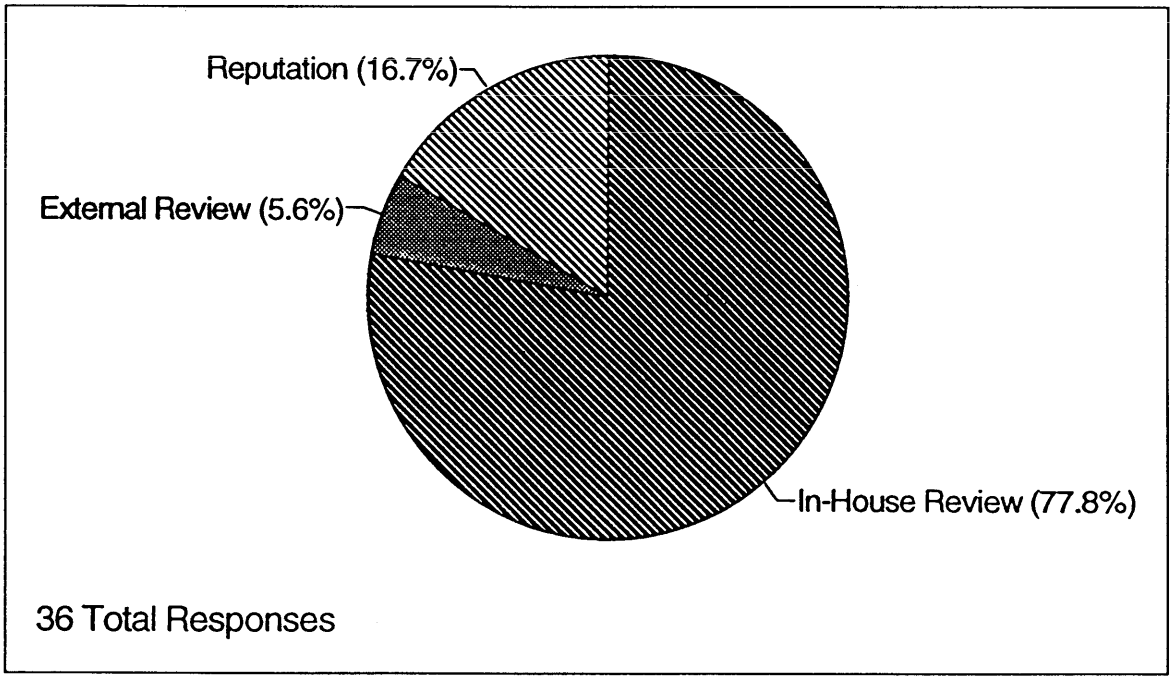


Figure 21. Methods used in evaluation of contractors' proposals for modeling

questionnaire have said that they feel they lack the experience to comment on whether groundwater models are overly expensive or difficult to use. With that, note that of the people who responded to Question 13, over three-fourths said they conduct in-house review only in the assessment of contractors' proposals. Note also that 6 of 36 respondents said they go primarily on contractors' reputations when assessing the worth of contractors' proposals.

Question 14. When groundwater modeling results are presented, which of the following is generally the <u>primary</u> means of assessing the reliability of those results? (Check one please)

___ **In-house technical review**

___ **External technical review. Who generally conducts this review?** ______________________

___ **Other; please explain** ______________________
____
____

The results of responses to Question 14 are shown in Figure 22. Note that in-house review is used almost exclusively to evaluate groundwater modeling results. Coupled with the results from Question 13, and recalling the overall experience level of Army modelers, it is imperative that steps be taken quickly to improve in-house groundwater modeling expertise. The ramifications of these results relative to the quality control of contractors' studies are unquantifiable from the results of this questionnaire.

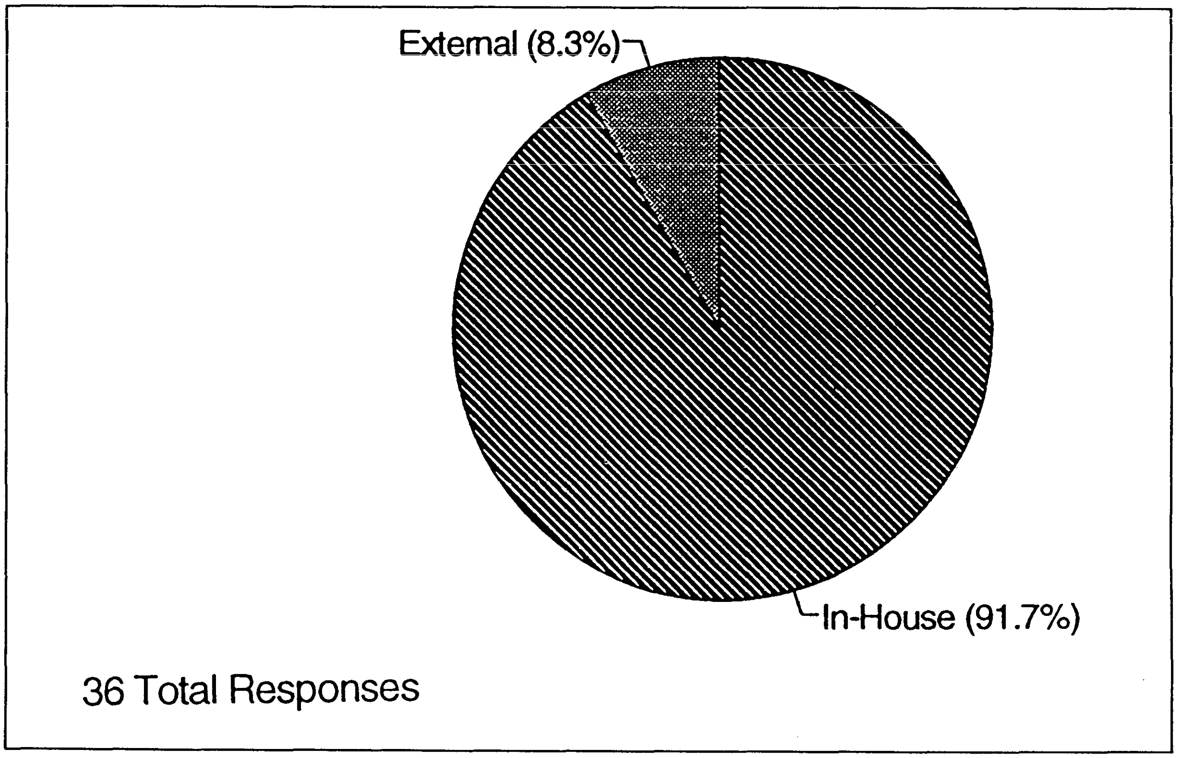


Figure 22. Methods used in review of groundwater modeling results

Question 15. Please provide any additional comments you have including your projected future needs for groundwater models.

____
____
____

A variety of comments were provided in this section. The most common response was an explanation for the respondents' failure to complete the questionnaire. The usual reason for this failure, or reticence, was a cited lack of modeling expertise required to complete the text.

Question 16. Please provide (reproductions or originals) of either cover pages or references to any contractor and in-house reports dealing with the modeling of groundwater flow and/or transport at Army sites. Reference materials were provided by several respondents. These materials are being used in-house.

Summary

In early February 1992 WES developed a questionnaire that solicited Army use of and experience with groundwater flow and contaminant transport modeling tools in support of contaminated site characterization and remediation. The questionnaire also sought user input on the research and development requirements for future model development. The questionnaire was mailed to 22 Corps district and/or division offices. Forty-seven (47) responses from 17 Corps offices were received. Additionally, questionnaire responses were obtained from 28 users at USAEC, representing seven USAEC elements, and from two Army installations (Aberdeen Proving Grounds, Maryland, and Fort Richardson, AK). While only two installations were polled directly, USAEC representatives provided input for all other known uses of groundwater models at Army installations.

These responses were analyzed for trends and content as presented in this Chapter. From these analyses, certain points have appeared:

a. The Army is presently investigating organic solvents, hydrocarbons, and explosives as their primary contaminants of concern. Heavy metals were listed as of medium concern.

b. The Army is performing modeling primarily for military installation restoration, followed by Superfund activities.

c. Army groundwater model users have limited in-house experience in modeling. To date, approximately 80 percent of all ongoing or completed modeling efforts have been contracted. Several questionnaire respondents expressed a lack of sufficient modeling experience to complete the questionnaire. There are organizations within the Army, however, that have acquired significant levels of modeling experience.

d. A sizeable portion of the experience base employed by Army model users for decision making regarding modeling results is derived directly from contractors' experiences and comments.

e. Users expect an increase in requirements for groundwater modeling over the next 5 years. Questionnaire respondents cited 67 expected modeling studies in the next 5 years, in contrast to the 61 ongoing or completed studies (over the last 10 years) reported.

f. The needs for all levels of training and guidance on the use, applicability, and limitations of groundwater modeling tools were stressed in users' responses.

g. The need to make much improved use of existing modeling tools through interface and visualization extensions to current models, modification of existing technology, etc., was stressed in users' responses.

h. Additional research and development needs, ranging from probabilistic model development to parameter database creation, were ranked by questionnaire respondents.

i. The need for Army in-house technical assistance was suggested by the overall tenor of users' responses. The form for this assistance was not recommended by users.

j. Most experienced Army groundwater model users felt existing models were overly expensive or difficult to use.

k. A variety of reasons for nonuse of groundwater models was reported. Chief among them were inadequate site data and resource limitations regarding model training, upkeep, execution, and analysis.

3 Panel 1: Groundwater Problems, Users Needs and Model Use

Objective/Scope of Panel

The scope of this panel was to provide the Army groundwater model user community with the opportunity to present their general insights into modeling experiences and more importantly their insights into requirements for future activities. The responses to the preworkshop users survey provide an overview of the user community's needs, but the panel discussion was able to amplify based on individual experiences past Army efforts in the modeling arena. Successes and failures of previous modeling efforts at IR sites were addressed. Suggestions were offered on the Army groundwater modeling user community's greatest needs, including their perception of future research needs in the field of groundwater modeling. Three state-of-the-art papers were presented, and a panel discussion with audience participation followed. Panel members and their affiliations follow; additional panel information is provided in Appendix D: Moderator, Mr. Ira May, USAEC; Mr. Brian Anderson, Program Manager, Rocky Mountain Arsenal; Mr. Khal Masoud, U.S. Army Engineer District, Baltimore; Dr. Fred Baker, Baker and Associates; and Mr. Sam Bass, U.S. Army Engineer Division, Missouri River.

Key Lessons from Papers Presented

"Description of Ground Water Modeling Experience for the RI/FS Process at the Rocky Mountain Arsenal," Brian Anderson, Program Manager, Rocky Mountain Arsenal

Rocky Mountain Arsenal (RMA) is both one of the most contaminated and most studied sites in the Army's IR Program (Figure 23). Some of the earliest groundwater model studies in this country to track and understand pollutant transport were done by the U.S. Geological Survey (USGS) in the 1970's at RMA. Perhaps the most famous was the one by Konikow (1977) using chloride as a tracer for modeling contaminant transport. While these early

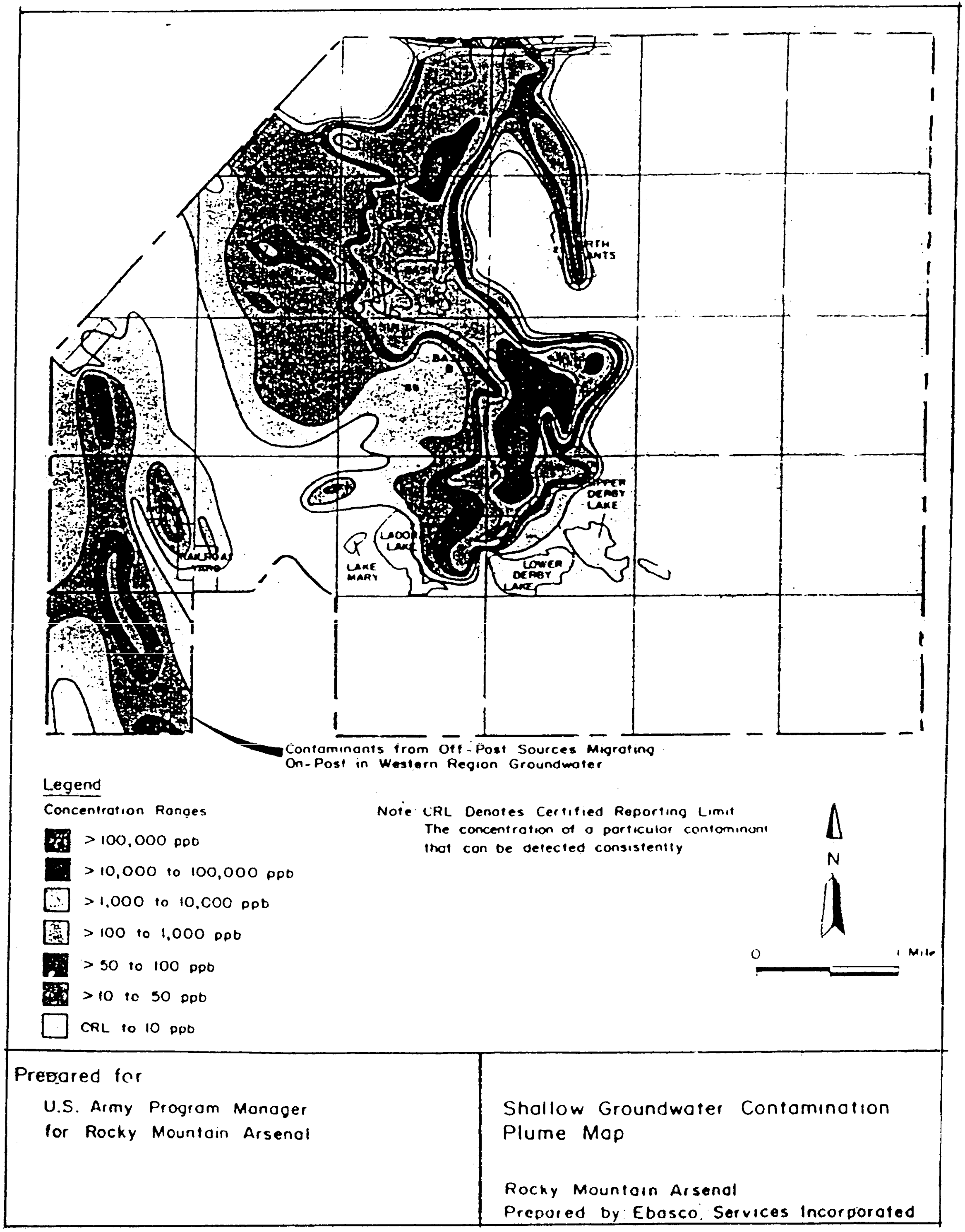


Figure 23. Rocky Mountain Arsenal Plumes (from B. Anderson's slides)

models can be termed crude by present-day standards, they helped provide an understanding of the hydrogeology of the RMA region. Since those earliest modeling efforts, approximately 30 models have been applied at RMA for differing remedial investigation purposes, design and operation of individual interim remedial actions, endangerment and risk assessments, and most recently water quality management.

Much of the early modeling effort at RMA, in hindsight, was wasted. One of the major reasons for these failures was the use of proprietary codes by different organizations. The codes and models became unusable upon the completion of the individual study. There is no way of running or updating these particular models with new data or with new scenarios that might have developed after the model was completed. Modeling efforts were often undertaken without an understanding of the data requirements of the model. Models were also developed without a clear-cut objective for the modeling effort. Finally, there was a lack of in-house Army expertise and resources to understand the results of individual models and how to use the information from one modeling effort to guide either the work being done at RMA or the next modeling effort.

Many of these major problems have been addressed by the formation of a peer review board for groundwater modeling efforts at RMA. This panel is made up of Army representatives, other governmental organization representatives, and modeling contractors (both academic and industrial). Formal presentations are made before this group on all proposals for modeling efforts and the results of all modeling efforts. This process has been a great help in ensuring that objectives are clearly understood, relevant past efforts are considered, and the latest modeling effort will be useful to the overall cleanup of RMA. In effect, this board, with its blend of state-of-the-art personal experience, overcomes for this one installation the technology transfer problem so strongly expressed in the user survey. While it is not certain that such a formal process can be set up at every installation doing groundwater modeling, it is certain that guidance of this type is desperately needed to ensure that modeling efforts are conducted efficiently.

"Overview of Major Remedial Investigation/Feasibility Study Work in Edgewood Area of Aberdeen Proving Ground, MD, as Related to Groundwater Modeling and Its Needs," Khal Masoud, U.S. Army Engineer District, Baltimore

Since 1917, the Edgewood Area of the Aberdeen Proving Ground has been the primary chemical warfare research and development center and a chemical agent production area for the United States. This long history of chemical production, research and development, and disposal has led to the designation of Edgewood Area as an NPL site with the identification of over 150 potentially contaminated subsites. These individual subsites have been grouped into 55 clusters. Groundwater modeling efforts under the direction of the USGS have been going on since the middle 1980's in the Canal Creek and O Field areas. Data collection has been challenging because of the large amount of unexploded ordnance (both chemical and conventional) in the study areas. These special risks have led to the development of remote drilling and sampling techniques, which, while safe for the workers, are very expensive and time-consuming. Much effort in the future is to be expended on developing less expensive data collection alternatives to the present methodologies.

To date, the majority of the groundwater modeling efforts have been conducted by the USGS using the USGS MODFLOW model. This three-dimensional model has been used to model a two-aquifer system with boundary conditions for the rivers and the Chesapeake Bay, which ring the site. This and future modeling efforts have the objectives of (a) characterizing the contaminant plumes; (b) determining migration pathways to potential receptor populations; and (c) simulating remediation activities. Modeling throughout the course of the field data collection efforts has proven fruitful, especially that done early in the process, in determining data requirements and study needs. These efforts have led to the conclusion that there is a need to further use and integrate state-of-the-art geostatistical and probability tools in the process. They will help in reducing the uncertainties in understanding the hydrogeological parameters that are critical for reliable groundwater modeling and are, of course, the hardest data to gather reliably.

"Development of Groundwater Modeling Objectives and Performance Criteria," Dr. Fred G. Baker, Baker Consultants

A common problem with modeling efforts seems to be the failure of the model to meet the expectations of the end user. This failure can be traced to several causes, which often lead to the end user feeling uncomfortable and burned by the modeling process. The major causes of this disappointment are (a) communication failures between the end user and the modeler; (b) a misunderstanding of the problem that the model is being created to address; and (c) a lack of understanding of the modeling objectives or the project objectives in general. Therefore in many ways, the most important activity of any modeling effort is the establishment of modeling criteria and objectives (Figure 24). The first step involves establishing project objectives and evaluating modeling needs. This step is basically a go/no-go decision on the modeling effort and in general defines the required level of modeling sophistication. After the modeling need is established, the specific project modeling objectives are determined. These objectives should include a definition of the major attributes or assumptions being made about the hydrogeologic system, the calibration criteria that will be used to evaluate the model at the end of the effort, and most importantly the expected limitations of the modeling effort.

Selected Questions and Answers

Question from Dr. Paul Hadala, WES, to Brian Anderson and the Panel

"Does your peer review panel look at just the plans for groundwater

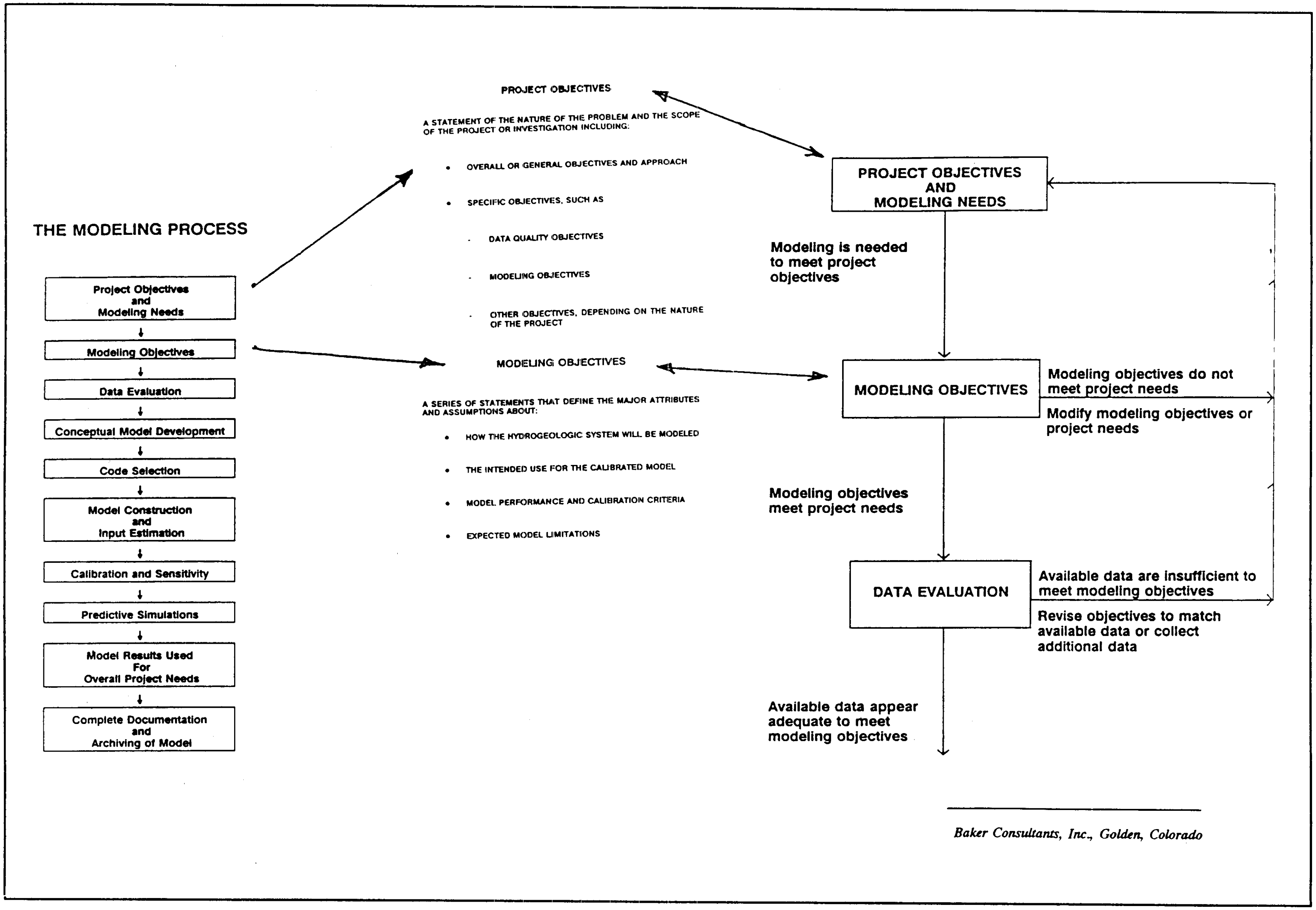


Figure 24. Key elements of the groundwater modeling process

models? Or does the panel also look at the modeling results?" Mr. Anderson responded that the peer review panel looked at the modeling effort at all stages, from start to finish. This answer started a panel discussion as to the availability and practicality of peer review panels at every installation for every proposed groundwater model. Mr. Anderson responded that historically RMA had never had the internal resources to really identify what their true objectives were. Groundwater modeling was understood internally as a tool, but not understood as to what the tool was accomplishing. Because of this lack of internal guidance and understanding of the modeling process, the results were often unsatisfactory. Often RMA had difficulties in just writing a good contract for modeling efforts. Therefore without good in-house modeling understanding or guidance, a peer review panel from outside the Army was the best possible mechanism for RMA. It would not necessarily be the best for other installations or situations.

Question from Dr. Robert Oswald, Headquarters, U.S. Army Corps of Engineers, to Panel

"It has been stated that a groundwater model would be useful from the beginning of the investigation process. If this is so, can I use the same model throughout the entire process, through the feasibility study and remedial design? Or do the changing conditions and level of data make that impossible?" Mr. Anderson answered that this was very difficult, especially because of the lack of in-house understanding of the modeling processes, and that the lack of institutional knowledge made such a long-term approach practically impossible. However, he further suggested that if proprietary codes were avoided, perhaps a Corps laboratory or the USGS would be in the position to help the installation make such long-term institutional arrangements possible. He reemphasized a point made by several panelists that modeling had to be looked at as an iterative process and that only institutional knowledge would prevent modelers from constantly reinventing the wheel.

Question from Dr. Oswald to Panel

"Have any of the models predicted the end of the necessity of remedial actions at RMA?" Mr. Anderson responded that the models predicted very long time periods, but that the early predictions had predicted quicker clean-ups. This led to a general panel discussion of the changing technology of groundwater modeling in the last 15 years and if it was appropriate to compare recent predictions with predictions made 10 or 15 years ago. The panel also discussed that it was hard to go back and look at 5- or 10-year-old modeling efforts, both because of changing technologies and because organizations rarely want to look at those older predictions. Organizations would rather move ahead, and it has been difficult to get resources for post-mortem type studies. However, the panel agreed that modeling studies and codes needed to be archived to allow such retrospective looks, and that much could be learned from post-mortem studies of past modeling efforts.

Question from Dr. Steve Grant, Cold Regions Research and Engineering Laboratory, to Panel

"The survey of end users identified that there was a large cost component in developing the data necessary to run a good groundwater model and that this was a major impediment. If this is the case, should research efforts be placed on developing models that require less data?" Ira May, USAEC, responded that from his perspective that would be an inappropriate use of research resources as he felt that the data needed to construct a good groundwater model were data on the parameters necessary to have any understanding of groundwater flow. After all a bad model is far worse than no model at all. The problem was not the types of data needed for models, but rather that these types of data were not routinely gathered at all sites. While these data can often be expensive to collect, knowledge of these parameters is necessary with or without mathematical groundwater modeling. He suggested that research efforts would be better spent on better data collection technology for these parameters than on trying to make groundwater models run with less data. This led to a general panel discussion on research needs to better understand the chemistry and physics of the subsurface, the transport of particular organic chemicals, and aquifer properties.

Comment from Sam Bass, U.S. Army Engineer Division, Missouri River

"One of the reasons we got together was to gather the end users together to give advice to the R&D community on what the users need. It appears to me that a majority of the users are reporting that models are too expensive and too difficult. The users did not identify a need for additional or new computer codes, rather help in using and understanding the existing codes. We do not need to spend our time and money developing new codes to reflect subsurface conditions; rather we need to spend that time on learning the existing tools and trying to get training on understanding the application of those tools."
Mr. Baker backed up that idea that what was required was better application of the existing models and the better understanding of the proper utilization of those tools. Since much of the proper usage of models has to do with the integration of the existing data from a site to a coherent form, cookbooks on how to apply a model are impossible to write effectively. That judgment comes through experience and training, and there is no reasonable alternative to that.

Summary

The panel discussed the specific models and installations that had been presented during the short papers. The exchange of lessons learned and experiences between installation projects proved quite valuable to many users in the audience. Some of the general ideas shared include the following:

a. Inadequate data for modeling is not an adequate excuse. The data will be needed to define the problem, not just the model.

b. Complexity of the modeling effort should be a reflection of the complexity of the problem.

c. Model capabilities and modeling efforts should never drive project objectives.

d. An established group of people to develop institutional knowledge of a site and to peer-review modeling efforts is a good idea.

e. The competitive contracting system creates problems for long-term modeling efforts. The only solution is in-house institutional knowledge of the program and of modeling processes.

f. The calibration process should not involve simply manipulating the hydrogeologic parameters to match the observations. Calibration should be more scientifically based by improving if possible the site conceptual model and understanding.

g. Future modeling should include optimization methods for design and should employ sensitivity analyses on site parameters prior to model application.

h. Save all previous models and data at a site. They will be useful for long-term comparisons as model capabilities and site characterization improve. More post-mortem analyses are needed as much can be learned from such studies.

i. Do not use proprietary codes.

j. Most problems with modeling efforts are miscommunication and misapplication.

k. Training in the use of and understanding of existing models is the users' most pressing need.

4 Panel 2: Model Use in Remedial Investigations (RI)

Background

The RI aspects of the overall RI/FS process at hazardous, toxic, and radiological waste (HTRW) sites involve field and laboratory studies commonly referred to as site characterization or site assessment. RI activities are inherently interdisciplinary, involving geology, hydrogeology, geophysics, and contaminant geochemistry. Groundwater modeling is or should be used before, during, and after the RI activities.

Objective/Scope of Panel

The Panel 2 presentations and discussion addressed a subject area that is commonly recognized as the most important and yet most difficult problem encountered in a groundwater modeling effort: defining the problem to be modeled. While the previous statement is true, it may contribute to a misconception that views groundwater modeling as a separate entity from the RI activities. The primary purpose of the RI is to define a site, in terms of geology, hydrogeology, contaminant sources, and contaminant transport processes and properties, to the extent necessary to support FS and remediation activities. Groundwater modeling plays an important role in the FS and remediation activities by evaluating remediation alternatives and assessing remediation effectiveness. However, groundwater modeling can also play a key role in conceptualizing site processes and planning the RI. Groundwater modeling during the RI is effectively used to enhance understanding of the site during data acquisition and to modify the RI strategy to more effectively address data gaps and uncertainties. Panel 2 emphasized the synergism between groundwater modeling and the RI process. This modeling/RI synergism is suggested in Figure 25, where a feedback loop, which includes groundwater modeling, remains active until remediation decisions can be made with "acceptable risk."

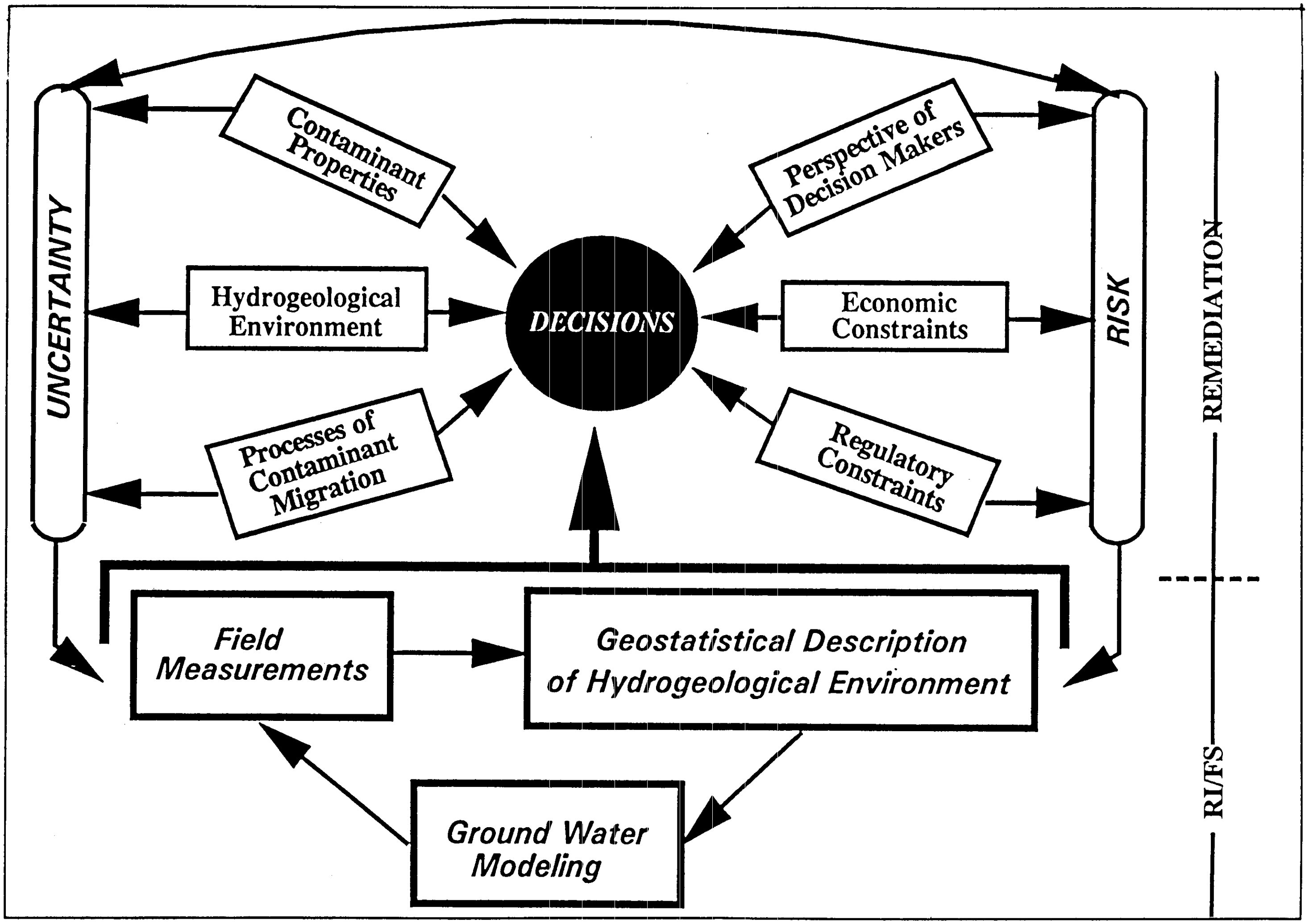


Figure 25. RI/GW Modeling/FS Synergism concept (adapted from the cover of class notes of the short course "Contaminant Hydrogeology: From Field Investigation to Remedial Design: A Strategy for Decision-Making," by P. A. Domenico, R. A. Freeze, F. W. Schwartz, and L. Smith

Among numerical groundwater modeling concerns are uncertainties related to the validity of the defining equations, accuracy of the numerical approximations to the defining equations, and accuracy of the computational algorithms. However, accuracy and uncertainty related to numerical groundwater modeling are at least second order in significance when compared to uncertainties related to definition of the geologic model, hydrogeologic model, and contaminant transport processes. Although the numerical models require definition of properties at all points in the domain of the model (the subsurface), this can never be achieved in practice. Field data must be interpolated and extrapolated in a statistically and geologically meaningful and rational manner to account for the geologic heterogeneity/variability and resulting parameter uncertainty that will inevitably exist after any site characterization/RI. The cost of reducing site characterization uncertainty by acquiring additional data must be balanced against the results of acceptable risk analyses.

The site characterization requirements addressed in the RI include definition of (a) geologic structure, stratigraphy and lithology; (b) hydrogeologic properties; (c) flow boundaries; (d) surface hydrology; (e) contaminant types, sources, properties and mechanisms; and (f) transport and transformation processes in the subsurface environment. The techniques used to obtain information for these definition requirements are diverse: geologic mapping; surface geophysical surveying; borehole drilling, sampling, and logging; borehole geophysical logging; borehole pumping tests; dye tracing; laboratory testing, including physical and chemical properties; and others. A large and/or complicated site will involve a significant data management effort and require a quality control and assessment program. The factors, considerations, and parameters that must be considered and determined in the RI are summarized in Figure 26.

The panel format consisted of (a) two synopsis presentations on hydrogeology/groundwater modeling and contaminant transport processes/groundwater modeling, (b) a case history presentation emphasizing the role of geostatistics in site characterization, (c) an interactive discussion (questions and answers) with Workshop attendees, and (d) a concluding statement by each panel member. Members of Panel 2 are listed as follow; additional information on this panel is provided in Appendix D: Moderator, Dr. Dwain Butler, WES; Mr. Carlos Tamayo-Lara, Colorado State University; Dr. Frank Schwartz, Ohio State University; Dr. Carl Enfield, U.S. Environmental Protection Agency Kerr Environmental Research Laboratory; Dr. James May, WES; Mr. Gregory Hempen, U.S. Army Engineer District, St. Louis; Mr. Dennis Bowser, USAEC; Dr. James Brannon, WES; and Dr. Jesse Yow, Lawrence Livermore National Laboratory.

Key Points from Panel 2 Presentations

"Groundwater Models and Remedial Investigation," Dr. Franklin W. Schwartz, Ohio State University

There are two approaches to groundwater modeling: (a) a conventional

Project Type

- DERA (Defense Environmental Restoration Act Program)
  - IR (Installation Restoration)
  - NPL (National Priority List)
  - Formerly Used Federal Properties
  - Other Hazardous Wastes
- Superfund Site
- Contamination Remediation
- Unexploded Ordnance
- Site/Remediation Monitoring

Geologic Environment

- Fractured Rock/Porous Media
- Consolidated/Unconsolidated Materials
- Aquifers/Aquitards (Permeable/Impermeable)
- Structure, Stratigraphy and Lithology
- Heterogeneity
- Geometry and Scale
- Parameter Uncertainties

Hydrogeologic Environment

- Boundary Conditions
- Hydraulic Head Distribution
- Unsaturated/Saturated Flow
- Steady State/Transient
- Hydraulic Conductivity Distribution in Three Dimensions
- Porosity Distribution in Three Dimensions
- Saturated Thickness Distributions in Three Dimensions
- Contaminant Source Locations
- Initial Conditions
- Parameter Uncertainties

Contaminant Properties and Transport Mechanisms

- Single/Multiple Species
- Soluble/Insoluble
- Density (Relative to Water)
- Conservative/Nonconservative
- Advective Transport
- Dispersion/Diffusion
- Chemical and Biological Reactions/Transformations
- Retardation/Decay
- Radionuclides
- Parameter Uncertainties

Data Management and Quality Assurance/Quality Control of Field Surveys and Laboratory Measurements

RI and Groundwater Modeling Synergism

Figure 26. Factors and considerations in RI's

approach and (b) a state-of-the-science approach. The conventional approach is the norm, and the same general strategy is followed at all sites, regardless of site-specific details. The conventional approach has some important advantages:

a. It requires little technical sophistication, and the same standard tests are performed according to more or less standard procedures by the same personnel at all sites.

b. It is relative easy to manage, since there is little deviation from one project to the next.

c. It is simple from the perspective of regulators, since proposals, scopes of work, and final RI reports all look very similar from site to site.

d. The standardization leads to a homogeneity and simplification of management and execution and is the least expensive approach.

There are, however, some serious disadvantages to the conventional approach:

a. In many cases, the site is not adequately characterized to support groundwater modeling, FS, and ultimately the decisions which must be made.

b. It results in a very unpredictable cost of remediation.

c. It gives few clues regarding the time required to remediate and the effectiveness of remediation.

The conventional approach typically uses state-of-the-practice methodology, which in many cases is not equivalent to the state of the art. A state-of-the-science approach requires "cutting edge" technology and the best available personnel. The state-of-the-science approach discussed here is a model-based, mass transport approach to RI, where the ideas and procedures of a modeler are applied to RI. Procedures and techniques used in the mass transport approach will vary from site to site. Generally the model-based, state-of-the-science approach will involve a general methodology that requires the geo-scientist to (a) identify the contaminants and their distribution at the site, (b) identify the transport processes and the key parameters that describe/quantify the processes, and (c) develop a measurement strategy that will enable the determination of the key transport parameters. The advantages of the model-based approach are as follows:

a. Sites are much better characterized and problems are better defined; data gaps are less likely.

b. The results are presented in forms which directly support groundwater modeling and FS.

c. Remediation/cleanup costs are more predictable.

d. It is easier to predict compliance as a result of remediation.

The disadvantages of the model-based approach are as follows:

a. Better trained, specialized personnel are required.

b. Field and laboratory measurement programs and interpretation tools are more exotic.

c. RI planning, management, and regulatory oversight become more difficult, since each site/project will have an individualized RI.

d. The RI will be more expensive than for the conventional approach.

In summary, the model-based, state-of-the-science approach will result in a better site characterization and a greater chance for successful remediation.

Groundwater modeling is important early in the RI process as an aid in conceptualizing the site geology, hydrogeology, and contaminant transport. Early site modeling has tangible benefits that include (a) an awareness of the key processes and parameters, (b) a feel for the sensitivity to changes in parameter values, (c) identification of deficiencies in background data, and (d) a valuable aid in designing the RI. Inverse groundwater modeling is used during the RI to determine hydrogeological and transport parameters from field measurements. An expert system-based inverse groundwater modeling program called Expert ROKEY (McClymont and Schwartz 1987) was described, and an example presented of its use with varying amounts of input data. The program has embedded knowledge to guide the user through data input, and can be a valuable aid for problem conceptualization and for parameter determination from field measurements.

"Contaminant Transport Processes, Determination of Important Processes for a Given Site," Dr. Carl G. Enfield, U.S. Environmental Protection Agency

Three areas relevant to contaminant transport processes were briefly discussed: (a) hydrogeological factors contributing to significant differences between contaminant transport model calculations and field measured values; (b) chemical transport processes; and (c) transformations. In situ, hydraulic conductivity can vary by orders of magnitude over short distances (microscale variability) depending on the geologic environment of deposition (Figure 27). This hydraulic conductivity variation has the effect of allowing rapid flow and transport in some regions and much slower flow and transport in nearby regions. Commonly, based on a very limited number of hydraulic conductivity measurements, this is modeled by some "average or typical" hydraulic conductivity value, when in actuality there is no typical value, and a large dispersion coefficient is used in an attempt to account for observations. This practice applies a theory to the wrong problem, for only if the hydraulic conductivity distribution is completely random (very small correlation distance) will

Figure 27. Variation in geologic environment of deposition

Processes that act to delay chemical transport, relative to the flow, are commonly described by partition coefficients, which to many people may seem like "voodoo magic." Partition coefficients can vary significantly from one part of a site to another, and can vary significantly along the path of transport of a contaminant, as the contaminant concentration varies. Partition coefficients in the literature assume only water and one contaminant compound, where the contaminant is an organic, neutral, nonpolar material and the partitioning (sorption) is to the organic carbon in the soil. If all the assumptions are valid at the site, the theory works fairly well as long as the contaminant concentration is very low (dilute). However, at many sites, the concentration is not low. Also at many sites, there will be a mixture of chemicals, nonaqueous phase liquids (NAPL's) as well as dense nonaqueous phase liquids (DNAPL's), and there may be more than one solvent, such as alcohol.

Cosolvents, such as alcohols, and additive surfactants have the effect of speeding up contaminant transport. With surfactants, there is a critical concentration. Below the critical concentration, the surfactant can be treated as a cosolvent with water; above the critical concentration, the surfactant and water must be considered as a multiple-phase system. Other factors, such as residual saturation of an organic compound in a soil, can delay contaminant transport relative to predictions using a simple partitioning model for transport through a "pristine" soil. The residual saturation will not only slow contaminant transport but will act as a contaminant source for many years (possibly centuries).

Transformations involve chemical or biological interactions that change the nature of the contaminants being transported through the geologic media. Most contaminant transport models assume first-order kinetics for describing transformations. However, transformation rates are not first order for all chemical interactions, for all geologic media, and for all concentrations of the chemicals. Generally, two chemicals must be in intimate contact, i.e., at the same place at the same time, for major transformation to occur; this implies transformations. However, transformation rates are not first order for all chemical interactions, for all geologic media, and for all concentrations of the chemicals. Generally, two chemicals must be in intimate contact, i.e., at the same place at the same time, for major transformation to occur; this implies that mixing must occur. For cases where one contaminant displaces another in a soil/water/contaminant system, transformation may occur in a narrow zone on either side of the contact surface, but mixing and hence transformation may not occur on a large scale.

"Geostatistical Characterization and Stochastic Ground Water Modeling, Offpost Operable Unit, Rocky Mountain Arsenal," Mr. Carlos Tamayo-Lara, Colorado State University

The key reason for groundwater modeling problems and failures is poor site characterization. The success or failure of groundwater modeling depends on how well the site is characterized. Likewise, the success or failure of activities leading to the design, construction, and operation of remedial measures is dependent on the understanding (characterization) of the site geology. Two factors that must be addressed in all RI and groundwater modeling efforts are uncertainty and aquifer heterogeneity. Any groundwater modeling effort that characterizes an aquifer with a single value of hydraulic conductivity, single value of saturated thickness, etc., can give, at best, only a crude approximation of flow and transport through the aquifer, although this type modeling is useful before and during the RI. The final geological/hydrogeological/transport process model that provides the input data to groundwater modeling for FS and remediation should include/account for aquifer heterogeneity and parameter uncertainty.

The application of geostatistics and stochastic process theory to characterize geologic heterogeneity and parameter uncertainty is illustrated by a site characterization effort at an offpost area north of RMA. Three statistical techniques/procedures were described for characterizing heterogeneity and parameter uncertainty: parameter semivariogram for determination of variances and spatial correlation distances; kriging for parameter estimation in areas where there are no measurements; and co-kriging for parameter estimation in areas where there are no measurements of a given parameter, but where there are measurements of another parameter that is correlated to the given parameter (such as transmissivity and saturated thickness). The parameter semivariogram is analyzed to yield a correlation distance that describes the distance from a given measurement position at which the parameter values are correlated or spatially continuous. Kriging is a technique for estimating parameter values away from measurement points that have the same variance and spatial correlation structure as the measured data. In many cases, only a few values of hydraulic conductivity (usually the most undersampled variable) will be available in an area; however, there will generally be substantially more values of saturated thickness, and hydraulic conductivity and saturated thickness will likely be correlated (as they were for the case presented). Co-kriging improves the estimates of the undersampled variable, based on the correlation. The kriged and co-kriged estimates are used in stochastic process modeling for remediation alternative evaluation and predictions.

Selected Questions and Answers and Panelist Comments

Question to Dr. Enfield by unidentified speaker

"Can you see a use for a model such that it could justify a 'no-action' at a particular site?" Two cases were identified by Dr. Enfield that might justify a "no-action": (a) where the natural chemical and biological processes that are taking place will reduce the plume concentration to below regulatory criteria before leaving site boundaries; (b) where there is sufficient dilution from natural water input to reduce the concentration at the points of control to below regulatory criteria. "No-action" could be justified by modeling in these cases if the processes and input parameters are carefully documented and the modeling procedure is demonstrated to be realistic for the site.

Question to Dr. Schwartz by Mr. Stephen White, U.S. Army Engineer District, Omaha

"Many times the Districts are assigned 'modeling tasks' with very little data; often another party has acquired the data and there is no option to obtain additional data. There is a great need for basic modeling tools with 'low learning curves,' such as Expert ROKEY, that can be used as learning tools themselves and can help conceptualize flow and transport, particularly at sites with limited data. With respect to doing the more complex RI [model-based approach] up front, we have a lot of trouble getting architect-engineers [A-E's] to go through and manage and carry out the more simple...or more standard task [conventional approach]....[What do we do to] get them capable to do this, and what parameters, in specific, are you talking about getting up front in that more model-oriented RI?" Dr. Schwartz stated that the problem of encouraging more proactive science-oriented RI is a difficult one, because the level of education of the responsible parties is the limiting factor. More sophisticated RI will come only through education. The parameters that are missing most frequently in the conventional approach, that are needed in the state-of-the-science approach, are all the critical mass transport parameters. Personnel conducting RI are more accustomed to determining groundwater flow parameters than the mass transport parameters, and the transport parameters are neglected.

Comment, Mr. Mat Johansen, U.S. Army Engineer District, Walla Walla

"On my wish list of the ultimate model is a model that helps the user effectively link the input uncertainty with the variability and the output uncertainty. I think we may deceive bosses, regulators, and the public when we give single [simple] answers to complex problems. I look forward to any research and development of modeling that helps us deal with that [uncertainty]."

Comment, Mr. Greg Hempen, Panel Member, U.S. Army Engineer District, St. Louis

"I would like to mention a pet area, that I think there is reason to save considerable amounts of money on site investigation....And that is the classical geologic input of depositional information [environment of deposition]. If you know the depositional environment before you go to a site, all your site samples mean much more than they would in a stark sense....The new field of geostatistics and the classic geologic depositional history will give much better answers much sooner."

Comment, Dr. James May, Panel Member, WES

Dr. May reemphasized the importance of understanding and quantifying geologic heterogeneity and parameter uncertainty. Dr. May stated "...regardless of what model is ultimately used [for groundwater modeling], you have to have the correct conceptual model and input parameters and get a handle on geologic uncertainty."

Comment, Dr. James Brannon, Panel Member, WES

"...I can't overemphasize the importance of really understanding the geochemistry and the chemistry of the contaminant which you are dealing with, in addition to understanding geological properties of the site and the formation and the way that the water moves, because if you don't understand all the other processes that are occurring, that are contaminant specific, then I don't think you will do a very good job of modeling or being able to predict what's going to happen at the site."

Comment, Dr. Jesse Yow, Panel Member, Lawrence Livermore National Laboratories, Department of Energy

"The DOE [Department of Energy] faces environmental restoration problems similar in magnitude to the DOD. There are differences in emphasis, but also some common ground. The four areas of primary interest to the DOE are as follows:

a. Subsurface contamination; solvents (DOE has TCE [trichloroethylene] contamination on virtually all its properties).

b. Petroleum products; DOE has its share of hydrocarbon spills.

c. Heavy metals and radionuclides (a departure from DOD concerns).

d. Energetic materials, explosives, and propellants (the magnitude of this problem is less for DOE than for DOD)."

Miscellaneous comments and suggestions from workshop attendees

Personnel in Corps districts and at military installations frequently do not have the training and experience to enable them to adequately review the progress and results of groundwater modeling and site characterization input to the modeling process. Also the personnel are often not equipped to make informed decisions regarding when to model, when not to model, and the level/extent of groundwater modeling appropriate to given situations. The Army needs a unified strategy and guidelines for application of groundwater modeling. An Army in-house capability for evaluation, assessment, verification, and validation of groundwater modeling results is needed. An Army-wide methodology for quality control and quality assurance of site characterization and groundwater modeling would greatly enhance the role and success of groundwater modeling in the RI/FS process.

Written Comments on the Tenets of Good or Usable Groundwater Models, Mr. Hector Magallanes, White Sands Missile Range

Mr. Magallanes provided the following comments:

a. Easy to input variables, hopefully from database.

b. Easy to use, i.e., user friendly, with prompts asking for data and "Help" function.

c. Clearly specifies limitations and what kinds of geologic and hydrogeologic conditions that it can represent well (two-dimensional flow, constant head, plug flow, homogeneous, isotropic, etc.).

d. Not unnecessarily complex to use.

e. Allows for easy sensitivity analysis of results.

f. Designed for the novice who has the capacity to learn.

g. Microcomputer (PC) based.

h. Takes into consideration retardation due to organic carbon, vapor phase transport, mass transfer, aquifer thickness.

i. Ability to do inverse calculations for hydrogeological parameters.

Summary and Research and Development Requirements

Summary

The following points summarize the key facts relevant to the subject of Panel 2 that were presented and discussed during the workshop:

a. A state-of-the-science, groundwater modeling-based approach to remedial investigations will result in predictable and decreased remediation costs and verifiable results.

b. Groundwater modeling should be used early and throughout RI for conceptual model formulation and program planning/modification.

c. The RI should be planned and conducted with the objective of supporting groundwater modeling, FS, and remediation, and not just to develop a database of facts about the site.

d. Geostatistics is currently the best way to rationally account for uncertainty and heterogeneity.

e. The Army needs an in-house capability to evaluate/assess/verify/validate groundwater modeling results.

f. There is need for an Army-wide quality assurance/quality control methodology.

g. The Army needs a unified strategy for application of groundwater modeling.

h. Many problems that are being encountered in practice are not technical, but caused by regulatory requirements, timeliness, budget, etc.

i. An increased emphasis on fundamental geology is needed, e.g., environment of deposition, characterization of types, and scale of heterogeneity, etc.

j. Many fundamental contaminant transport processes that are contaminant specific are poorly understood; the Army needs an enhanced understanding of fundamental transport process, particularly for solvents, hydrocarbons, and explosives.

Research and development requirements

The following research and development needs and requirements were identified:

a. Better guidelines and new procedures to make use of fundamental geology in RI planning and execution and site conceptualization.

b. Better understanding, new measurement techniques, and new/better modeling capability for contaminant transport mechanisms and processes.

c. Development of groundwater models or procedures for parameter sensitivity analyses and for linking input uncertainties to model output uncertainties.

d. Valid procedures for modeling transport at high contaminant concentration levels.

e. Development of procedures for identifying numerical transport (contrasted to physical transport) when it occurs during groundwater modeling.

f. Development of guidance on the appropriate level of analysis/modeling versus problem type/complexity and on personnel/time/cost to accomplish the objective.

g. Development of better, more effective mechanisms for groundwater modeling technology transfer.

h. Development of mechanisms for transitioning state-of-the-science approaches to RI to actual application and practice.

5 Panel 3a: Model Use in Remediation, Part 1

Background

The primary purpose of remediation activities is to protect human health and the environment. This overall objective is accomplished, where necessary, through implementation of passive and/or active remedial action alternatives. Once the site is characterized in the RI and the risk assessments establish appropriate remediation goals, numerous alternatives for attaining the established cleanup requirements may be evaluated during the FS process.

Panel 3 addresses one of the main reasons for developing an Army groundwater modeling system, i.e., the need to integrate the capability to evaluate the effects of remediation into groundwater flow and contaminant transport models. Panel 3 is divided into two subpanels. The objectives of Panel 3a are twofold:

a. Inventory modeling applications in the remedial alternative evaluation and implementation process.

b. Identify research and development issues related to the technically effective and cost-efficient use of groundwater modeling during the FS process.

As an increasing number of large complex contaminated sites move toward remediation, it is becoming increasingly important to develop methods to predict the performance of various subsurface remediation options. These performance models are critical to predict the potential cost effectiveness of remedial alternatives and to determine whether a particular technology is likely to achieve risk-driven remediation goals.

One state-of-the-art paper was presented and a panel discussion with questions from the audience followed. Panel 3 members (made up of subpanels 3a and 3b) are listed as follow; additional panel information is provided in Appendix D: Panel 3a Moderator, Dr. John Cullinane, WES; Mr. Jack Genereaux, U.S. Army Engineer District, Kansas City; Mr. Jim Zeltinger, U.S. Army Engineer District, Omaha; Mr. Don Koch, Engineering Technical Associates; and Dr. Gaylen Brubaker, Remediation Technologies, Inc.; and

Panel 3b Moderator, Ms. Tomiann McDaniel, HQUSACE; Dr. James Warner, Colorado State University; Dr. Randall Ross, U.S. Environmental Protection Agency Kerr Environmental Research Laboratory; Dr. C. Y. Chiang, Shell Development Company; and Ms. Carol McKinney, U.S. Army Engineer District, Kansas City.

Key Lessons from Paper Presented

Dr. Gaylen Brubaker, Remediation Technologies, Inc., presented a paper, "Process Options for In Situ Subsurface Remediation." This paper, using a case history approach, describes typical subsurface remedial action alternatives considered during the FS process. Two sites were described: a petrochemical facility on the Gulf Coast and a Superfund site in the Midwest. The subsurface remedial action alternatives considered at these sites included the following:

a. NAPL recovery.

b. Pump and treat.

c. In situ bioremediation.

d. Vapor extraction techniques.

Nonaqueous phase liquid recovery

In cases where a large release of material occurs, solubility limitations may result in the formation of NAPL's. Depending on density, NAPL's are classified as light (LNAPL) and dense (DNAPL). NAPL recovery incorporates the removal of "product" from the ground. Product recovery may result in a recyclable material or a concentrated waste material. A simple NAPL recovery system is shown in Figure 28. Multiphase models are required for evaluation of NAPL removal alternatives. Rules of thumb for evaluating NAPL removal alternatives are also being generated by the EPA. Parameters of interest in evaluating NAPL removal alternatives include viscosity, density, interfacial tension, and relative permeability.

Several techniques are available to enhance NAPL recovery. These range from merely increasing the head in the aquifer system to rather elaborate systems incorporating surfactant addition or hot water flushing (Figure 29). Hot water or steam processes are particularly significant for removal of DNAPL's. Raising the temperature of most DNAPL's reduces their viscosity and results in improved product recovery. From a modeling perspective, there is a need to model the effects of temperature and the chemical interactions of various additives with the NAPL's.

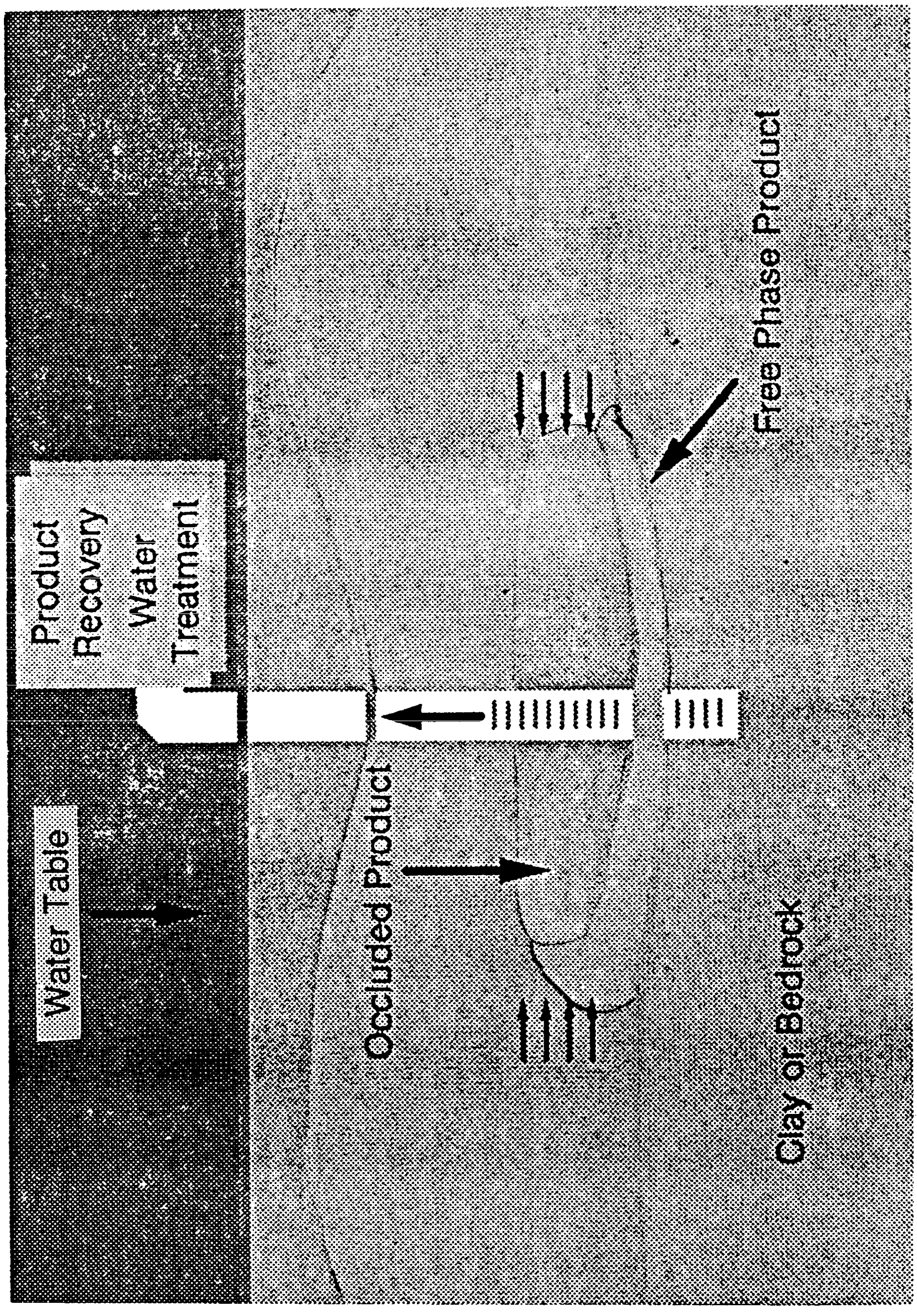


Figure 28. Simple NAPL recovery system

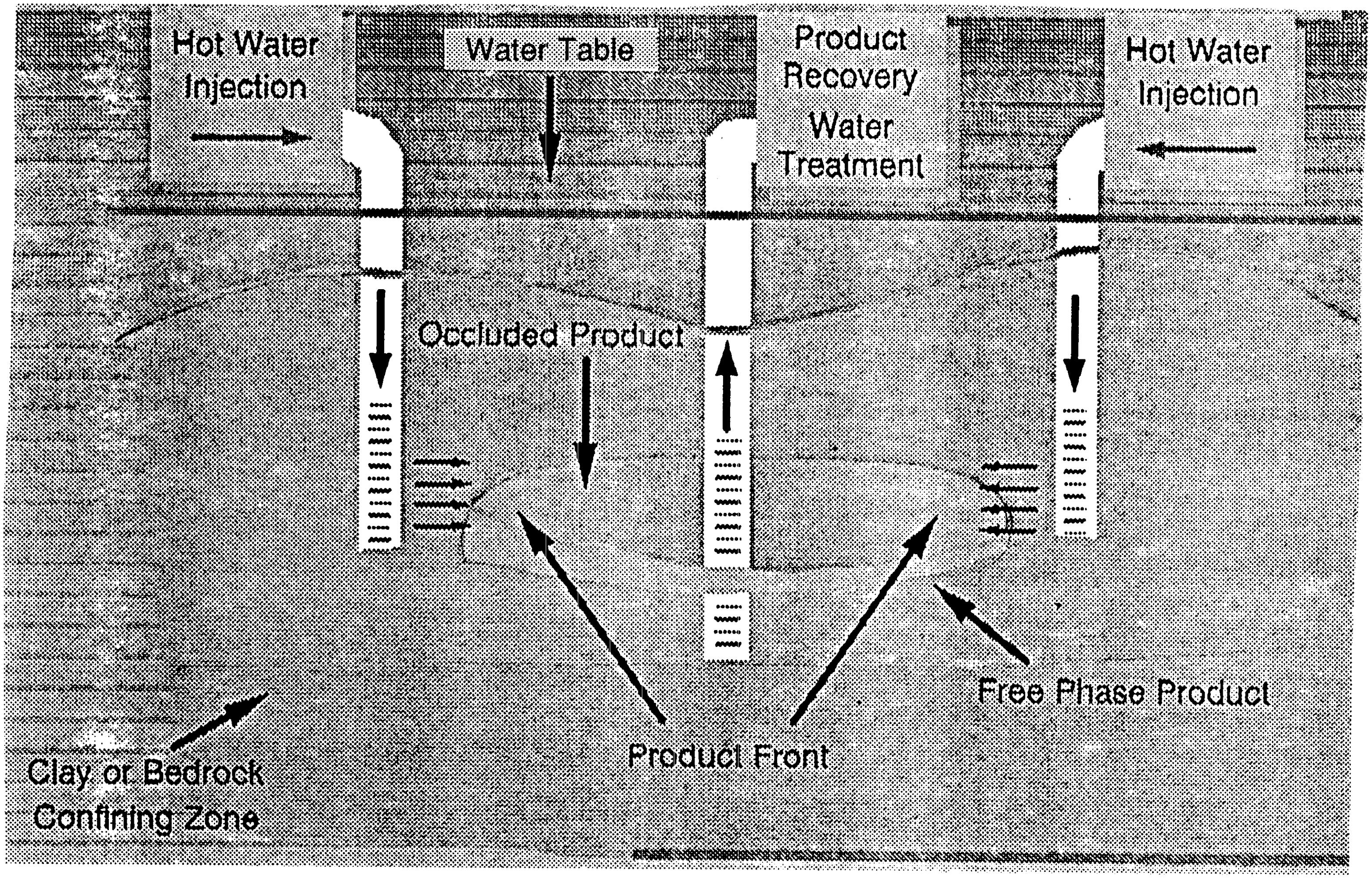


Figure 29. Enhanced recovery of dense organics using hot water flushing

Pump and treat

Pump and treat is the grandfather of subsurface remedial alternatives (Figure 30). Pump and treat systems employ extraction wells to simply pump the water to the surface for treatment. A variant of traditional pump and treat systems is the use of interceptor trenches for shallow groundwater systems. Enhanced pump and treatment systems (Figure 31) are also being developed.

Limitations of pump and treat systems include the following:

a. Contaminants may be insoluble.

b. Contaminants may be retained in unsaturated soils.

c. Geology may be complex and poorly defined.

d. Pumping can create dead zones.

e. Groundwater flow is limited in low permeability zones.

Original models for pump and treat systems were rather simplistic groundwater flow models. More sophisticated models, incorporating contaminant transport, are being developed. These models are beginning to account for such phenomena as advection, diffusion, partitioning, adsorption/desorption, biological degradation, etc. The sophistication of the model selected for use on a specific site should be appropriate to the complexities of the site. Different models may be appropriate at different stages of alternative development and evaluation.

In situ bioremediation

In situ bioremediation is an extremely popular concept (Figure 32). Very simple models of bioremediation process are currently used. Factors of interest in modeling the bioremediation process include the following:

a. Microbial versatility and diversity.

b. Microbial environment (pH, oxygen supply, temperature, nutrients).

c. Bioavailability of organic contaminant (thermodynamics, accessibility to enzyme systems, solubility).

Vapor systems

Vapor recovery systems are used primarily in the unsaturated zone; however, they have some application to remediation of the saturated zone. Vapor recovery systems, which are essentially in situ air stripping, incorporate the movement of air through the porous media. A variation on the vapor recovery

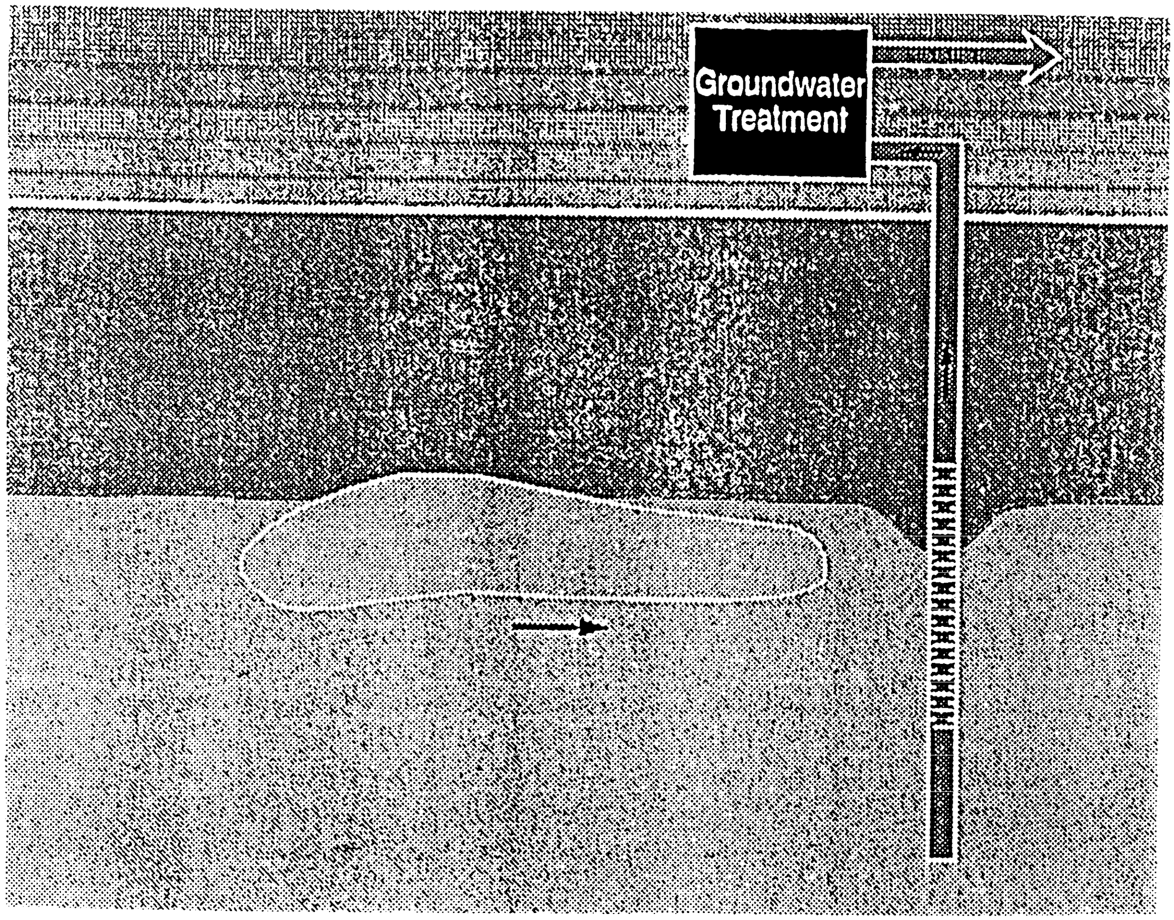


Figure 30. Simple pump and treat system

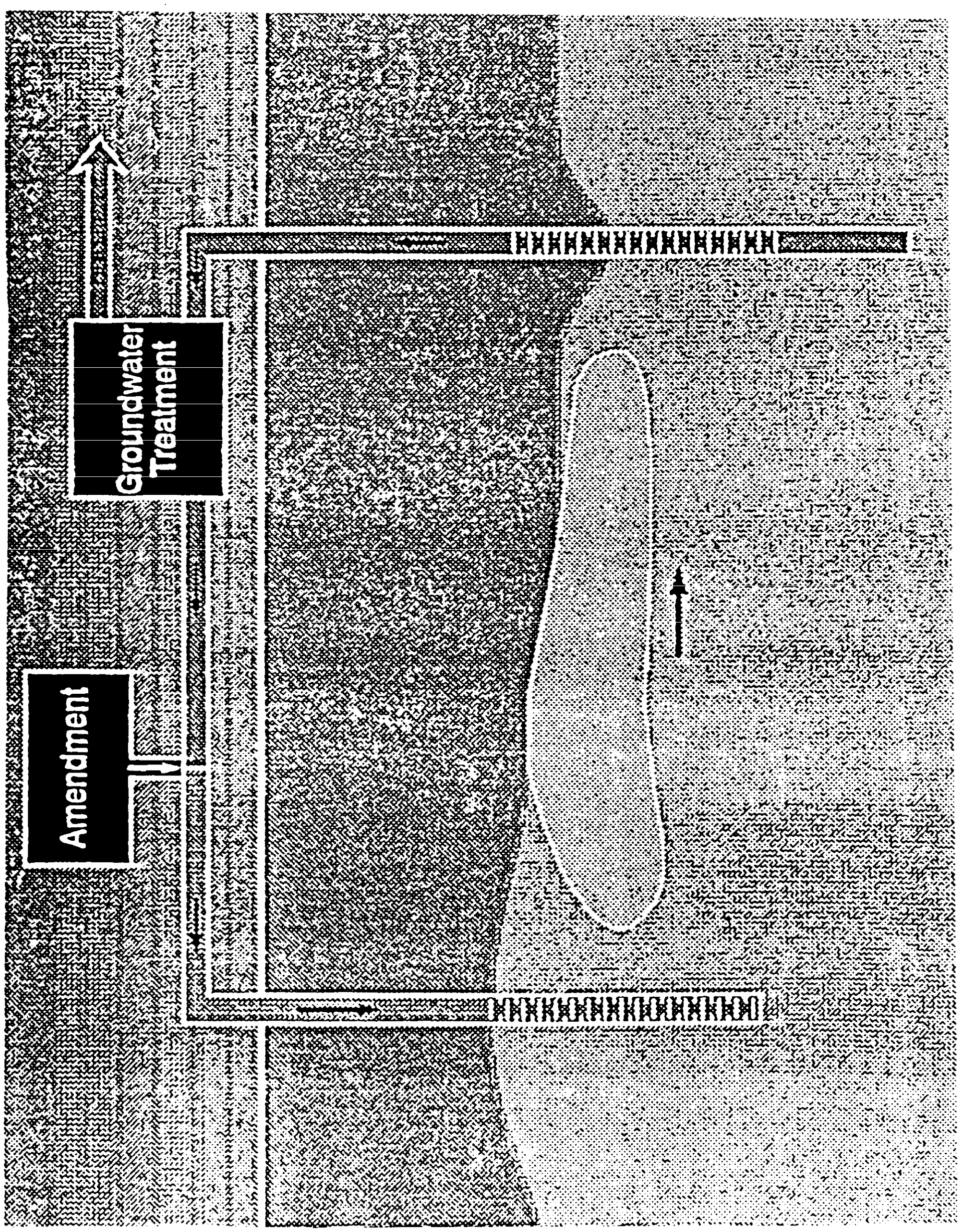


Figure 31. Enhanced pump and treat system

system is aquifer aeration. Henry's law and partitioning effects from the aqueous to the air phase are important considerations. Important modeling considerations include the following:

a. Vapor pressure.

b. Vapor density.

c. Diffusivity.

d. Aqueous solubility.

Selected Questions and Answers

Question to Dr. Brubaker from unidentified speaker

"The use of hot water flushing to convert DNAPL's to LNAPL's was an interesting prospect, but can't you create a much larger zone of residual saturation that way?" Dr. Brubaker replied that design and operation considerations can be used to minimize the possibility of this occurring. This is a technology that is used in the oil industry. Two pilot studies that evaluate this technology for the recovery of DNAPL's are currently underway.

Question to Dr. Brubaker from unidentified speaker

"Where are we in the use of genetic bacteria for remediation?" According to Dr. Brubaker, there are a variety of thoughts on this issue. Within the in situ bioremediation community, there is a strong preference for using the natural bacteria rather than trying to inject foreign bacteria. He thinks the injection of genetically engineered bacteria is a long way off.

Question to panel/participants from Dr. John Cullinane, WES

"Is modeling used to justify the no-action alternative?" According to Ms. Tomiann McDaniel, Headquarters, U.S. Army Corps of Engineers, the no-action alternative has been justified and selected for a variety of sites.

Comment from unidentified speaker. "I am working on a site where we are hoping to incorporate a no-action alternative. Modeling is definitely needed to justify compliance as far as concentrations at points of compliance."

Comment from Dr. C. Y. Chiang, Shell Development Company. "I think that modeling plays a crucial role if you have a no-action alternative."

Comment from Mr. Bass. "We have a site where modeling was used to justify a no-action alternative. This site used unsaturated zone modeling to predict the impact of contaminant release on the underlying groundwater."

Question from unidentified speaker

"Does anybody know how much data is required for a really good model? Can you say a number? How much should I pay for groundwater modeling?"

Comment from Dr. James Warner, Colorado State University. "It all depends on the objective of the modeling effort. There are no fixed rules on the type of model, data requirements, or costs."

Comment from Mr. Don Koch, Engineering Technologies, Inc. "There are a variety of interpretations on what a model is, ranging from merely extrapolating data to analytical models to complex finite difference/element models. The decision on what is appropriate has to be based on the amount of data you have or the uncertainty you need to resolve your problem."

Comment from Mr. Bass. "The time required for modeling also needs to be considered."

Summary

The issues and topics identified during the Panel 3a discussion can be categorized into four broad areas: technology transfer, communications, process science, and modeling science. The technology transfer and communications categories are oriented more toward the Corps of Engineers institutional environment, whereas the process and modeling science categories are associated with traditional research and development activities.

Technology transfer

The most important concern for the users attending the workshop is the technology transfer issue rather than "pure" research and development issues. The users require information on the existing state of the art and the application of existing models rather than the development of new models. Technology transfer is perceived as an immediate need. Technology transfer requirements stated by the audience included training, technical guidance documents, management guidance, and a formal technology update mechanism. See Chapter 7 for more detail.

Communications

The acceptance and efficient use of modeling depend on improved communications and interaction between modelers and the various disciplines that are using the information produced by the models. Specific issues included the following.

Improve scoping. Modeling and the use of information provided by models is a multidisciplinary activity. Each discipline (hydrogeologist, chemist, engineer, etc.) has different expectations for modeling and modeling results. The interaction between these disciplines should be improved and initiated early in the process. Modeling should be considered in the scoping process.

Objectives. Specific objectives should be developed and included in the definition of model expectations. Objectives should be written to incorporate the requirements of each discipline.

Jargon. The various disciplines should use terminology meaningful to other disciplines.

Process science

Process science relates to the physics, chemistry, and biology of groundwater flow and contaminant fate and transport. It was generally agreed that an improved understanding of the physical, chemical, and biological mechanisms associated with groundwater flow and contaminant transport is needed.

Groundwater flow. The physics of groundwater flow is a major aspect of development of accurate models. Users appeared to agree that the understanding of the groundwater flow portion of the overall problem is much further advanced than the understanding of the physical, chemical, and biological phenomena associated with subsurface transport of contaminants. Three issues were identified: multiphase flow, flow in the unsaturated zone, and flow in frozen soils.

Contaminant transport. The physical, chemical, and biological interactions between chemicals and soils need to be identified and mathematically described. Care should be taken to ensure that there is the capability to accurately evaluate diffusion, sorption, desorption, biological degradation, etc.

Modeling science

Use existing models. In general, users appear to be of the opinion that existing models are adequate for current needs. The use of existing models should be stressed. Improvements in existing models should be considered, but this is not a high priority. The most pressing need is to provide guidance on existing models. Procedures for use and application are needed. Many users felt that they did not have sufficient information or knowledge with which to make recommendations concerning research needs.

Universal model. Development of one "universal" model is not appropriate. A family of models may be more appropriate. Both analytical and numerical models have their place and should be viewed as arrows in the quiver of the engineers and scientists conducting a remedial action.

Model enhancement. Improvements to existing models should be oriented toward input requirements and output displays. Input needs to be user-friendly and output needs to be understandable. Output should be improved to provide for better visualization using graphics.

Model attributes. Several users provided a list of model attributes, summarized as follows:

a. If at all possible, the model should run in the PC (preferably on a 386 generation processor) environment.

b. Input data requirements should be minimized, subject to unacceptable reduction in model accuracy.

c. Models should include optimization capabilities.

d. Run time is extremely important. It is essential to be able to make numerous runs.

e. Models should include uncertainty analysis.

f. Models should include default data; however, some mechanism should be provided to prevent model misuse by novice modelers.

g. Models should have graphical input features, i.e., mouse input.

h. Methods for easy data input should include procedures to allow for the inclusion of output from prior runs into input of subsequent runs.

i. Models should easily accommodate various remedial action alternatives. For example, it should be easy to put in such features as extraction wells, extraction trenches, recharge wells, recharge trenches, barriers, and surface infiltration. The models should have the capability to simulate various remedial alternative operation scenarios such as pulse pumping.

j. Models should provide a time-phased estimate of contaminant concentrations in extracted water.

k. Models should be user-friendly.

Model calibration/verification. Procedures for model calibration/verification should be developed. Calibration/verification techniques should not require collection of inordinate amounts of data. Techniques should be developed that optimize the use of data.

Data requirements. Procedures and methods for obtaining data should be simplified. Techniques to incorporate existing databases with the modeling process should be developed. Interfaces with GIS type systems would improve model application and be more efficient.

6 Panel 3b: Model Use in Remediation, Part 2

Background

The feasibility study and site remediation process result in the implementation of a carefully considered course of action designed ultimately to protect human health and the environment. When such a course of action involves operation of a contaminated groundwater management or remediation project, it may range from fairly straightforward to quite complex. The variability may be due to the hydrogeologic conditions, the objective of the remediation, or the system design itself.

Objective/Scope of Panel

The scope of this panel was to discuss the potential benefits and other issues related to using groundwater modeling in the operation phase of groundwater remediation projects.

Key Points from Panel 3b Presentations

"Case Study: Gilson Road Superfund Site," Dr. Randall Ross, U.S. Environmental Protection Agency

Groundwater modeling is best approached as an iterative process beginning with the RI and continuing through the evaluation of feasible alternatives to design of the remedial action and assessment of remedial action performance. A numerical groundwater model can be useful in testing a conceptual site model to determine the validity of data interpretation and the relative value of additional data points. Once the objectives of the remediation are determined, numerical modeling is useful in evaluating the effectiveness of different methods of obtaining those objectives. The efficiency of a groundwater pump-and-treat or containment design can be enhanced through the use of groundwater modeling. As illustrated in this case study, groundwater modeling is also useful in evaluating the effectiveness of pump-and-treat systems and in determining potential locations and pumping rates for future extraction wells or recharge trenches.

Evaluation of the Gilson Road Superfund Site remedial action using monitoring data led to reevaluation of the numerical groundwater modeling originally done to design a containment project. Several problems were found with the original conceptual site model including poor characterization of the source and an incomplete understanding of the site hydrogeology, despite having what might be considered a well-characterized site, i.e., over 100 monitoring points in a 20-acre (8-ha) site. The importance of maintaining continuity throughout the process was illustrated when the data files from the original modeling activity by a contractor could not be located in order to continue with further groundwater analyses by another contractor.

The use of a reputable consulting firm did not guarantee that good modeling practices were used in later modeling attempts. Some of the problems noted include modeling a heterogeneous aquifer in a homogeneous manner, significant adjustment of site physical features in order to calibrate head data, incorrect location on the model grid of physical features with hydraulic impact, and significant size differences between adjacent nodes.

The integration of proven flow models with transport models and geostatistics in order to evaluate the effectiveness and efficiency of a pump-and-treat system is being tried on this site. A GIS will be combined with the modeling activities to aid in presenting volumes of data in a meaningful way. The use of GIS packages helps with data input to a numerical groundwater model as well as with management of data generated by modeling activities. This is considered to be the future trend in data/model interfacing and data management.

"Use of Numerical Groundwater Modeling for Operation and Management of the North Boundary Containment System at the Rocky Mountain Arsenal," Dr. James Warner, Colorado State University

A detailed numerical groundwater model of the North Boundary Containment System was developed to aid the RMA in its operation of the barrier system. Since this barrier system was one of the first of its kind, there was no previous operational experience on which to base decisions. Management of such a system turned out to be a complex task.

To answer the detailed operational questions being asked by RMA, a finite element model (CSU-GWFLOW) with a very fine grid (14,000 nodes) was used (Warner 1987). This allowed each well to be represented by separate nodes. Direct comparison of model results with field data was possible with this configuration. Transport of contaminants was not modeled.

Model calibration with an average error of about 0.5 ft (0.15 m) was achieved through the use of steady-state and transient calibrations. This was possible because of the amount of field information that was available. Lack of monitoring data did, however, present problems.

The model was used to explore what operational changes would work best to achieve the desired results in management of the contaminated groundwater plumes. Overpumping of wells with installation of recharge trenches has been used to reverse gradients across the system. The model was also used to predict the time available before undesirable effects from a system shutdown would be felt. This allows RMA to plan, not merely react.

There is now a good body of experience gained through the operation and management of this barrier system, which should be studied by anyone involved in designing or operating a contaminated groundwater management system.

"Bioremediation - Parameters Estimation, System Design, and Prediction of Cleanup Time," Dr. C. Y. Chiang, Shell Development Company

Models are a useful aid in designing bioremediation systems. It is imperative to the success of the design that the physical processes at the site are well understood and that site-specific parameters are used in the model. A case study was used to illustrate the interactive nature of modeling and data gathering.

Field data were gathered and analyzed in order to make hypotheses about the processes that were taking place. Modeling was used in these analyses. Additional data collection and modeling were done as the hypotheses were refined. Laboratory studies were also used to supplement and further correlate the trends that were observed from the field data. This procedure led to a better understanding of the processes that were and were not taking place in the field.

Modeling was then used to aid in designing an injection and capture system. Multilevel injection wells were used to assure the oxygen was available to the entire contaminated aquifer. Pure oxygen at a concentration of 40 ppm was injected into the site. A system to prevent iron precipitation was used and nutrients were also added. The nutrients were later found to be unnecessary.

There are many uncertainties that must be considered when modeling attenuation or transport processes. Some of these problems can lead to what appear to be abnormally high predicted contaminant concentrations when compared to field data. The sampling method can affect apparent concentrations of contaminants. Correlations between monitor well sampling and formation sampling were found to be poor, possibly due to dilution effects. Water table fluctuations change the effective screen length and so affect the average concentration of contaminant at that sampling point. The source term is very important to the way contaminants begin to migrate, and its accurate definition can have significant impact on the accuracy of transport models. Partial penetration effects can also be important in the model and must be considered when defining aquifer thickness.

Having the appropriate regulators involved along the way in this process was very important. By being familiar with the thought processes and the analyses that were taking place, the regulators were willing to allow some innovative things to be done on the site.

Selected Questions and Answers and Panelist Comments

Comment, Dr. Warner, Panel Member

"Modeling can be used in the design stage to consider the effects of the proposed design on existing groundwater users in the area of the project and also help to predict what effects other new groundwater projects may have on an existing or proposed remediation system. When you start looking at how these types of projects need to be operated in conjunction you will see that the real lesson to be learned is it's not a trivial problem to turn a few wells on and solve your problem."

Comment, Ms. Carol McKinney, Panel Member, U.S. Army Engineer District, Kansas City

"We modeled quite a large site in Nebraska for a project. I was skeptical about what a number of irrigation wells that were pumping most of the summer would do to our plume, and we modeled that quite successfully. The modeling has helped us understand what has happened at the site and to anticipate having to shut down some of the irrigation wells and supply water from another source to those people."

Question to the Panel from Dr. Cullinane

"I was wondering if anybody has actually gone back and looked at how the system actually performed and compared that to the initial modeling effort and tried to decide whether or not the model was actually a success?"
Dr. Chiang's comparison of the actual capture zone (as determined by head data from monitoring wells and piezometers) to the flow model predictions of capture showed complete agreement. Dr. Brubaker commented that whenever you have injection into an aquifer, you should use modeling to control hydraulic gradients. Without using modeling in conjunction with trial and error, you can get very far along in your project before you are able to determine if you are getting the type of performance you need.

Question to Dr. Chiang from unidentified speaker

"What model did you use to help design your extraction and injection system?" He proposed that BIOPLUME, basically the USGS Method of Characteristics (MOC) model (Konikow and Bredehoeft 1978; Goode and Konikow 1989), was used.

Question to the Panel from Mr. W. Dickinson Burrows, Biomedical Research and Development Laboratory

"Is there any need to continue developing a method of estimating physical, chemical properties for organic materials: solubility, absorption, partition coefficients?" Mr. Koch replied that the two greatest sources of uncertainty in his transport modeling are the source term and the contaminant/soil adsorption characteristics, so more work is needed in this area.

Question to Panel from Mr. White

"We are having massive problems with biofouling of some sort or other in otherwise productive wells. Is there any way to model this problem?" Dr. Stewart at the University of Buffalo has done a lot of work in modeling those efforts using the basic biofilm modeling processes, so there is a mechanism to model this. Most of the work has been done in laboratory scale, columns, and filters, and they work. But there is some work out there and some modeling.

Summary

Many good ideas were expressed during the panel discussion related not only to operation and monitoring of remediation activities, but to all aspects of environmental restoration. The research and development needs that were identified and major points from the panel discussion follow.

Research and development needs

Methods are needed to quantify the biological, geochemical, and hydrogeological processes that are occurring and how they interrelate.

Development of a process to determine the cost-benefit ratio of numerical modeling is needed. How do professionals quantify to management and customers the potential benefit of undertaking a costly, time-consuming modeling project when they want to see action instead of more study?

Ways to better characterize source terms are needed in order to improve the predictive capabilities of contaminant transport modeling activities. Better definition of the processes such as dispersion that affect bioremediation are needed.

Benefits could be gained by developing software to help relate model input and output to data management and presentation software such as GIS's.

Major points

The need to maintain continuity between successive modeling activities on a project was stressed. Many instances were cited when activities needed to be tied into earlier modeling studies that were no longer available. Guidance on minimum documentation requirements for every modeling activity would help to establish continuity.

In situ remediation technologies are still fairly new. There are many uses for models in the design and operation of such systems. Modeling can be very useful in helping to determine the types and placement of monitoring devices needed to accurately evaluate performance.

The operational complexity of groundwater remediation projects was emphasized. Modeling was illustrated as a very important tool in optimizing the efficiency of a pump-and-treat system.

Everyone must consider at the beginning of any modeling activity how success is to be defined. Comparison of the model predictions to actual field data gathered after implementation of a remediation activity should be a part of every project.

The concern that seemed to echo throughout the workshop was people did not feel they had the knowledge and other resources at their disposal to take full advantage of the powerful tool that numerical modeling can be. Development of general and specific guidance to aid people in making better use of groundwater modeling and having appropriate training available are necessary to alleviate this concern.

7 Technology Transfer Mechanisms

The Army User Community

The workshop and the questionnaire defined a near-term technology transfer challenge to bring the state of Army practice in in-house groundwater modeling and in Army contractor groundwater modeling closer to the state of the art (see Summary, page vii, subparagraphs *b*, *d*, and *e*, and page viii, subparagraphs *d*, *e*, and *h*). Indeed, many of the findings in the Summary deal with the user community consensus that state-of-the-art computer codes are available but the knowledge and experience on how and when to use these codes are not in the hands of in-house Army users. Training, guidance (technical manuals; standard scopes of work; and specifications for contracting, planning checklists, and product review checklists, etc.), and a source for in-house technical assistance were suggested.

The Army user community can be divided by role. First, there are those who are concerned with the technical management of the risk assessments, remedial investigation, remediation, and/or postremediation monitoring at a given site. They make decisions as to what project and modeling objectives are and whether or what general kind of numerical modeling should be done and when (see Figure 24). Second, there are those who execute all or parts of the modeling process (again, see Figure 24) when the work is done in house. These people set up the data, run the groundwater codes, and analyze the output. Finally, there are those who write the scopes of work for contractor modeling, technically monitor contractor efforts, and technically review the contractor's product. Ideally, people in this third group should be people who have had extensive experience in the second group so they will be smart buyers of technology. In many instances, Army individuals are performing some of these roles at the same time.

Near-Term Means of Transferring Technology (1-2 years)

The users recognized that the fundamental kernel of groundwater modeling technology is knowledge and experience and that all else was a means toward that end. The presentation and especially the discussion of case histories of use of groundwater modeling in Army and other HTW problems presented at the workshop proved to be beneficial for the participants. Learning took place through the sharing of experiences and guidance by peers. This is a most effective way to help everyone grow on the experience curve. It is recommended that an Army Groundwater Modeling Workshop (note the minor change of title) be continued on an annual or biannual basis. Emphasis would be on sharing of experiences from case histories and the state-of-the-art improvements.

Based on user comments, the Army today has at least 100 individuals needing varying forms of training in groundwater modeling for HTW applications. Based on reasonable employee turnover, it can be anticipated that even when this need is filled, there will be enough new people needing training to support a continuing PROSPECT Course[1] every few years.

As a prelude to such a course, a committee should establish a curriculum that involves a concise representation of the fundamental principles and processes and hands-on (i.e., a learning laboratory) set up, execution, and interpretation of results from groundwater flow and transport models. Rather than rushing into adopting a curriculum for a formal PROSPECT course, the first attempt at this training event should be a workshop (possibly 2 weeks duration) using a mix of in-house and academic resources. This will allow faster response to the field need than a formal course and will provide room for some experimentation with the training scenario before finalizing the curriculum for a PROSPECT course.

Checklists for (a) developing scopes of work, (b) report content, and (c) report review for contracted groundwater modeling efforts are needed and could be developed in the near term. Example decision trees and benefits/limitations checklists could be developed to help accomplish the processes described in Figures 24 and 25. A task group of experienced model users from government, industry, and academia should be established to develop these checklists. Users also asked for time and cost estimating guidelines for groundwater modeling studies. Information on cost and duration of past studies could be collected and provided to those planning future in-house and contract efforts in this area.

The RMA review panel (page 32) is a concept that should be more widely used and could be implemented quickly. This is technology transfer via the use of a small group of consultants who are at the cutting edge of the state of the art to impart just enough of the best technology to the project staff

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[1] A 1-week PROSPECT Course tentatively entitled "Geotechnical Aspects of Hazardous and Toxic Waste Sites" is presently under development by the Corps and scheduled for first presentation in May 1993. It will not teach how to do numerical modeling of groundwater flow transport but will provide an awareness that technology exists in this area.

PROSPECT is an acronym for "Proponent Sponsored Engineer Corps Training," which is a large body of technical, management, and administrative short courses established by the Corps and managed by the US Army Engineer Division, Huntsville.

responsible for action to get a good solution to a site-specific problem. Funding vehicles could be established to enable the entire Army HTW community to use these consultants (a small group of recognized experts from academia, various Corps organizations, and/or other Federal agencies) for this purpose.

Midterm Technology Transfer (2-5 years)

Guidance taken to its logical conclusion includes a technical manual on groundwater modeling. Indeed, conference and survey participants asked for such a manual. Preparing such a comprehensive document is a major project. The manual would be comparable to a major textbook. If it is to be a reasonably sized document, its development must be preceded by choices of (a) which few of the numerous existing groundwater flow and transport codes it is to be written around (van der Heijde, El-Kadi, and Williams 1988), (b) whether to repeat (for the sake of having all the information in one place) or just supplement the information available in existing code documentation, (c) whether to include software with the manual, (d) whether to improve certain of the software to make it easier to use (easier input/output) before promulgating it, (e) what kinds of examples to include in the manual, and (f) how to teach the process of reviewing site investigation results, developing a conceptual model of the site, and how to select model input parameters from site investigation data. The reason this manual is proposed for the midterm category (although the field says the need is immediate) is related to items (a)-(d). A Corps research and development Work Unit entitled "Groundwater Model Assessment" is scheduled to be completed in Fiscal Year 1994. Its products in 1993 will provide management with the information needed to decide items (a)-(d). Another reason is that the development of a comprehensive technical manual is not a short or easy technical task, and once the information (items (a)-(d)) is available, there is at least a year's effort involved in creating the document.

Consideration should be given to the establishment of an in-house technical center of expertise in numerical modeling of HTW groundwater flow and transport that the Army could draw upon either to do numerical modeling for them or technically advise a Contracting Officer's Representative in the contracting of the work. This center would be an environment where hands-on experience would reside (and could be increased by on-the-job training). The other midterm technology transfer involves longer term training. In past years, when the Corps felt the need for more extensive training in soil mechanics than could be provided in a 2-week short course, a 120-day annual course was set up at Harvard (later moved to University of California at Berkeley). A similar program in rock mechanics was set up by the Corps and operated for a number of years, and there is a currently operating program in coastal engineering. These courses were and are eminently successful in bringing technology into Corps district offices. An analogous program emphasizing hydrogeology with a strong emphasis on numerical groundwater modeling should be considered. The size of the Army need for this kind of course, its costs, and its benefits should be evaluated.

Planning technology transfer and especially resourcing the training portion of technology transfer will be impacted by the Army's choice as to the optimum mix of in-house and contractor efforts in this area. It is clear that the Army needs to continue and expand in-house groundwater modeling practice because

a. The Army, as a minimum, needs to do enough HTW groundwater modeling in house to train its future key staff to be smart buyers of contracted modeling work and smart technical decision makers.

b. As indicated in the survey results for question 3, page 6, in the next 5 years, the Army has a significant number of groundwater modeling studies planned. Based on past history (see Figure 12), at least 20 percent will be done in house. While the survey did not ask the users to look beyond 5 years, it is certain that the need for in-house groundwater modeling expertise will continue to grow.

Long-Term Technology Transfer (Greater than 5 years)

The workshop did not address long-term technology transfer. However, if groundwater modeling research is to be done by the Corps, an obvious lesson the workshop teaches is that the technology transfer of research results should be carefully planned and resourced.

The Army environmental restoration programs are moving very fast. They are pictured as short-term programs where contamination problems will be corrected in the near term. One target date was to have all remedial actions underway by the year 2000. Even if this schedule is met, the need to use groundwater modeling in postremediation monitoring will still remain. In order to assure continued success in the future, the value of groundwater modeling must be recognized and plans need to be made now to be able to meet future needs.

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Appendix A
Papers, Abstracts, and/or Vugraphs

The Role of Groundwater Modeling in Army Activities
Army Groundwater Modeling Use and Needs Workshop
31 March 1992 - 1 April 1992
by

Mr. Jim Ballif
Chief, Environment and Chemical Engineering Branch
Environmental Restoration Division - HQUSACE

In this application by the Army Activities being spoken of are the HTRW activities in these programs:

Installation Restoration
Formerly Used Defense Sites
Base Realignment and Closure
Superfund
Civil Works

The Installation Restoration Program addresses the determination and remediation of environmental damage caused by past disposal practices at active military installations.

The Formerly Used Defense sites program addresses the same types of environmental problems caused by DOD activities on property that was once controlled by DOD.

BRAC addresses the remediation of existing environmental damage on military installations which are closing and are planned for return to other DOD purposes.

Superfund is the EPA program to remediate the worst uncontrolled hazardous waste sites across the country. The Corps designs and remediates the sites for which EPA has adopted a plan of remediation.

The Corps' Civil Works program sometimes encounters hazardous waste when planning, designing, construction or operating its water resource projects. The Corps must evaluate potential cost increases and delays to a project caused by the presence of hazardous waste and then determine how to address it if there is no sponsor involved.

These programs have been growing rapidly. Some programs are beginning to level out while others are still growing. Groundwater contamination is a problem for the majority of the projects in these programs.

We are mandated to accomplish remediation work as rapidly as possible. To do so in a technically sound fashion in order to deliver a quality project is our challenge. In order to meet that challenge we must make good use of all the tools that are available as well as find new ones.

We all know how difficult groundwater problems are to understand and remediate efficiently. One of the tools available for this task is groundwater modeling.

But that is just what it is, a tool. I hope this workshop will give us all a better understanding how groundwater modeling is being used in the area of hazardous waste remediation within the Army, will create an atmosphere of idea exchange and mutual support among the people using groundwater modeling in the Army, and will enable your HQ and the R&D community to provide appropriate guidance and support in the future.

INSTALLATION RESTORATION:
SITE INVESTIGATION/CHARACTERIZATION AND REMEDIATION

Presentation by Dr. M. John Cullinane, WES

This presentation will provide an overview of the Installation Restoration portion of the Environmental Quality Technology program with an emphasis on groundwater problems. The primary objective is to enhance the capability of the Army to meet its environmental obligations to protect the public health and environment. The primary research effort is on military unique contaminants. Installation Restoration research and development activities have been divided into two major thrust areas: Site Investigation/ Characterization and Site Remediation. Each major thrust area will be described particularly as it relates to groundwater and groundwater modeling, including major R&D activities, past accomplishments and future work efforts. The interrelationship of the work effort with the Installation Restoration will be presented.

Installation Restoration

The Problem

- The Army has over 11,000 IR sites
- The Army will face increased national pressure to complete IR cleanup activities
- On-the-shelf technologies are expensive and often ineffective for Army-unique cleanup problems
- Cost of cleanup using current technologies is estimated to be over $6-10 billion

The Impact

- The 10-year time line for IR cleanup cannot be affordably met with existing technologies
  - Installations will be cited for compliance violations and public pressure will increase
  - Costs for IR cleanup will continue to increase without new and innovative technologies
- Schedules for base closures will not be met

ENVIRONMENTAL QUALITY TECHNOLOGY PROGRAM
INSTALLATION RESTORATION

CLASSES OF CONTAMINANTS

- EXPLOSIVES / ENERGETICS
- ORGANICS
- METALS
- POL
- CHEMICAL AGENTS
- MIXED WASTE

OBJECTIVES

- ENHANCE THE ARMY CAPABILITY TO PROTECT THE PUBLIC HEALTH AND ENVIRONMENT
- FACILITATE REMEDIATION AND RESTORATION ACTIVITIES
- IMPROVE SITE CHARACTERIZATION TECHNOLOGIES
- IMPROVE HAZARDOUS WASTE TREATMENT TECHNOLOGIES
- IMPROVE RISK ASSESSMENT TECHNOLOGIES
- SUPPORT BASIC AND APPLIED TECHNOLOGY RESEARCH

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WASTE SITE INVESTIGATION / CHARACTERIZATION

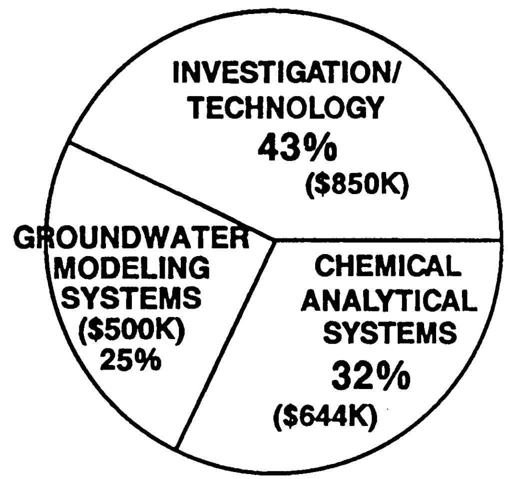
SCIENCE & TECHNOLOGY OBJECTIVES

- REDUCE WASTE SITE CHARACTERIZATION COSTS
- ENHANCE CAPABILITIES TO CHARACTERIZE WASTE SITES

R&D ACTIVITIES

- DEVELOP ADVANCED SYSTEMS AND SENSORS
- DEVELOP IMPROVED FIELD AND LABORATORY ANALYTICAL PROCEDURES
- DEVELOP INTEGRATED SURFACE AND SUBSURFACE SURVEY SYSTEMS
- DEVELOP ADVANCED SOIL / FLUID SAMPLING METHODS
- DEVELOP IN SITU TESTING PROCEDURES
- DEVELOP GROUNDWATER MODELING SYSTEMS

FY 92 FUNDING SUMMARY



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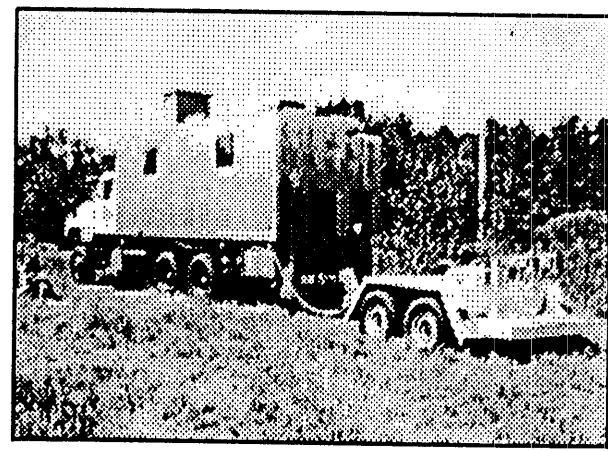
INVESTIGATION / CHARACTERIZATION TECHNOLOGY

DEFICIENCIES

- MONITORING WELLS ARE COSTLY, TIME CONSUMING TO INSTALL, AND OFTEN INEFFECTIVE
- SAMPLING AND ANALYSIS ARE DISCONTINUOUS
- VADOSE ZONE SAMPLING TECHNIQUES ARE LIMITED
- TECHNIQUES FOR CHARACTERIZATION OF BUILDINGS AND STRUCTURES ARE LIMITED

R&D ACTIVITIES

- ENHANCE CONE PENETROMETER TECHNIQUES
- EVALUATE THE ENVIRONMENTAL SAFETY OF CHEMICAL GROUTS AND TRACERS
- DEVELOP NEAR REAL TIME AND REAL TIME SENSORS
- DEVELOP IMPROVED SAMPLE COLLECTION TECHNIQUES



MISC OPT/1A 8@#CU083

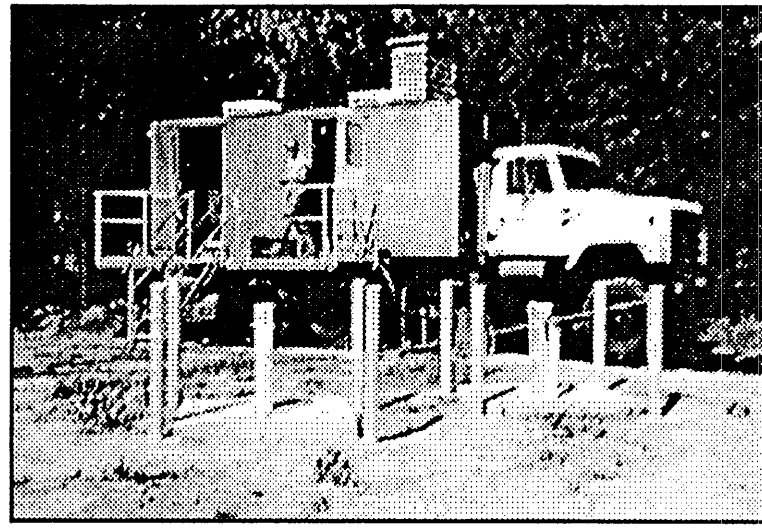
Cone Penetrometer

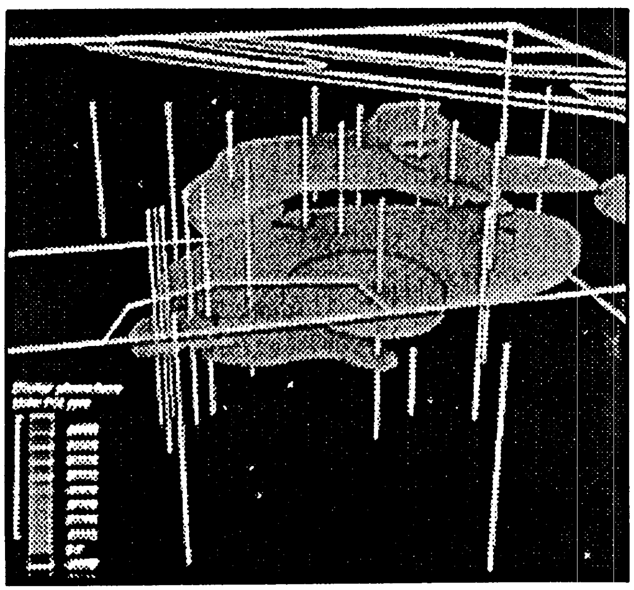
Problem

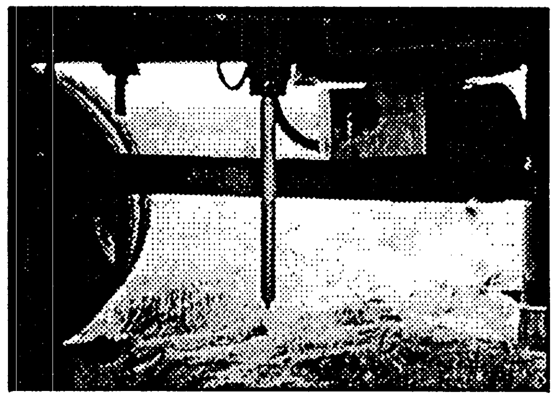
- Identify and analyze hazardous materials in soils.
- Drill and sample procedure is slow, and costly.

Technology

- Real time collection of data on soil strength, layering, soil type, and location of contaminants.
- Sensors and probe built into mobile truck.
- POL sensor to high parts/millions range.







Benefits

- Time savings on site--25 minutes vs. 9-10 hours for drill rigs.
- Time savings for test results--real time vs. 2 months.
- Costs of data collection and analysis--$750 vs. $40,000.

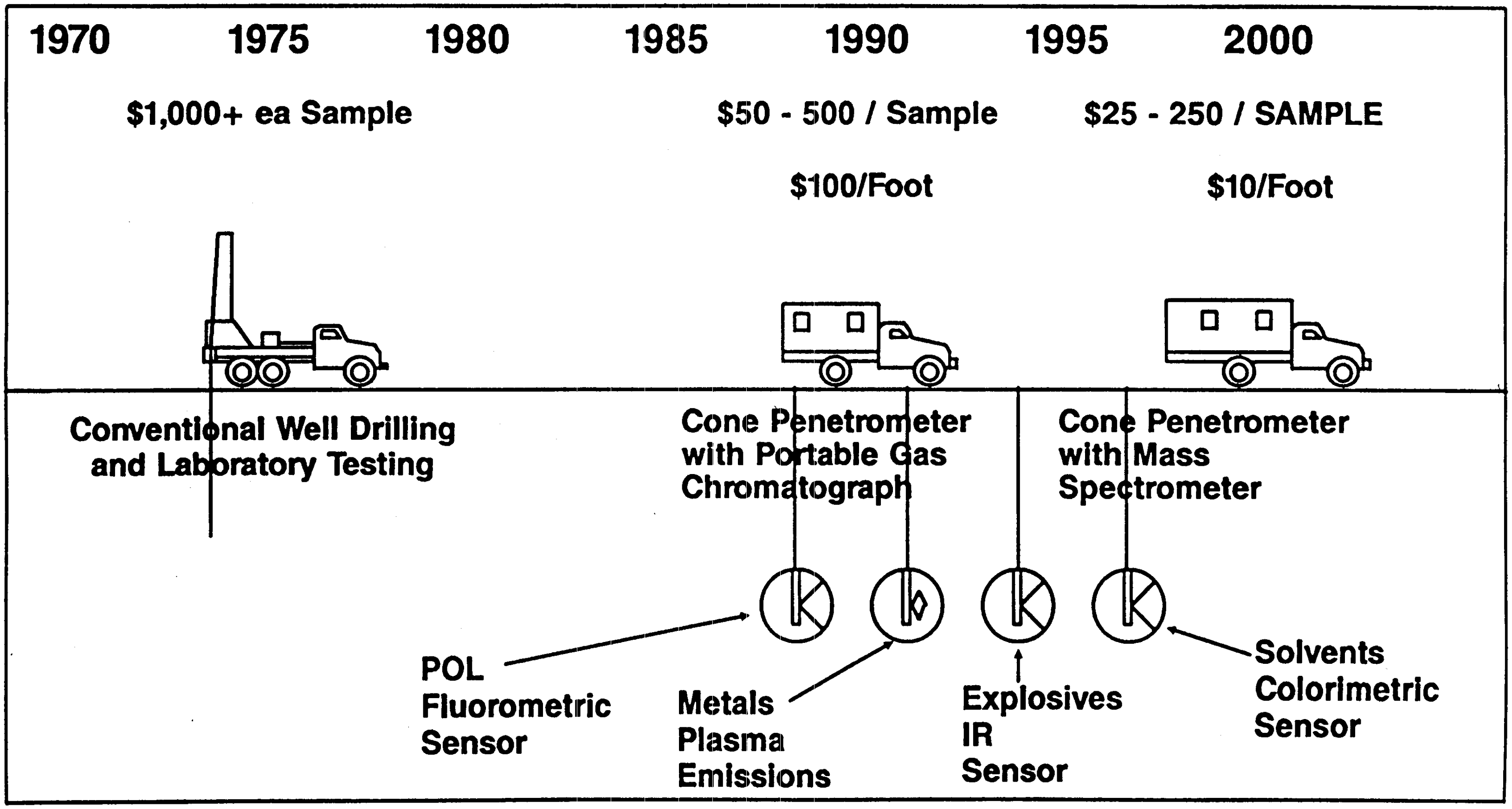
MIS1OPTA 8@#CU021

SENSOR DEVELOPMENT

CONTAMINANT CLASS	SENSOR	CAPABILITIES: CURRENT	CAPABILITIES: FY93 GOAL	CAPABILITIES: FY96 GOAL
POL	FIBER OPTIC, RLIF, 2nd GENERATION DUAL FIBER	200 ppm THRESHOLD WITH N_2 LASER (AT 1 METER/MIN RATE OF PENETRATION)	Nd YAG LASER, 15X POWER IMPROVEMENT, 50 ppm TARGET	LOW ppm
METALS	X-RAY	UNDER EVALUATION		ppb
	ARC SPECTROSCOPY	METHOD HAS BEEN PROVEN IN AIR AND UNDER WATER. JOINT EFFORT PLANNED WITH BIOTRONICS FOR USE IN SOIL. WES PROVIDES PACKAGING AND WILL HOLD PATENT FOR SOILS APPLICATIONS.		
SOLVENTS	IR LASER ABSORPTION FLOURESCENCE AND COLORIMETRY	UNDER EVALUATION. BENCH TESTING IN PROGRESS WES AND NOSC USING Nd YAG LASERS		ppb
EXPLOSIVES	IR LASER ABSORPTION FLOURESCENCE AND COLORIMETRY	UNDER EVALUATION. BENCH TESTING IN PROGRESS AT WES AND NOSC USING Nd YAG LASERS		ppb

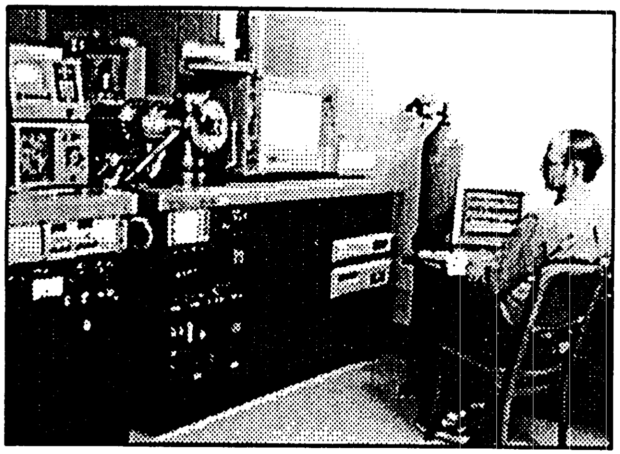
8#CUL084

Site Characterization Costs Subsurface Investigation and Screening Sample Costs



8#CUL024

CHEMICAL ANALYTICAL SYSTEMS



DEFICIENCIES

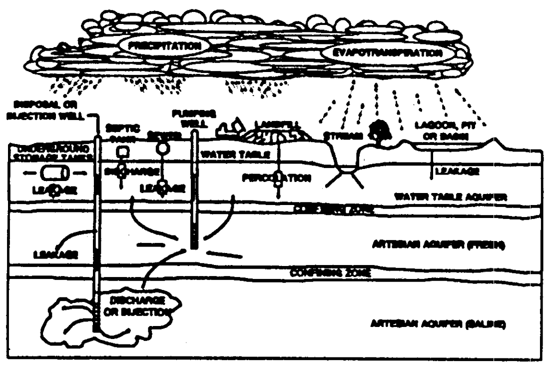
- TRADITIONAL ANALYTICAL TECHNIQUES ARE COSTLY
- ANALYTICAL TECHNIQUES ARE INADEQUATE OR NONEXISTENT
- TIME LAG BETWEEN SAMPLING AND RECEIPT OF ANALYTICAL DATA
- INADEQUATE DATA STORAGE, ANALYSIS, AND EVALUATION TECHNIQUES

R&D ACTIVITIES

- DEVELOP ANALYTICAL TECHNIQUES FOR EXPLOSIVES IN COMPLEX MATRICES
- DEVELOP FIELD SCREENING TECHNIQUES FOR EXPLOSIVES AND AGENTS
- DEVELOP STANDARD ANALYTICAL REFERENCE MATERIALS
- DEVELOP ANALYTICAL TECHNIQUES FOR CHEMICAL AGENTS

GROUNDWATER MODELING SYSTEMS

SOURCES OF GROUNDWATER CONTAMINATION



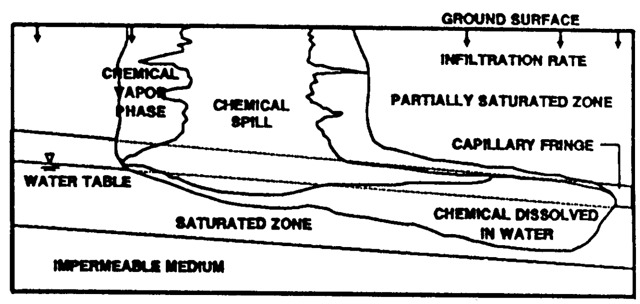
DEFICIENCIES

- EXISTING GROUNDWATER MODELS INADEQUATELY DESCRIBE CONTAMINANT INTERACTIONS WITH SURROUNDING MEDIA AND SUBSURFACE FLOWS
- INSUFFICIENT GUIDANCE ON THE SELECTION AND USE OF GROUNDWATER MODELS
- PRIMARY PROCESSES AFFECTING SUBSURFACE FLOW AND CONTAMINANT TRANSPORT ARE POORLY UNDERSTOOD
- SIMULATION OF REMEDIAL ALTERNATAIVE EFFECTIVENESS FOR CONTAMINATED GROUNDWATER CLEANUP IS INADEQUATE

R&D ACTIVITIES

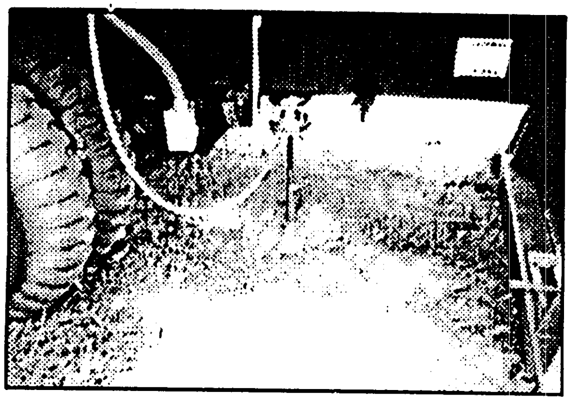
- DOCUMENT UTILITY OF EXISTING GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODELS
- IDENTIFY, QUANTIFY, AND DESCRIBE THE PHYSICAL, CHEMICAL, AND BIOLOGICAL FACTORS AFFECTING SUBSURFACE CONTAMINANT TRANSPORT
- DEVELOP OR ADAPT NUMERICAL MODELS FOR CHARACTERIZATION OF SUBSURFACE CONTAMINANT TRANSPORT
- DEVELOP OR ADAPT TECHNIQUES TO INCORPORATE GROUNDWATER MODELING INTO REMEDIAL ALTERNATIVE EVALUATION
- VERIFY AND DEMONSTRATE GROUNDWATER MODELS

SCHEMATIC DIAGRAM OF A LIGHTER-THAN-WATER CHEMICAL SPILL OF A VOLUME GREATER THAN THE RETENTION CAPACITY OF THE SOIL



8#CUL080

SITE INVESTIGATION/CHARACTERIZATION

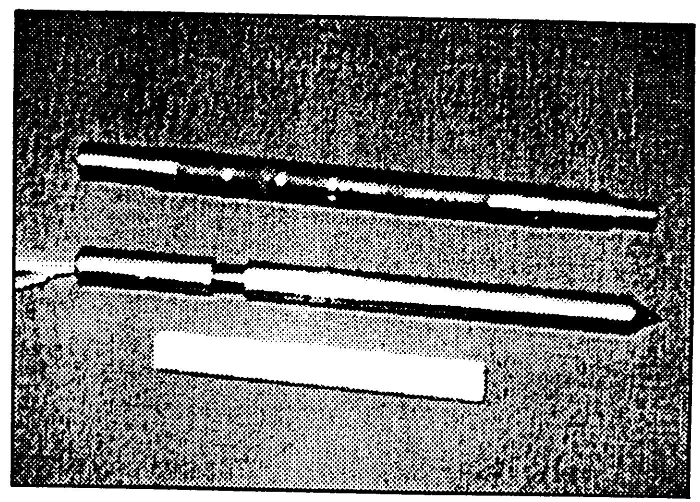


ACCOMPLISHMENTS

- FIELD TESTING OF FIRST GENERATION CONE PENETROMETER SENSORS/SAMPLERS.
- FIELD KIT FOR EXPLOSIVES.
- ANALYTICAL TECHNIQUE FOR EXPLOSIVES IN WATER.
- MONITORING WELL MATERIALS COMPATIBILITY.

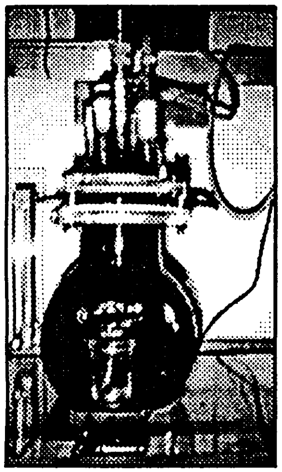
FUTURE PRODUCTS

- FY 92: TECHNICAL DATA PACKAGE ON ENVIRONMENTAL IMPACTS OF THE CONE PENETROMETER SYSTEM.
- FY 93: TECHNICAL DATA PACKAGE ON USE OF CONE PENETROMETER FOR SUBSURFACE SAMPLING AND REMOTE DETECTION.
- FY 94: SELF-CONTAINED FIELD UNIT CONE PENETROMETER SYSTEM EQUIPPED WITH LEADING STATE-OF-THE-ART CONTAMINANT SENSORS.
- FY 96: ADVANCED SOIL/WATER SAMPLERS.
- FY 97: ADVANCED SENSOR PACKAGE.



MIS1OPTA 8@#CU019

EXPLOSIVES TREATMENT TECHNOLOGY

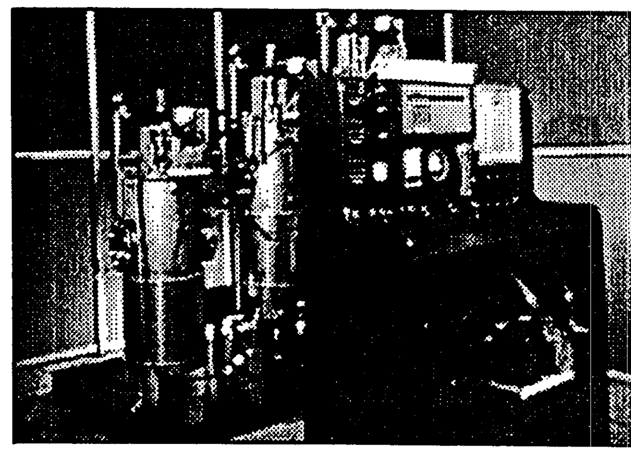


DEFICIENCIES

- TREATMENT RELIES HEAVILY ON INCINERATION
- CONTAINMENT TECHNOLOGIES REQUIRE LONG-TERM MAINTENANCE
- TREATMENT IS EXPENSIVE AND REQUIRES EXCESSIVE MATERIAL HANDLING
- FUNDAMENTAL MECHANISMS NOT UNDERSTOOD

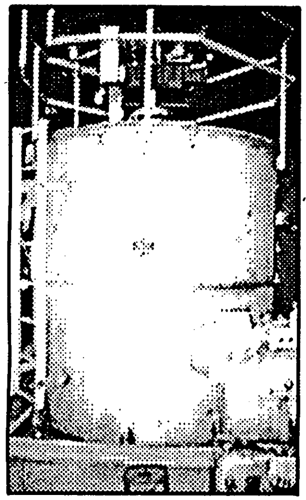
R&D ACTIVITIES

- DEVELOP PHYSICAL, CHEMICAL AND BIOLOGICAL TREATMENT TECHNOLOGIES
- DEVELOP OR IMPROVE MICROBIAL CONSORTIA FOR EXPLOSIVES TREATMENT
- DEFINE BIOLOGICAL AND CHEMICAL MECHANISMS
- IMPROVE EXISTING THERMAL TECHNOLOGIES



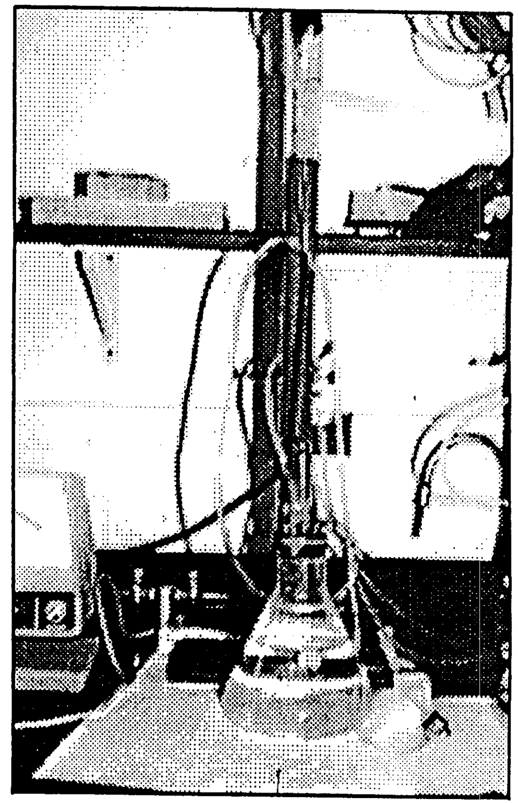
MIS1OPTA 8@#CU028

ORGANICS TREATMENT TECHNOLOGY



DEFICIENCIES

- INCINERATION IS COSTLY
- EXCESSIVE MATERIALS HANDLING
- UNKNOWN DEGRADATION PRODUCTS OF BIOLOGICAL TREATMENT
- UNKNOWN FEASIBILITY OF INSITU TREATMENT



R&D ACTIVITIES

- DEVELOP INSITU PHYSICAL, CHEMICAL, AND BIOLOGICAL TECHNOLOGIES
- DEFINE BIOLOGICAL, CHEMICAL, AND PHYSICAL MECHANISMS FOR TREATMENT
- DEVELOP NEW OR ENHANCED MICROBIAL CONSORTIA

MIS1OPTA 8@#CU029

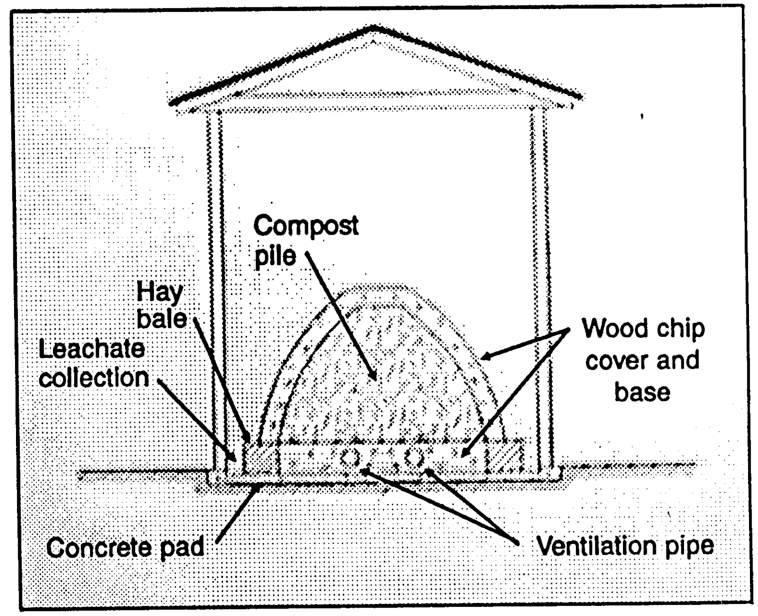
Bioremediation: Composting

Problem

- Incineration is costly
- Containment technologies require long term maintenance
- Excessive materials handling
- Unknown degradation products of biological treatment
- Unknown feasibility of insitu treatment

Technology

- Composting biodegrades explosives and organics in soils.
- Compost mixture consists of contaminated soil, carbon source such as animal waste or alfalfa, and bulking agents such as wood chips.

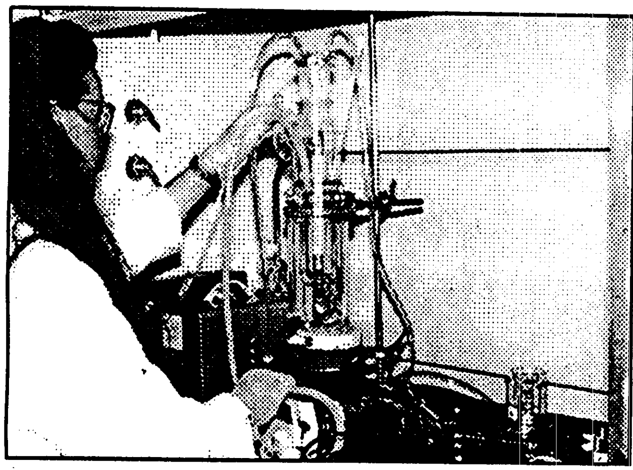


Benefits

- Low-cost techniques; 1/3-1/2 as costly as incineration.
- Testing showed total explosives were reduced by 99%.
- End product is agriculturally enriched and usable as fill.
- Full scale remediation, using composting, planned for NPL site at Umatilla Depot Activity for 1991-1992.

MIS1OPTA 8@#CU030

CHEMICAL OXIDATION FOR TREATMENT OF ORGANICS AND EXPLOSIVES CONTAMINATED SOILS AND GROUNDWATER

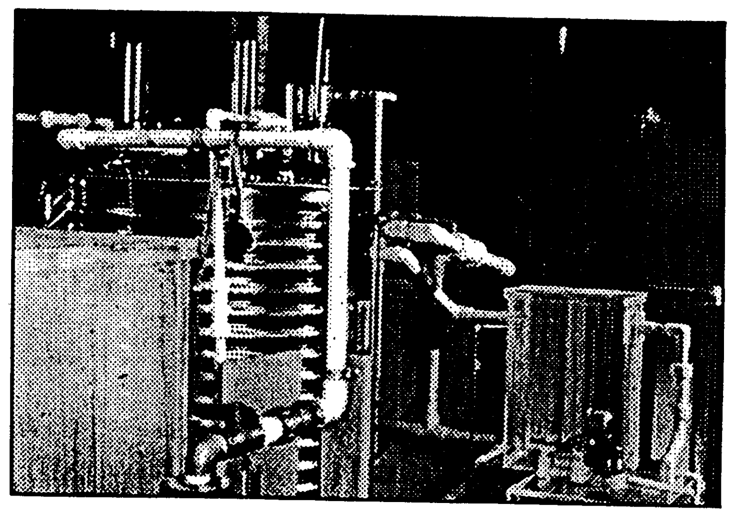


TECHNOLOGY ISSUES

- PROCESS CHEMISTRY
  - AVAILABLE OXIDIZERS
  - TREATMENT CONDITIONS
  - CATALYSTS
  - INTERMEDIATE PRODUCTS
- ENGINEERING
  - DESIGN PARAMETERS
  - REACTOR DESIGN
- REGULATORY

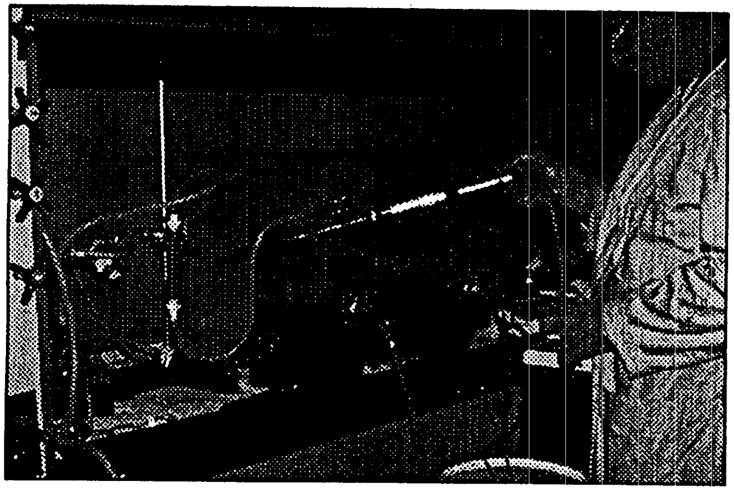
OBJECTIVE / APPLICATION

- USE CHEMICAL OXIDATION PROCESSES TO DESTROY TOXIC ORGANIC COMPOUNDS
  - NEAR TERM DEVELOPMENT OF EX SITU APPLICATIONS
  - LONG TERM DEVELOPMENT OF IN SITU APPLICATIONS



misc opt/a 8#@CU008

BIOTREATMENT TECHNOLOGY FOR TREATMENT OF ORGANICS AND EXPLOSIVES CONTAMINATED SOILS AND GROUNDWATER

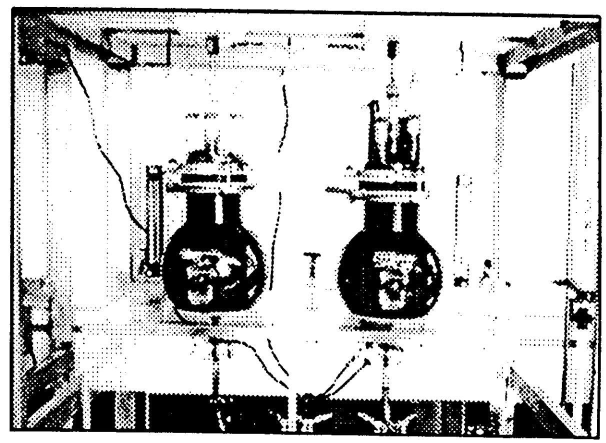


TECHNOLOGY ISSUES

- MICROBIOLOGY
  - MICROBIAL CONSORTIA
  - ENVIRONMENTAL CONDITIONS
  - DEGRADATION PRODUCTS
- ENGINEERING
  - DELIVERY SYSTEMS
  - VERIFICATION
- REGULATORY

OBJECTIVE / APPLICATION

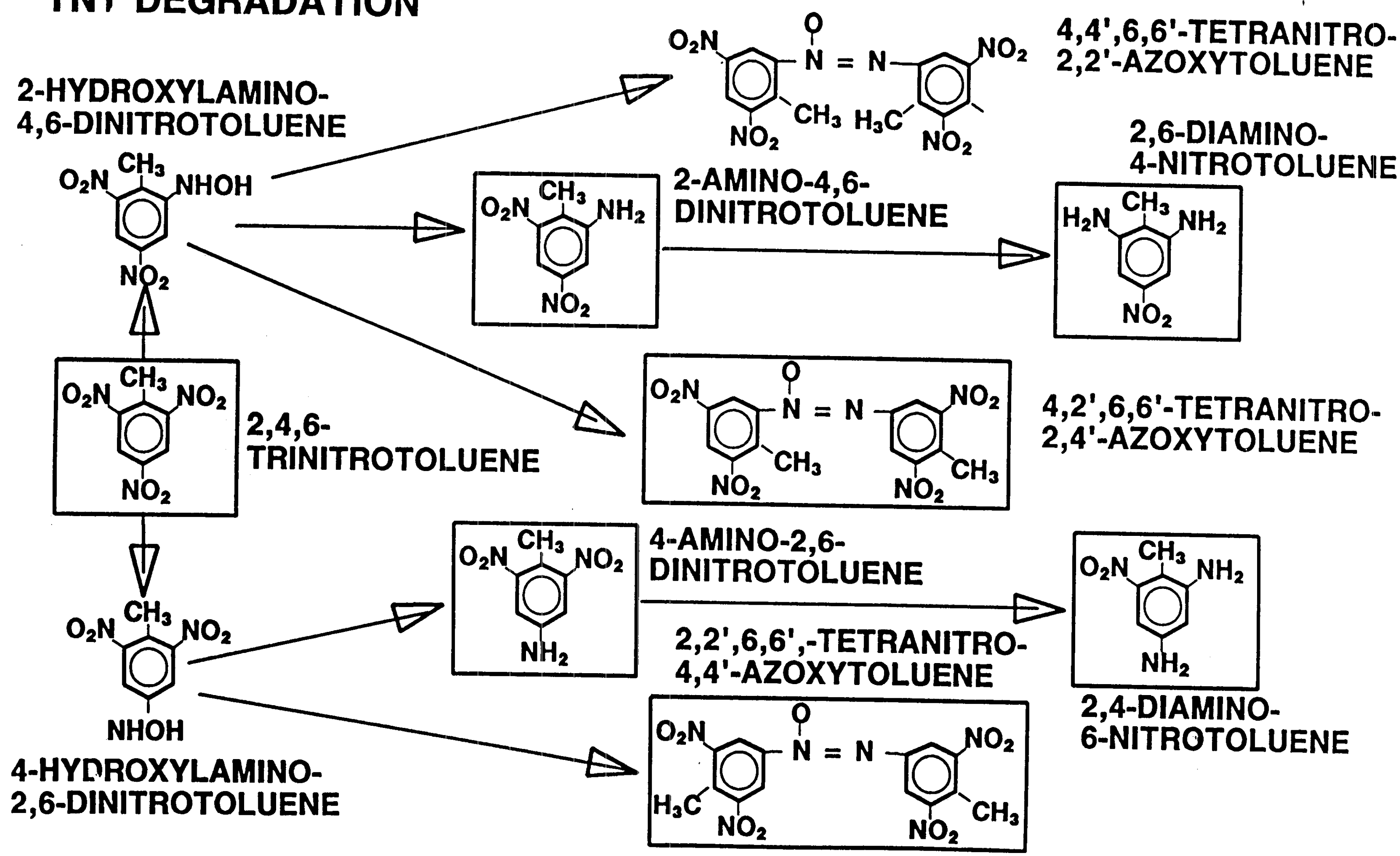
- USE MICRO ORGANISMS TO TREAT CONTAMINATED SOILS AND GROUNDWATER
  - NEAR TERM DEVELOPMENT OF EX SITU APPLICATIONS
  - LONG TERM DEVELOPMENT OF IN SITU APPLICATIONS



misc opt/a 8#@CU004

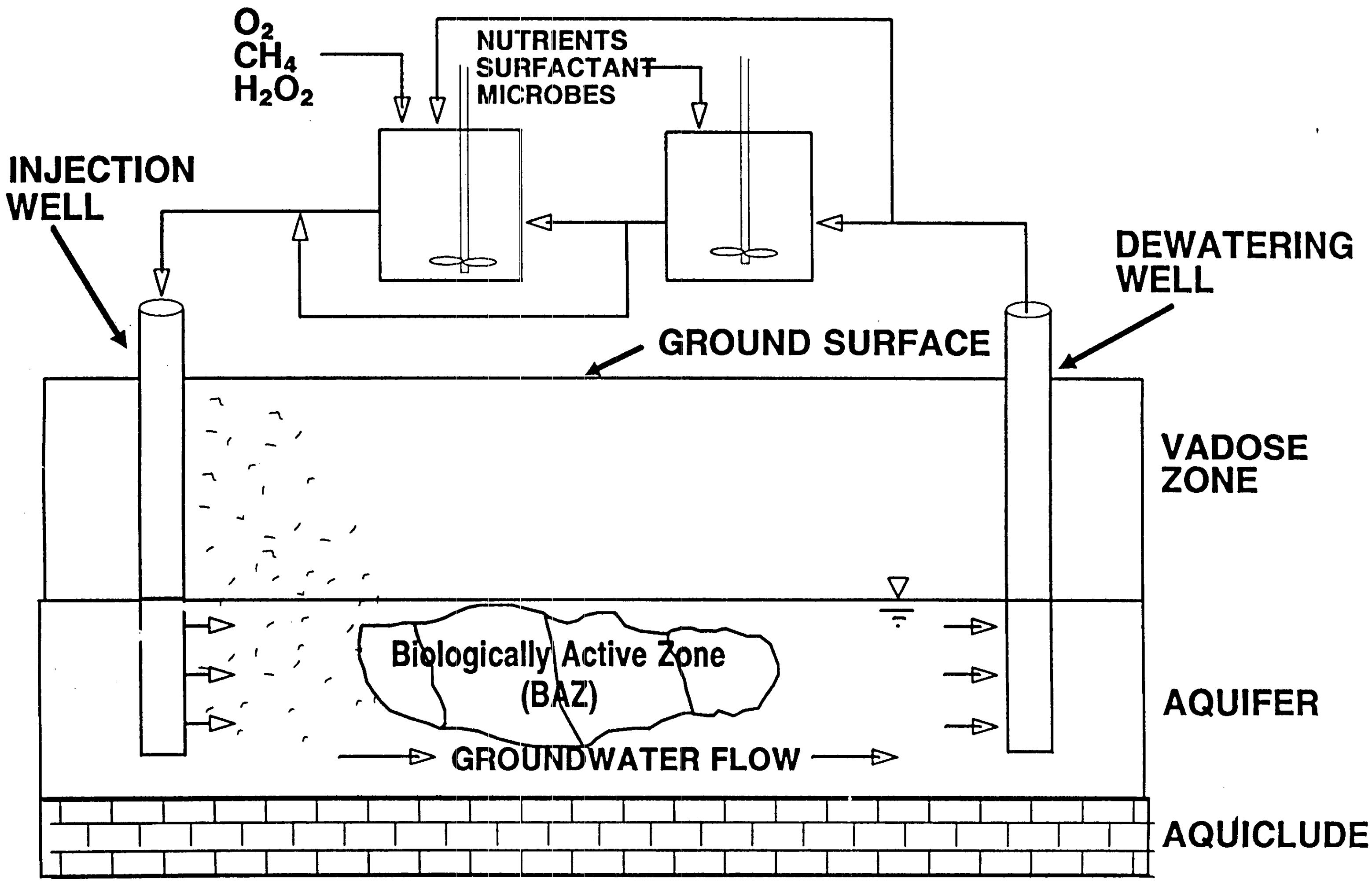
BIOLOGICAL REDUCTION

TNT DEGRADATION



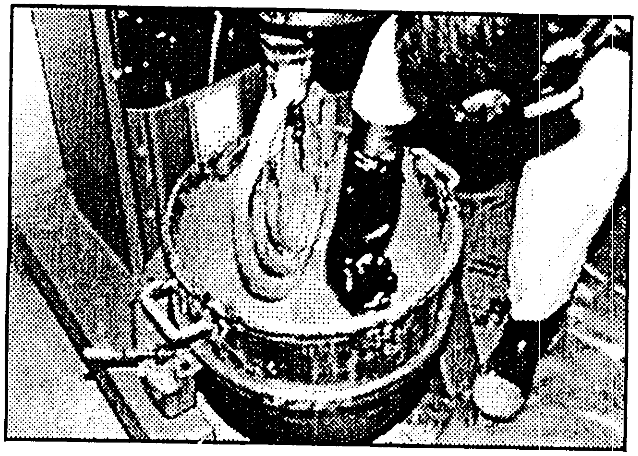
8CULL011

CONCEPTUALIZED IN-SITU BIOTREATMENT SYSTEM



8CULL006

HEAVY METALS TREATMENT TECHNOLOGY

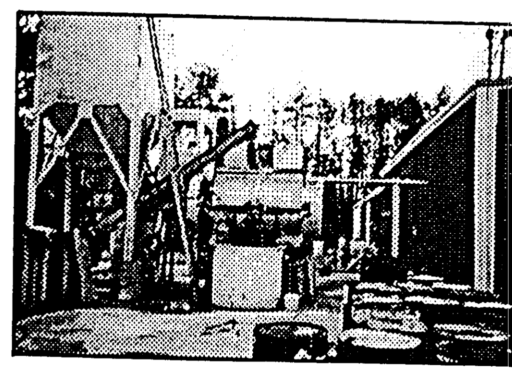


DEFICIENCIES

- MOBILITY OF METALS IS NOT UNDERSTOOD
- TREATMENT PRACTICES RELY ON IMMOBILIZATION
- TREATMENT IS EXPENSIVE
- LONG - TERM DURABILITY NOT DEFINED

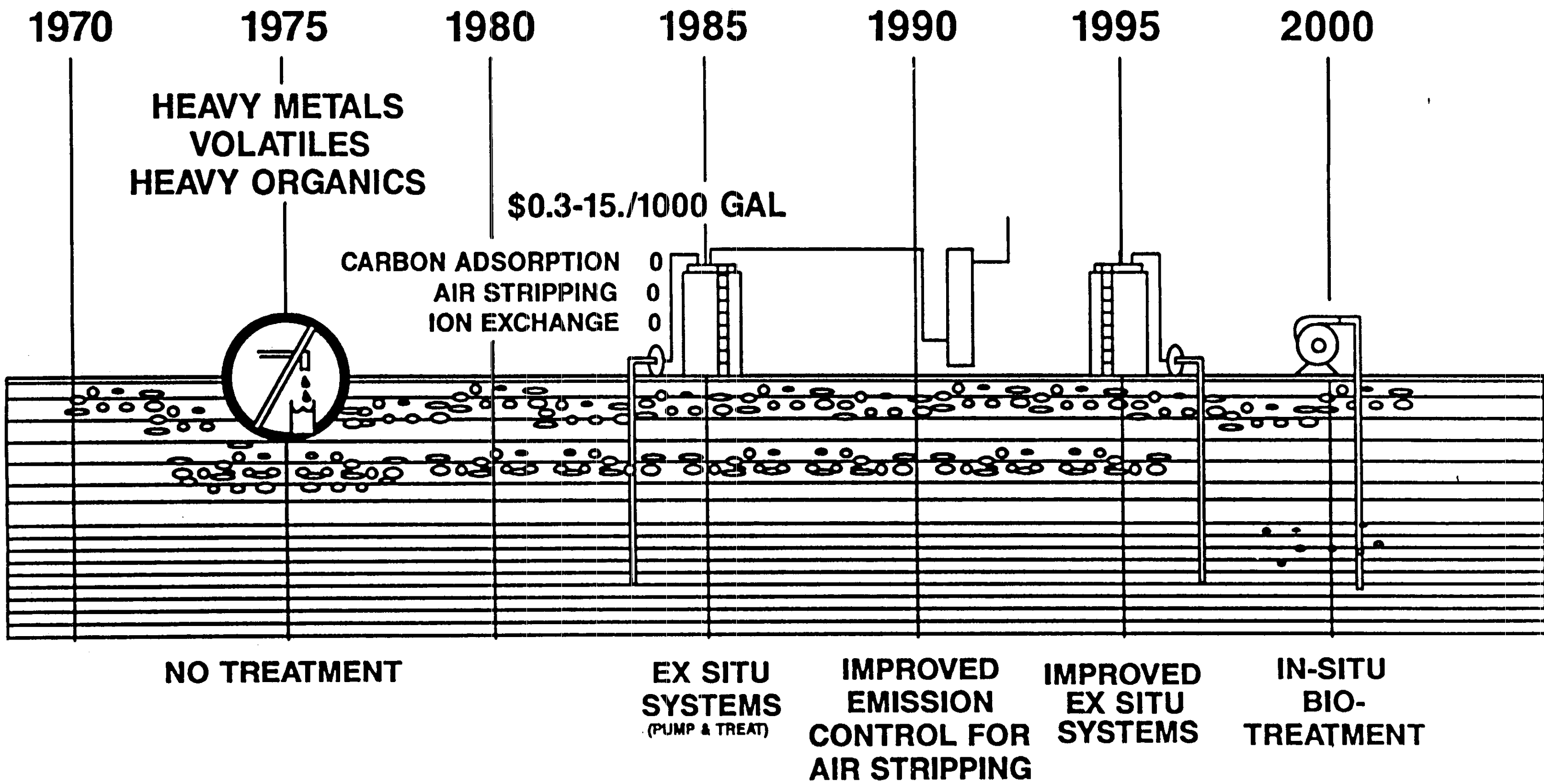
R&D ACTIVITIES

- METAL PARTITIONING, SPECIATION, MOBILITY AND MASS TRANSPORT RELATIONSHIPS AND MECHANISMS
- DEVELOP ENHANCED METALS RECOVERY TECHNOLOGIES
- DEVELOP ENHANCED METAL IMMOBILIZATION TECHNOLOGIES



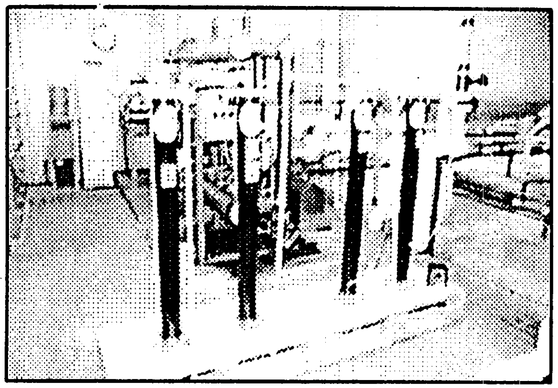
MIS1OPTA 8@#CU031

Remediation Time Line



8#CUL007

WASTE SITE REMEDIATION

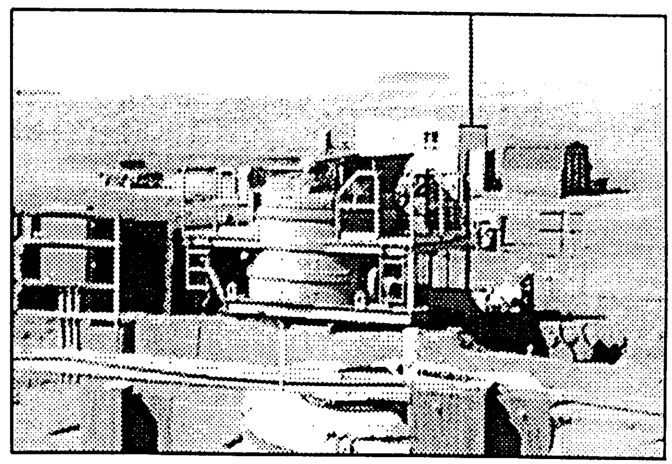


ACCOMPLISHMENTS

- GRANULAR ACTIVATED CARBON FOR TREATMENT OF EXPLOSIVES CONTAMINATED GROUNDWATER.
- SOIL VAPOR EXTRACTION FOR ORGANICS REMEDIATION.
- INCINERATION FOR EXPLOSIVES CONTAMINATED SOIL REMEDIATION.
- COMPOSTING FOR EXPLOSIVES CONTAMINATED SOIL REMEDIATION.
- ASSESSMENT OF METALS TREATMENT TECHNOLOGIES.

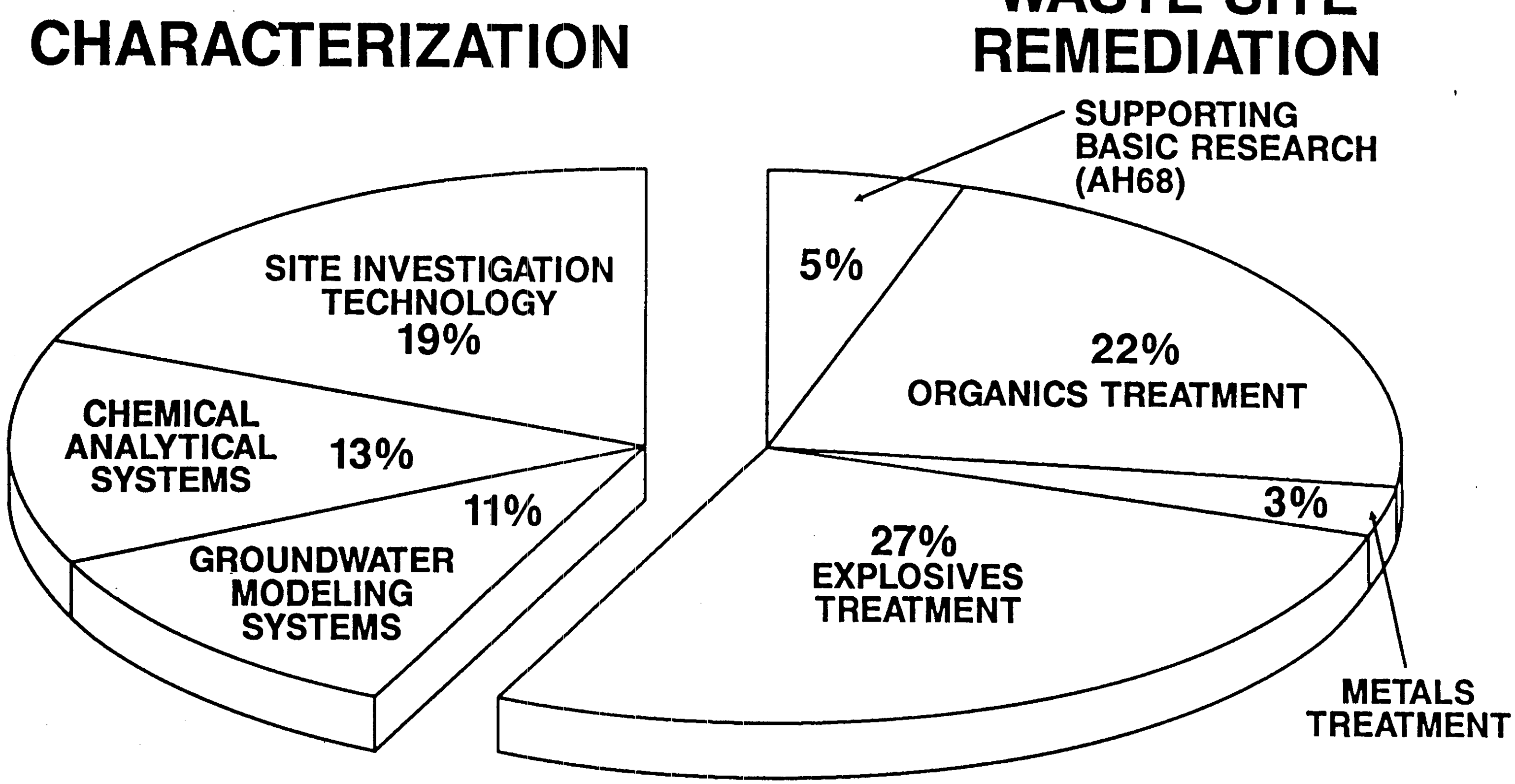
FUTURE PRODUCTS

- FY 92: PROTOCOL FOR COMPOSTING TECHNOLOGY ASSESSMENT.
- FY 93: TECHNICAL DATA PACKAGE ON BIOLOGICAL TREATMENT OF HEAVY METALS CONTAMINATED GROUNDWATER.
- FY 94: TECHNICAL DATA PACKAGE ON BIOSLURRY TREATMENT.
- FY 95: TECHNICAL DATA PACKAGE ON TREATMENT OF METALS CONTAMINATED SOILS.
- FY 96: TECHNICAL DATA PACKAGE ON CHEMICAL EXTRACTION OF EXPLOSIVES.
- FY 97: TECHNICAL DATA PACKAGE ON IN SITU BIOTREATMENT.



MIS1OPTA 8@#CU027

INSTALLATION RESTORATION



FY 92 PROGRAM FUNDING
$4,500 K

8#CUL032

Panel 1: Groundwater Problems, User Needs and Model Use

Anderson, Brian. "Description of Ground Water Modeling Experience for PI/FS at RMA"

Masoud, Khaled. "Overview of Major Remedial Investigation/Feasibility Study (RI/FS) Work in Edgewood Area (EA) of Aberdeen Proving Ground (APG), MD, as Related to Groundwater (GW) Modeling and Its Needs"

Baker, Fred G. "Development of Groundwater Modeling Objectives and Performance Criteria"

Overview of Major Remedial Investigation/Feasibility Study (RI/FS) Work in Edgewood Area (EA) of Aberdeen Proving Ground (APG), MD, As Related to Groundwater (GW) Modeling and Its Needs

by

Khaled M. Masoud, P.E.
US Army Corps of Engineers, Baltimore District
31 Hopkins Plaza, Baltimore, Maryland 21201
31 March 1992

Throughout its history as a military installation (dating from 1917), EA of APG has been the primary chemical warfare research and development center for the United States. A Federal Facility Agreement was signed between Environmental Protection Agency and APG in March 1991. All of EA has been identified as a National Priority List site. With Exception of Canal Creek area, O-field, and J-field, all the RI/FS work EA is conducted under a Memorandum of Understanding executed among APG, Waterways Experiment Station (WES), and Baltimore District (NAB) in February 1991. Canal Creek, O-field, and J-field RI/FS work has been underway since mid eighties.

The major RI work in EA conducted by WES and NAB involves 151 Solid Waste Management Units divided into 55 clusters. The clusters fall in four (4) major areas; Bush River, Lauderick Creek, Westwood, and Other Edgewood areas. RI underway in support of GW modeling includes geotechnical borings and electronic logging, conducting paleochannels study, well installations and development, slug tests, Total Organic Carbon measurements, investigating potential Biofouling problems, sampling and analysis (soil, sediment, surface water, and groundwater). Cost reduction was possible by developing downhole-magnetometer methodology for drilling in lieu of remote control drilling from behind bombproof shelters.

WES and NAB are studying the GW modeling work conducted by USGS in Canal Creek and O-field areas and also reviewing the Rocky Mountain Arsenal Experience in GW modeling for lessons learned, and reviewing the state of the art to identify future GW modeling needs early in the RI phase. The consensus seems to indicate that there is a critical need to utilize and introduce state of the art geostatistical and probability techniques in reducing the uncertainty and variability in the hydrogeological parameters (e.g. conductivity, transmissivity, etc.) that are critical factors in a reliable GW model.

DEVELOPMENT OF GROUNDWATER MODELING OBJECTIVES AND PERFORMANCE CRITERIA

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Phone (303) 278-1179

I. INTRODUCTION

Mathematical groundwater flow and solute transport models are being widely used in engineering geology, hydrogeology, environmental sciences, and hazardous waste remediation studies (National Research Council, 1990). These models can be used as tools to evaluate simple or complex hydrogeologic regimes, estimate the direction and rate of migration of solute or contaminant plumes in groundwater, design remediation systems for contaminated groundwater, and for many other applications. Given this broad range of potential modeling uses, it is clear that an equally broad range of models can be developed to meet the needs of a specific application.

The value of a model as a tool for solving a given problem depends on a number of factors including the ability of the model to address modeling objectives and to meet performance criteria established for the application of the model. It is important that modeling objectives be carefully formulated and documented so that they can serve as the basis for model development. When modeling objectives are not clearly or completely defined during groundwater investigations, it is possible that the model will not meet its stated objectives, and users, clients, or regulators relying on the outcome of the modeling work may become disillusioned with model results. Disillusionment occurs because users perceive that the groundwater modeling effort does not fulfill project expectations or needs, and as a result, they become dissatisfied with the specific model application and, potentially, with modeling in general. Therefore, in nearly all model applications, the development and clear definition of objectives is an essential planning step that must be carried out before the modeling effort is initiated.

It is equally important for model performance criteria to be established at the beginning of the project as part of the planning process. Performance criteria provide an important mechanism by which the model can be evaluated to determine whether the stated modeling objectives have been achieved. In addition, these criteria assist the modeler and the client to focus on the information, level of effort, and degree of sophistication required to meet the modeling objectives. Model performance criteria provide a self-imposed test of whether the model application is consistent with the established expectations for the work.

II. MODELING OBJECTIVES

The development of groundwater modeling objectives is a critical component of the modeling process. Modeling objectives are established to ensure that the model application meets its intended purpose. For a model application to be completely successful, it must meet all stated objectives and be applicable to the intended modeling use. If the model does not meet all of the modeling objectives, it can only be partially successful. In some cases, a perfectly good model may be developed, but it may not be appropriate for the intended use; such a model has to be considered a failure because it does not achieve the intended goals.

Modeling objectives for a groundwater model application consist of a statement or series of statements that define: (1) the major attributes of the hydrogeologic system and assumptions about how the system is going to be modeled; (2) calibration criteria; (3) the intended use of the model once it has been calibrated; and,

(4) expected limitations of the model. The major assumptions about the model depend on how completely the mathematical model attempts to describe the conceptual model, components of the hydrogeologic system, initial and boundary conditions, aquifer or transport properties, overall model behavior, and specific properties or behavior that the model is expected to represent. The calibration criteria are the standards against which the model will be tested during calibration and the standard of performance deemed necessary for the successful application of the model to its intended use. The calibration criteria may represent a subset of the overall model performance criteria. The intended use of the model should be clearly defined including the overall purpose, general and specific applications, level of sophistication of problems to be solved, and how particular problems are to be addressed. It is also appropriate to explain how the performance criteria relate to the planned use. Finally, the limitations to model use and the expected sources and relative magnitude of uncertainty should be stated. The limitations may simply be a restriction to steady-state conditions, low water table periods, or two-dimensional flow. The limitations of input data and estimated aquifer and transport parameters used in the model should be pointed out along with any corresponding limitations in model output. Any other limitations that may affect the use or interpretation of simulated results should also be acknowledged.

Modeling objectives should be established very early in the modeling process because they drive decisions made throughout the modeling effort. The objectives should be viewed as a statement of the goals that will allow the model to be used as a tool for the intended purpose. Objectives that are defined at the outset of modeling can be used as a basis for decisions such as model selection, evaluation of calibration progress, and evaluation of the appropriateness of the final model for the intended use. During the modeling process, the objectives should be frequently reviewed to determine whether the model and available data can support the objectives, and to evaluate whether the objectives can be met given existing data gaps, uncertainty in the available data, and any other constraints to level of effort, budget, or schedule. If any of these factors suggest that the resulting model will not be adequate to meet the stated modeling objectives, then the objectives and modeling approach should be reviewed. If information about the hydrogeologic system is insufficient to support the required modeling effort, then additional data should be collected, or the objectives should be modified to reflect the limitations of the modeling application. In either case, the modeling objectives should be reviewed and adjustments made as necessary. Frequent review and evaluation of the model against the objectives will help to keep the modeling effort on track and allow the model to meet expectations.

III. MODEL PERFORMANCE CRITERIA

The development of groundwater model performance criteria represents another step in the modeling process. These criteria are established at the outset of modeling to provide a basis for evaluation of overall model performance as well as to test the mathematical accuracy of the model. Performance criteria can be used to assess whether the model meets modeling objectives and specific efficiency and accuracy goals. If the performance criteria are not met, then additional work is required to bring the model to an acceptable level of performance.

Performance criteria consist of standards of performance for the model as a whole as well as specific modeling standards. These may include the overall appropriateness of the modeling approach and procedures used for construction of the model, representativeness and completeness of modeling results, comparability of results from other model representations, model dimensionality or discretization goals, model efficiency or run-time criteria, model precision, and calibration or accuracy goals. The appropriateness of the modeling approach and model construction depend on the reasonableness of the assumptions made during the setup of the model, and in the approach taken to model construction. The representativeness and completeness of model results reflect how well the mathematical model represents the components and behavior of the hydrogeologic system that are expected based on the conceptual model. The comparability of model results with the results of other reasonable models provides a test of the consistency of modeling assumptions and a representation of essential processes and behavior. This can represent a form of model validation if properly posed. Model dimensionality and discretization goals should be appropriate and realistic so that they can represent the conditions being simulated, meet minimum application needs, and be consistent with numerical modeling constraints. Model efficiency and run-time constraints include transportability and operating environment constraints as well as hardware, software, and turn-around time goals. Model precision goals refer to the reproducibility of predicted results and reduction of uncertainty due to modeling methods. Finally, calibration or accuracy goals can be established to verify that the model reproduces observed data within an acceptable level of bias or systematic error. This is usually evaluated by comparison of simulated output with observed measurements of variables such as groundwater surface elevation, solute concentration, or hydraulic gradient. The basis for the comparison is frequently the minimization of residuals or differences between observed and simulated values.

SUMMARY

Groundwater modeling objectives and performance criteria need to be developed and clearly defined during the planning of any modeling effort. If they are developed early in the modeling process, they can be used as a basis for decisions made throughout the process, and consequently, ensure that the model will be suitable for the model application. The development of objectives and performance criteria can lead to the creation of useful and unambiguous model applications.

REFERENCES

National Research Council. Ground Water Models: Scientific and Regulatory Applications. National Academy Press, Washington, D.C., 1990.

Panel 2: Model Use in Remedial Investigations (RI)

Schwartz, Franklin W. "Groundwater Models and Remedial Investigation"

Enfield, Carl G. "Contaminant Transport Processes, Determination of Important Processes for a Given Site"

Tamayo-Lara, Carlos; Warner, J. W.; and May, James. "Geostatistical Characterization and Stochastic Ground Water Modeling, Offpost Operable Unit, Rocky Mountain Arsenal"

Groundwater Models and Remedial Investigation

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ABSTRACT

The objective of this presentation is to identify two key roles that groundwater flow and contaminant transport models might play in a remedial investigation. The first contribution that a model can make is to alter conventional thinking about what remedial investigations are all about and how they should be conducted. There is a variety of evidence to suggest that increased knowledge and understanding about a site that naturally falls out of a model-based conceptualization will reduce the costs of remediation.

In terms of the "styles" of remedial investigation, the conventional approach provides fundamentally less useful information about a site and problem than a state-of-the-science approach. The conventional approach represents a minimalist, cookbook procedure for site investigation that has many attractive features - inexpensive relative to other styles, relatively easy for contractors to execute and manage, and relatively straightforward for regulators to understand. As a case study of an industrial site will help illustrate, this conventional style has one important limitation. Often, major gaps in knowledge remain after the remedial investigation, which ultimately increase the costs of remediation and the ability to demonstrate regulatory compliance. Designing the remedial investigation using a "model framework" is a more costly state-of-the-science approach. Indications are that increased knowledge about the site translates into cheaper cleanups. However, these studies are more expensive, much more difficult to execute, and much more difficult for regulators to evaluate.

In addition to information gaps due to how the study was undertaken, there will always be gaps because it is not ever possible to characterize the spatial variability in parameter values. Modeling work by Gorelick on the design of pump and treat systems shows again that information deficiencies translate into remedial costs.

Beyond the role of models as a framework to guide studies, there are at least two important uses for models during a remedial investigation. Early site modeling using background data and expert knowledge assists in understanding the problem and in identifying the key variables affecting the spread of contaminants. One knowledge-based package (Expert ROKEY) has been demonstrated for contaminant systems that illustrates the great promise for the approach. Unlike more traditional modeling packages, this software provides advice and assistance in parameter selection and recommendations for the remedial design based on the parameters.

ABSTRACT

Contaminant Transport Processes
Determination of Important Processes for a Given Site

by

Mr. Carl G. Enfield
Robert S. Kerr Environmental Research Laboratory
United States Environmental Protection Agency

Remediation of subsurface environmental contamination requires the use of mathematical codes (sometimes called models) in a prospective rather than a retrospective mode. The mathematical codes require input data describing the system including existing contamination and additional inputs which might be applied in an effort to remediate the site. The mathematical code and input data are combined to create a model of the system which is then used to forecast how the system is expected to behave. The model is an approximation of the real system. Mathematical codes consider a limited number of assumed processes. Ideally, the processes that are included in the code describe the controlling processes at the site under consideration. The objective of this presentation is to illustrate three broad classes of transport/transformation processes which are infrequently incorporated in mathematical codes and indicate where these processes might be important.

The transport/transformation processes which are frequently ignored at remediation sites include:

1. The significance of microscale variability in hydraulic conductivity.
2. The importantance of non-aqueous fluids and particles on chemical transport.
3. The importance of how transformations are incorporated in mathematical code and the importance of numerical dispersion on the forecasts made by these codes.

Geostatistical Site Characterization and Stochastic Groundwater Modeling Offpost Operable Unit Rocky Mountain Arsenal

by

Carlos Tamayo-Lara, Research Associate
James W. Warner, Associate Professor
Colorado State University
Department of Civil Engineering
Groundwater Program
Fort Collins, Colorado 80523

Jim May, Hydrogeologist
US Army Corps of Engineers
Waterways Experiment Station
Geotechnical Laboratory
Vicksburg, Mississippi 39182

Pump and treat systems are becoming the preferred remedial alternative for cleanup and remediation of contaminated aquifers. Currently, the design of most of these systems is commonly performed under assumptions of aquifer homogeneity, even though it is well know that in reality, the concept of a deterministic, homogeneous and isotropic media does not exist. To ignore unknown variations of aquifers properties such as hydraulic conductivity, aquifer transmissivity, saturated thickness, etc. can significantly affect the successful operation and effectiveness of these systems. To overcome this situation, the stochastic nature of the aquifer properties must be considered in making decisions about the design, operation and management of pump and treat systems.

Description of the spatial variability of hydrogeological parameters within a porous media can be approached by using a state of the art technique called geostatistics. This technique is a branch of applied statistics specializing in the analysis and modeling of spatial variability in earth sciences. In this study, geostatistical analysis were performed for site characterization in the offpost area north of the Rocky Mountain Arsenal near Denver, Colorado, where a pump and treat system is planned for implementation.

Geostatistics was used to estimate the best, linear, unbiased values of hydrogeological regionalized variables at unsampled locations based on the available measurements of these variables. Contrary to the most used estimation techniques such as inverse distance, least squares, or polynomial interpolation (either applied by hand or computer), geostatistics also account for the uncertainty in the estimated values and the precision of the results. As part of this analysis, experimental semivariograms and cross-semivariograms that describe the spatial structure of the regionalized variables were determined at the study site. Different mathematical models were fitted to these semivariograms and cross-semivariograms and the results were cross-validated. Kriging and Cokriging techniques were used to describe the spatial variability of several aquifer properties including hydraulic conductivity. Estimated values were used to generate contour maps based on limited number of sample points while all data available was optimized. Also, these geostatistical techniques were used to show the errors of estimation at all selected estimated points and to create maps of ninety-five percent confidence limit to obtain the range of the estimated variables.

The obtained results are currently being used in a stochastic model of the pump and treat system to provide the operational personnel a basis for managing this system so as to have the greatest likelihood of achieving project goals. This procedure will also provide estimates of uncertainty in model predictions and will permit examination of the error in designing the system using an assumption of a homogeneous aquifer.

The geostatistical and stochastic analysis presented in this study are part of a cooperative research effort of groundwater management modeling between the US Army Waterways Experiment Station and the Groundwater Program at the Department of Civil Engineering, Colorado State University.

Panel 3: Model Use in Remediation

Part 1 Brubaker, Gaylen P. "Process Options for In Situ Subsurface Remediation: Can We Predict Performance?"

Part 2 Ross, Randall R. "Case Study: Gilson Road Superfund Site:

Warner, James and May, James. "Use of Numerical Groundwater Modeling for Operation and Management of the North Boundary Containment System at Rocky Mountain Arsenal"

Chiang, C. Y. "Bioremediation-Parameter Estimation, System Design, and Prediction of Cleanup Time"

Process Options for In Situ Subsurface Remediation: Can We Predict Performance

Gaylen R. Brubaker, Ph.D.
Remediation Technologies, Inc.
Chapel Hill, NC

As an increasing number of large complex contaminated sites move toward remediation, it is becoming increasingly important to develop methods to predict the performance of various subsurface remediation options. These performance models are critical to predict the potential cost-benefit of various remedial options and to determine whether a particular technology is likely to achieve risk-drive remediation goals.

This paper will use two sites, a petrochemical facility in the gulf coast and a Superfund site in the midwest, to illustrate the types of performance questions that are being explored while developing corrective actions plans at typical industrial sites. In each instance a series of in situ remediation processes are being considered in various combinations. The processes to be discussed will include: simple NAPL recovery, enhanced recovery using hot water injection, simple pump-and-treat, enhanced pump-and-treat using surfactants, in situ bioremediation, vapor extraction and aquifer aeration. Key site parameters will be discussed for each process as an introduction into the role of modeling in evaluating the performance of these remediation options.

ABSTRACT

Randall R. Ross
R. S. Kerr Environmental Research Laboratory
USEPA

The Gilson Road (Sylvester) Superfund site located near Nashua, New Hampshire, was the first hazardous waste site in the nation to initiate remedial actions funded under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), more commonly known as the Superfund Program. During the 1960's, sands and gravels were removed from a six acre borrow pit. Initially, the site received domestic refuse and demolition debris. During the early 1970's the site received unauthorized heavy metal sludges and industrial wastes. It is estimated that 800,000 gallons of industrial waste were illegally discharged directly to the subsurface through a leach field. An emergency groundwater interception and recirculating system was installed in an effort to contain the most heavily contaminated portion of the plume to prevent contamination of surface waters (Lyle Reed Brook and Nashua River). A 4000-foot long, 3-foot thick soil-bentonite slurry wall was installed through the stratified glacial outwash and discontinuous till to the fractured bedrock in a attempt to further contain the groundwater contaminants at the site. Additionally, a membrane cap was constructed over the 20 acre containment areas.

Two previous modeling studies were conducted to 1) evaluate potential remedial options for the site and 2) characterize regional flow conditions to evaluate the most likely pathways for contaminant transport from the site. The primary objectives of the ongoing modeling efforts are to evaluate the effectiveness of the pump and treat system presently in operation and to determine potential locations and pumping rates for future extraction wells and recharge trenches. Groundwater flow and advective transport (particle tracking) models are being used in conjunction with geostatistical programs to evaluate the performance of the existing groundwater extraction and recirculating system with respect to effectiveness and efficiency. Future modeling efforts will combine these tools under the umbrella of a geographical information system (GIS) to allow greater flexibility and versatility of the current system with respect to incorporating new groundwater monitoring.

USE OF NUMERICAL GROUNDWATER MODELING FOR OPERATION AND MANAGEMENT OF THE NORTH BOUNDARY CONTAINMENT SYSTEM AT THE ROCKY MOUNTAIN ARSENAL

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Waterways Experiment Station, Geotechnical Laboratory,
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ABSTRACT

Three groundwater barrier systems have been installed at the boundaries of the Rocky Mountain Arsenal to prevent the off post migration of contaminated groundwater. The first of these was the North Boundary Barrier System which was constructed in the period of 1978-81. The North Boundary Barrier System was a pioneering effort in the use of groundwater barrier systems for the control of contaminant migration. Previous design and operational experience for such systems was unavailable. Because of the complex hydrogeologic conditions at the arsenal, this barrier system has proved very difficult to manage and operate. Colorado State University and the U.S. Army have cooperated in developing an operational management model of this system.

A pilot boundary system was installed at the north boundary in 1978. This pilot system consisted of a 1,500 foot long bentonite slurry wall, 6 dewatering wells and 12 recharge wells. In 1978 the barrier system was extended to a total length of 6,470 feet. In 1989 and 1990 the barrier system was modified to include the addition of recharge trenches. The complete barrier system consists of 35 dewatering wells, 38 recharge wells, and 15 recharge trenches, separated by a bentonite slurry wall. Contaminated groundwater is pumped from the upgradient side of the slurry wall, treated by granular activated carbon adsorption, and the treated water is recharged downgradient of the wall. The dewatering wells are divided into three collection manifold (A, B and C). Flow from each manifold has historically been treated by separate adsorber units. Manifold A intercepts a plume of Diisopropylmethylphosphonate (DIMP) flowing from the Basin F area. Manifold B intercepts a Dibromochloropropane (DBCP), chlorinated pesticides, Aldrin, Dieldrin, and Endrin, and several organosulfur compounds. Inorganic contaminants include chloride and fluoride. In 1990, the treatment process was reconfigured to treat the combined inflow from the separate manifolds as a single inflow stream.

Since the bentonite slurry wall extends across the entire north boundary of the arsenal (keyed at its ends into relatively impermeable bedrock highs), the barrier system, regardless of how it is operated, should intercept all of the contaminated groundwater in the shallow alluvial aquifer reaching the north boundary. However, concerns have been expressed about the integrity of the bentonite slurry wall and about the potential underflow past the barrier system of contaminated groundwater in the underlying Denver Formation. The prevailing thought is that this potential underflow is best controlled by maintaining a reverse gradient (a gradient inward towards the arsenal) across the bentonite slurry wall. Management of the contaminant plumes approaching the barrier system is also desired. Questions about the operation of the barrier system concern: 1) What is the total barrier system flow rate?; 2) What is the distribution of manifold flow rates?; 3) What is the best distribution of the treated recharge water?; 4) In the case of system failure, time and location of overtopping of the bentonite slurry wall?; 5) The Feasibility of achieving a gradient reversal?; and 6) The system modifications to improve barrier operation?

A finite element groundwater model (CSU/GWFLOW) was applied to the North Boundary Barrier System to study these concerns. A very detailed mesh was used for the model grid which consisted of about 14,000 nodes. Each of the 35 dewatering wells and the 38 recharge wells were represented in the mesh by separate nodal points so as to allow specification of individual well pumping rates. Each of the 15 recharge trenches were represented by 3 to 6 nodes in the model grid. Similarly, 36 monitoring wells at the arsenal in the vicinity of the barrier system were represented in the mesh by separate nodal points so as to allow direct observation of model results with field observations. In the mesh the bentonite slurry wall was simulated as an interior no-flow boundary.

A steady-state calibration of the model was initially performed to the pre-barrier conditions (February-March 1978). This calibration was then further refined by a series of transient calibrations. This consisted of simulating actual barrier system operation beginning with the pilot system to full barrier system operation (December 1991). This consisted of 13 separate transient calibrations at selected time periods. The model results were compared with field observations at the monitoring wells. One of the difficulties with the transient calibration is that records kept about barrier system operation were often incomplete because of metering problems. The model calibration was considered to be excellent with an average model calibration error of about .5 feet.

Utilizing the calibrated model, various operational, breakdown and barrier reconfiguration simulations were performed. One of the major questions asked by arsenal personnel was whether a gradient reversal could be achieved using the original barrier configuration (no recharge trenches). The line of recharge wells is located 250 feet downgradient of the slurry wall and the line of dewatering wells are located 250 upgradient of the slurry wall. The rate of underflow of groundwater to the North Boundary Barrier System has varied with time but in recent years has been about 220 to 230 gpm. Under this natural interception rate the average head difference between the two lines of wells is about 4 feet. Model results indicated that the best that could be achieved by the barrier system in the long term was the natural interception conditions. A gradient reversal over the entire length of the barrier system was not possible in the long term but in the short term over pumping of the barrier system could be used to increase the section of the barrier with a gradient reversal.

The recharge capacity of the injection wells has considerably decreased since the wells were first installed. This loss of recharge capacity is thought to be due to deposition of carbon fines from the adsorber units and from microbial growth in the wells. These problems are currently being studied in a separate project between Colorado State University and the U.S. Army Corp of Engineers. Because of this loss of recharge capacity of the wells, much of the treated recharge water has historically been disposed of in a bog at the east end of the barrier system. Additionally Manifold C was over pumped relative to Manifolds A and B because of concerns about overtopping of the slurry wall in that section if the barrier system were to breakdown for an extended period of time. As a result the actual head differential across the slurry wall have been considerably different than that for natural interception rates. For this historical operating condition the head differential across the slurry wall in the Manifold A section was typically greater, and in the Manifolds B and C sections was less than natural conditions.

Since Manifolds A and B intercept contaminated groundwater of high concentrations and Manifold C intercepts low concentration groundwater, it is desirable to maintain a reverse gradient over at least Manifolds A and B. In order to accomplish this, several barrier system modifications were tried in the model. The best configuration was to replace the recharge wells with a series of recharge trenches located 45 feet downgradient from the slurry wall. The concept was to provide better control over the distribution of the recharge water on the downgradient side of the slurry wall. Treated water previously discharge to the bog near the east end of the barrier system would then be discharged through trenches located in the western half of the barrier system to try to cause a gradient reversal in this region. For this simulated operating condition a gradient reversal was achieved over the entire section for Manifold A and most of the section for Manifold B. With this supporting results, the Army has installed 15 recharge trenches.

These recharge trenches have performed excellently and have achieved the desired gradient reversal over the critical sections of the North Boundary Barrier System. In actuality, the Army has thus far been able to maintain a gradient reversal over most of the length of the barrier system. This has been achieved by over pumping the dewatering wells. Consequently parts of the alluvial aquifer on the upgradient side of the barrier system has been desaturated. The effect of this over pumping with time was studied using the model.

The experiences learned at the Rocky Mountain Arsenal are that groundwater barrier systems are often complex and difficult to operate for effective system performance. The experiences (difficulties and successes) learned in operating the barrier systems at the Rocky Mountain Arsenal should be valuable to others desiring to use similar barrier systems. The operational management groundwater model developed jointly by Colorado State University and the U.S. Army Corp of Engineers has proven to be a very useful and practical tool in the management of these systems.

ABSTRACT

Bioremediation - Parameters Estimation, System Design, and Prediction of Cleanup Time

C. Y. Chiang
Shell Development Company
Houston, Texas

In-situ bioremediation provides a potentially cost effective alternative to a conventional pump and treat system by utilizing indigenous microorganisms to increase the rate of decay of the soluble hydrocarbon plume as well as the residual hydrocarbon source. Mathematical models are often used to design the bioremediation system. Before applying models to a field site, it is crucial to understand the interplays of several key parameters: macrodispersion, hydraulic conductivity, biodegradation rate, sorption, and source strength. Well characterized site data are used to illustrate the interactions among these parameters. For example, threshold limits for aromatic hydrocarbon oxidation under varying levels of dissolved oxygen were determined from both laboratory microcosms and field data; the results were remarkably consistent with each other.

Subsequently, these predetermined parameters are used in numerical models to design an optimal bioremediation system and to predict the cleanup time. A case study will be used to illustrate the modeling processes and limitations. Finally, Some preliminary results from an enhanced aerobic bioremediation system will be presented.

Appendix B
Agenda

ARMY GROUNDWATER (GW) MODELING USE AND NEEDS WORKSHOP

Sheraton Denver Airport Hotel, Denver, CO

30 March - 1 April 1992

30 Mar

1900-2100	Optional Pre-registration, Icebreaker, and Panel "Get Acquainted" Sessions	Dr. Hadala

31 Mar

0800-0830	Registration	Ms. Lloyd
0830-0835	Welcome	Mr. I. May
0835-0840	Administrative Announcements	Mr. Dardeau
0840-0850	Purpose of Workshop	Dr. Oswald
0850-0910	Role of THAMA	Mr. I. May
0910-0925	Role of GW Modeling in Army Activities	Mr. Ballif
0925-0935	Introduction to Panel Discussions	Dr. Holland
0935-0950	Break	
0950-1030	Groundwater Problems & Remediation Methods	Dr. Cullinane
1030-1115	Report of Groundwater Modeling Survey	Dr. Holland
1115-1230	Lunch	
1230-1430	Panel 1: GW Problems, User Needs & Model Use	Mr. I. May
1430-1500	Break/Board Buses	
1500-1700	Optional Trip to Rocky Mountain Arsenal	Dr. J. May
1700	Adjourn	

1 Apr

0800-0815	Announcements and Comments	Dr. Holland
0815-1000	Panel 2: Model Use in Remedial Investigations	Dr. Butler
1000-1015	Break	
1015-1200	Panel 3: Model Use in Remediation (Emphasis on Feasibility Studies)	Dr. Cullinane
1200-1315	Lunch	
1315-1515	Panel 3: Model Use in Remediation (Concluded) (Emphasis on Design, Operation & Monitoring)	Ms. McDaniel
1515-1530	Break	
1530-1630	Wrap-up	Dr. Hadala
1630	Adjourn	Dr. Holland

Appendix C
Survey Form

QUESTIONNAIRE ON ARMY USE OF GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODELS

INSTRUCTIONS: **Prior to beginning, please provide the following information:**

Name: ______________________
Office Symbol: ____________
Address: ____________________
Telephone: __________________

Now, please answer the following questions.

1. What percentage of the hazardous and toxic wastes (HTW) problems you are encountering at military or Superfund sites is associated with

____ Petroleum Hydrocarbons
____ Organic Solvent Liquids
____ Explosives
____ Metals
____ Other (please specify) ___________________________

2. For the sites referred to above, how many of them are, or are projected to be, involved with the cleanup of contaminated groundwater resources for both saturated and unsaturated conditions? ____(military) ____(Superfund) What percentage of the total number of your HTW sites is this number? ____(military) ____(Superfund)

3. How many of your groundwater-related cleanup studies (over the last ten years) contained, or are projected (over the next five years) to contain, a groundwater modeling effort? ____ If this number is zero, skip to Question 10.

4. For each groundwater modeling study planned or executed, please provide the information requested in the attached Table 1. Please reproduce additional sheets as needed.

5. For each groundwater modeling study listed in Table 1, please provide the information requested in the attached Table 2 on a sheet per study basis. Please reproduce additional sheets as needed.

6. Are groundwater models overly expensive or difficult to use for your applications? ____ If the answer is no, please continue to Question 7.

If the answer is yes, please check the following that supports your answer:

____ Models typically require more cost or effort than the information gained from them is worth.
____ User manuals or other instructions for using the individual models are inaccurate, incomplete, and/or out of date.
____ Too much labor and/or time is required to compile the field data needed to define the problem to be modeled.
____ Too much labor and time is required to put results of model analyses in a form that is useful for making engineering decisions.
____ Other; please explain. ______________________
____
____

7. Was your answer to Question 6 based on your own experience, discussions with contractors, or both? ____________

8. In your experience, are groundwater models comprehensive enough to account for the major details of real field problems? _____ Alternately, do you believe your organization generally collects data sets comprehensive enough for groundwater model use? _____

9. Rank the following items by assigning them a High (H), Medium (M), or Low (L) importance in making groundwater models more useful tools for your site applications.

____ software for personal computers (PCs) or work stations with a graphical user interface that enables easier input of data to groundwater models

____ software for PCs or work stations with a graphical user interface to aid in visualizing groundwater model results

____ software that would aid in extracting information from model results in the form of tables and plots similar to those now used to evaluate field data

____ interfaces that would couple groundwater models to CADD and GIS software

____ a data base of typical geophysical and biochemical parameter values for specific soil types and contaminants

____ a data base that would provide citations to pertinent published information on groundwater models

____ a probablistic modeling capability that includes measures of uncertainty in geologic conditions, aid in parameter estimation, and theoretical limits of modeling reliability

____ guidance on the use and limitations of existing groundwater models for site characterization, feasibility studies, and remediation operation

____ an expert system to aid users in the selection of appropriate groundwater models. The system would also provide users with recommendations for model parameter selection

____ groundwater modeling systems that have remedial alternatives integrated fully within their flow and transport models

____ Army-wide standardized groundwater modeling tools that have obtained EPA approval for use

____ Army technical support personnel to assist in model choice and application

10. If you are not using groundwater models for your groundwater cleanup studies, please indicate why (check each that is appropriate):

____ Generally insufficient time for model usage within normal project schedules

____ Insufficient funding or time to learn the use in-house of most groundwater models

____ Insufficient in-house manpower to apply groundwater models

____ Insufficient time to contract groundwater modeling efforts

____ Insufficient funds to pay for contracted modeling efforts

____ Current groundwater models have insufficient levels of credibility for decision making

____ Typically an insufficient amount of site data exists to warrant groundwater model use

____ No groundwater modeling was deemed necessary. Please explain the rationale for this decision __________
____

____ Other; please explain. ______________________________

11. Would you employ models more often if the items above in Question 9 were available? ____ If the answer is yes, please be sure you ranked the items in Question 9.

12. Do you have any access in-house to additional groundwater models that are not listed in Table 1? If so, please provide the names of those models below and whether they are run on personal computers (designate PC and class of PC; i.e., 286, 386, etc), workstations (designate WS with workstation name) or mainframes (M with machine name):

MODEL NAME	COMPUTER
____________	__________
____________	__________
____________	__________
____________	__________
____________	__________
____________	__________

13. When evaluating groundwater modeling proposals presented by contractors, which of the following is generally the <u>deciding</u> factor in contractor selection? (Check one please)

____ Quality of proposal based on in-house technical review
____ Quality of proposal based on external technical review. Who generally conducts this review? ______________________________
____ Known reputation of contractor
____ Other; please explain ____________________
____
____

14. When groundwater modeling results are presented, which of the following is generally the <u>primary</u> means of assessing the reliability of those results? (Check one please)

____ In-house technical review
____ External technical review. Who generally conducts this review? ____________________
____ Other; please explain ____________________
____
____

15. Please provide any additional comments you have including your projected future needs for groundwater models.

____
____
____
____

16. Please provide (reproductions or originals) of either cover pages or references to any contractor and in-house reports dealing with the modeling of groundwater flow and/or transport at Army sites.

FINAL INSTRUCTIONS: **Thank you for filling out this survey. Please mail the completed forms to:**

Dr. Jeffery P. Holland
USAE Waterways Experiment Station
3909 Halls Ferry Rd
Vicksburg, MS 39180-6199
ATTN: CEWES-HV-C
FAX: (601) 634-2818

If you have any need for assistance, please call Dr. Holland at (601) 634-2644 or (FTS) 542-2644.

TABLE 1: INPUT FOR QUESTION #4

Site Name	City, State	M, F or S [1]	Modeled Area [2]	Model Used	1D, 2D, or 3D?	SS or T [3]	Sat or Unsat [4]	Study Type [5]	F or FT [6]	Cont. Types [7]	Computer Hardware [8]

[1] Category of site: M - active military installation; S - Superfund site; or F - formally-owned military site (FUDS).

[2] Actual physical area modeled, in mi^2.

[3] Steady state (SS) or time-varying (T) conditions were modeled.

[4] Sat - only the saturated zone was modeled; Unsat - only the unsaturated zone was modeled. If both were modeled, input the word "Both" into the table.

[5] RI - remedial investigation and site characterization; FS - feasibility study; RE - remedial treatment method design and/or operation

[6] Flow only (F) or Flow + Transport (FT) was modeled.

[7] List each that is applicable: P - petroleum hydrocarbons; S - organic solvents; E - explosives; M - metals. If others were modeled, please write in the name(s) of the contaminant(s). Where possible, provide the name(s) of the explicit contaminants beside the major class designator (i.e., S - TCE).

[8] List each computing platform on which the given model is resident and executed: personal computer - PC with class of machine (i.e., 286, 386, etc); WS - workstation with name and model if available; and M - mainframe computer (i.e., supercomputer) with name and model if available.

TABLE 2: INPUT FOR QUESTION #5

a. Site Name, and its location (city, state)

_________________________, ____________________

b. What percentage of the study was performed
____ off-site, completely by contractor
____ in-house with the aid of a contractor
____ completely by in-house personnel

c. Was the study, or has it been to date
____ fully successful (continue to Question 6)
____ marginally successful
____ unsuccessful

d. To what do you attribute the lack of success with the above modeling venture? Check all that are appropriate for this study.

____ lack of contractor expertise in general
____ lack of in-house expertise to adequately write contract specifications
____ lack of in-house expertise to monitor contractor progress and activity
____ lack of in-house expertise to interpret contractor results
____ poor documentation of study results and modeling assumptions and methodologies
____ technology gaps in particular models used for this specific site. If so, who chose to use this model, your organization or contractors? ______
____ lack of proper support within the Army for model selection, validation, and review of contractor results
____ inadequate site characterization and data collection
____ inadequate time and/or funding to conduct an adequate study
____ other; please specify
____
____
____

Appendix D
Panel Objectives, Members, and Topics

Workshop on

ARMY GROUNDWATER (GW) MODELING USE AND NEEDS

Sheraton Denver Airport Hotel
Denver, Colorado

30 March - 1 April 1992

SUMMARY OF PANEL TOPICS

Panel 1: Current Installation Restoration Groundwater Problems
- Types of contaminants, sources and hydrogeologic conditions
- General types of remediation being applied
- RI/FS requirements related to modeling

Groundwater Model Applications
- Key examples
- Costs, timeliness and success

Critical Modeling Components and Requirements
- Data acquisition and management
- Computer system
- Staff knowledge, experience and training and guidance needs
- Contracting
- Proprietary codes
- Technical review, validation and verification
- Appropriate documentation of modeling results
- Regulatory acceptance and defensibility in court

User Needs
- Model selection and calibration
- Time and cost estimates
- Review and quality control of modeling efforts
- Results presentation, 3-D visualization and animation

Panel 2: Project Goals

Geologic Environment

Hydrogeologic Environment

Contaminant Properties and Transport Mechanisms

Data Management and QA/QC of Field Surveys

RI and GW Modeling Synergism
- Role of modeling in planning RI program
- Role of modeling in specifying supplemental RI
- RI role in supporting modeling

Panel 3: Remediation Alternatives

Currently Used Flow and Transport Models and Their Adequacy

Objectives of Model Use in Feasibility Studies

Data Requirements for Feasibility Studies

Model Requirements/Users for Feasibility Studies

Treatability Design

Flow Optimization for Pump-and-Treat Remediation Design

In Situ Remediation Optimization

Optimization of Monitoring Well Placement

Prediction of Remediation Response and Costs

Remediation Uncertainty

Regulatory Restrictions and Requirements

PANEL 1: Groundwater Problems, User Needs and Model Use

Objectives: The purpose of the User Panel is to provide representatives of the user community with a forum to present insight into their groundwater modeling requirements. The response to the groundwater modeling questionnaire will provide a generic overview of Army user needs but this Panel will give key representatives the opportunity to discuss pertinent Installation Restoration modeling needs and how these needs are being addressed. The successes and failures of previous modeling efforts can be addressed. Suggestions can be offered on what degree of expertise or expert systems need to be developed in the user community to be able to ascertain when and if modeling is required and what type of model is needed.

Presentations:

1. Mr. Brian Anderson, Program Manager, Rocky Mountain Arsenal (RMA). Description of groundwater modeling experiences for RI/FS at RMA. (20 min)

2. Mr. Khal Masoud, Program Manager, Baltimore District. Synopsis of modeling procedures, use and problems in RI/FS process. (15 min)

3. Dr. Fred Baker. Synopsis of modeling process, use and problems. (15 min)

Panel Members:

1. <u>Moderator</u>, Mr. Ira May, THAMA. Geologist. Represents THAMA as expert on Army modeling needs.

2. Mr. Brian Anderson, Program Manager Rocky Mountain Arsenal. Environmental Engineer. Expertise in application of models at Rocky Mountain Arsenal.

3. Mr. Khal Masoud, Baltimore District, COE. Civil Engineer. Project Manager with expertise in RI/FS needs.

4. Dr. Fred Baker, Baker and Associates. Civil Engineer. Groundwater model expertise with emphasis on hydrogeologic conceptual models.

5. Mr. Sam Bass, Missouri River Division, COE. Geologist, Chairman of MRD CAD Environmental Task Group Leader. Expertise in groundwater problems and RI/FS.

Topics:

* Current Installation Restoration Problems

* Types of contaminant
  -- Types of sources
  -- Types of hydrogeologic conditions
  -- RI/FS Requirements related to modeling
  -- General Types of remediation being applied

* Groundwater Model Applications
  -- Key examples
  -- Costs
  -- Timely Execution
  -- Results
    - Satisfactory
    - Unsatisfactory
    - Unclear

* Critical Modeling Components
  -- Contracting
  -- Proprietary codes
  -- Technical review
  -- Training
  -- Staff knowledge and experience
  -- Computer system
  -- Data acquisition
  -- Data management
  -- Validation
  -- Verification
  -- Appropriate documentation of model results
  -- Regulatory acceptance
  -- Defensible in court

* User Needs
  -- When is model needed?
  -- What kind of model?
  -- Cost?
  -- Time to develop and run?
  -- How to determine adequate calibration?
  -- Army expertise to review and provide QA/QC for groundwater modeling
  -- State-of-the-art presentation of results
    - 3-D
    - Animation

Questions:

Is contaminated groundwater the biggest problem?

What are types of contaminants present Army groundwater problems?

What are some key modeling efforts?

How were the results?

What are the most critical modeling components which hinder model application?

How do you know if you need a groundwater model or not?

If a model is needed, what kind is adequate?

How do you know if you have adequate input data?

How long will it take to get results?

What are the costs?

How do you determine adequate calibration?

Can anyone in the Army provide review?

Who should determine quality control of models being used?

What should a good model study report contain?

How does one estimate the level of effort required for a groundwater model study?

PANEL 2: Model Use in Remedial Investigations (RI)

(Role of RI in Model Definition and Models in RI Planning)

Objectives: This panel discussion will address the most difficult problem encountered in a groundwater (GW) modeling effort, defining the problem to be modeled. Uncertainties related to numerical methods and errors are second order compared to the uncertainties related to definition of the geologic model, hydrogeologic model, and contaminant transport processes. Two or three synopsis presentations and guided discussions will define requirements and problems associated with defining (a) subsurface structure and stratigraphy, (b) flow boundaries, (c) hydrogeologic properties, (d) properties of the fluids and transport processes in the subsurface environment, (e) initial conditions, and (f) the role of GW modeling in the RI process. The techniques involved in defining the hydrogeologic model are diverse: geologic mapping, surface geophysical surveying drilling and sampling, core/sample logging, borehole geophysical logging, borehole pumping tests, dye tracing, laboratory testing, and others. Although the numerical models require definition of properties at all points in the domain of the model, this can never be achieved in reality. The field data must be interpolated and extrapolated in a statistically meaningful and rational manner. Modeling is used in an interactive manner to guide the remedial investigations. This panel will emphasize the synergism between RI and GW modeling.

Presentations:

1. Dr. Frank Schwartz, Ohio Eminent Scholar in Hydrogeology, Ohio State University. Synopsis presentation on determining the hydrogeologic model and the role of modeling in planning RI (includes parameter uncertainty and geostatistical considerations). (30 min)

2. Dr. Carl Enfield, Chief, Processes and Systems Research Division, USEPA-ORD, RSKEL-Ada, Oklahoma. Synopsis presentation on contaminant transport processes--determination of important processes for a given site and parameters for modeling. (15 min)

3. Mr. Carlos Tamayo, Civil Engineer, Colorado State University. Case study on off-post (Rocky Mountain Arsenal) geostatistical groundwater modeling effort.

Panel Members:

1. Moderator. Dr. Dwain Butler, WES. Geophysicist. Expertise in site characterization for geology and hydrogeology.

2. Mr. Carlos Tamayo, Colorado State University. Civil Engineer. Expertise in geostatistics and groundwater modeling.

3. Dr. Frank Schwartz, Ohio State University. Ohio Eminent Scholar in Hydrogeology. Expertise in groundwater modeling, hydrogeologic description, geologic description and geostatistics for parameter estimation and uncertainty.

4. Dr. Carl Enfield, USEPA-ORD, RSKEL-Ada, Oklahoma. Chief, Processes and Systems Research Division. Expertise in contaminant transport processes and transport parameter determination for modeling.

5. Dr. James May, WES. Hydrogeologist. Expertise on modeling needs related to Remedial Investigation / Feasibility Studies.

6. Mr. Gregory Hempen, Saint Louis District. Geophysicist, past president of the Association of Engineering Geologists. Expertise in site characterization for hydrogeology.

7. Mr. Dennis Bowser, THAMA. Geologist. Expertise in geology and contract monitoring for hydrogeologic site characterization.

8. Dr. James Brannon, WES. Geochemist. Expertise in contaminate fate and mobility processes in soil and its modeling.

9. Dr. Jesse Yow, Lawrence Livermore National Laboratory, DOE. Manager of Environmental Technology Program. Expertise in modeling and remediation of radionuclides in groundwater.

Topics:

* Project Type
  -- Defense Environmental Restoration Program
    - Installation Restoration
    - Other Hazardous Waste
    - Formerly Used Federal Properties
    - National Priority List
  -- Superfund Site
  -- Contamination Remediation
  -- Unexploded Ordnance
  -- Monitoring Network

* Geologic Environment
  -- Fractured Rock/Porous Media
  -- Consolidated/Unconsolidated
  -- Aquifers/Aquitards
  -- Stratigraphy and Complexity
  -- Geometry and Scale
  -- Parameter Uncertainties

* Hydrogeologic Environment
  -- Boundary Conditions
  -- Hydraulic Head Distribution
  -- Unsaturated/Saturated Flow
  -- Steady State/Transient Flow
  -- Hydraulic Conductivity Distribution in 3-D
  -- Porosity Distribution in 3-D
  -- Contaminant Source Locations
  -- Initial Conditions
  -- Parameter Uncertainties

* Contaminant Properties and Transport Mechanisms
  -- Single/Multiple Species
  -- Soluble/Insoluble
  -- Density (relative to water)
  -- Conservative/Nonconservative
  -- Advective Transport
  -- Dispersion/Diffusion
  -- Retardation/Decay
  -- Radionuclides
  -- Parameter Uncertainties

* Data Management and QA/QC of Field Surveys

* RI and GW Modeling Synergism
  -- Role of Modeling in Planning RI Program
  -- Role of Modeling in Specifying Supplemental RI (Updating or Enhancing Geologic/Hydrogeologic Models)
  -- RI Role in Supporting Modeling

Questions:

Generally, what is the interface between the personnel responsible for planning and conducting RI and the personnel who must use to results of the RI to perform numerical groundwater model simulations?

Are the groundwater modeling input requirements ever taken into account in planning RI?

How does a knowledge of the contaminants, the source and site history affect the RI?

Which of the geologic, hydrogeologic, and transport process parameters generally have the greatest degrees of measurement and spatial uncertainties?

How do the uncertainties and unknowns in the hydrogeologic model compare to inaccuracies and errors in the numerical modeling process?

Are there parameters needed to support the use of new process theories in numerical modeling that can not now be practically obtained?

Is cost the greatest controlling factor in the level of detail in the final hydrogeologic model?

Typically how is the density of field measurements determined?

Are there any guidelines for determining scale and scope of the RI? That is, how is the size of the area which must be characterized in the RI determined, relative to the size of the site or facility of interest?

How often in practice is groundwater modeling used to plan RI?

How often are geostatistical procedures used to develop a parameter uncertainty model for the hydrogeologic parameters?

Is there a need for RI planning tools, such as expert system programs, to optimize the RI planning phase to support subsequent groundwater modeling efforts?

What are the major problems in RI data management? Are existing database management systems adequate for the task?

Is QA/QC of field surveys a major problem in RI?

PANEL 3: Model Use in Remediation

(Role of Groundwater Models in Feasibility Studies (FS), and Design, Operation and Monitoring of Remediation)

Objectives: This panel discussion will address one of the main reasons for developing a Army groundwater model: remediation, that is, the need to integrate remediation effects into groundwater flow and contaminant transport models. The purpose of the panel is to establish the need for models in the evaluation of remediation alternatives in the feasibility study (FS) and optimization of the design, operation and monitoring of the remediation process; identify current models and types of models and methods being used in the evaluation process; determine the frequency of model use in the FS and remediation process; and determine why models are not used more frequently. In addition, the panel should establish the required level of sophistication; potential use, products and impact of models; problems with existing models and their needed improvements; criteria for model selection; data requirements and who will use the model. The panel will be broken into two parts--model use in the FS and model use for optimization of the remediation including verification of the remediation process and the model based on monitoring data.

Presentations:

Part 1

1. Dr. Gaylen Brubaker, Remediation Technologies, Inc. Tutorial on types of remediation alternatives and how a groundwater model could aid evaluation and optimize design and operation of the alternatives. (30 min)

Part 2

2. Dr. Randall Ross, USEPA-ORD, RSKEL-Ada, Oklahoma. Tutorial on role of monitoring in modeling and remediation process along with a case study. (20 min)

3. Dr. James Warner, Colorado State University. Case study on modeling of Rocky Mountain Arsenal. (20 min)

4. Dr. C. Y. Chiang, Shell Development Company. Case study on modeling NAPL remediation by vapor extraction or biodegradation. (20 min)

Panel Members:

Part 1

1. Moderator. Dr. John Cullinane, WES. Environmental Engineer. Expertise on all aspects of remediation and treatment systems.

2. Mr. Jack Genereaux, Kansas City District. Geologist. Reviewer of remediation schemes with emphasis on feasibility based on groundwater flow requirements.

3. Mr. Jim Zeltinger, Omaha District. Geologist. Reviewer of remedial alternatives with emphasis on groundwater interactions.

4. Mr. Don Koch, Engineering Technical Associates. Expertise in groundwater modeling for RI/FS involving pump-and-treat remediation alternatives.

5. Dr. Gaylen Brubaker, Remediation Technologies, Inc. Consulting remediation specialist. Expertise in designing and evaluating remediation systems for a wide range of problems and in specifying groundwater modeling requirements.

Part 2

6. Moderator. Ms. Tomiann McDaniel, HQUSACE. Expertise in remediation of groundwater problems.

7. Dr. James Warner, Colorado State University. Professor of Civil Engineering. Expertise in GW flow and transport modeling.

8. Dr. Randall Ross, USEPA-ORD, RSKEL-Ada. Hydrogeologist. Expertise in remediation modeling at Superfund sites.

9. Dr. C. Y. Chiang, Shell Development Company. Environmental Engineer. Expertise in modeling and remediation of petroleum NAPL.

10. Ms. Carol McKinney, Kansas City District. Hydrogeologist. Expertise in remediation design.

Topics:

* Proposed remediation alternatives being considered

* Current model use
  -- names and type
  -- selection criteria
  -- frequency and objectives of use
  -- reasons for non-use
  -- deficiencies and needed improvements

* Potential use
  -- effectiveness evaluation
    - feasibility based on flow
    - feasibility based on transport and reaction kinetics
    - prediction of concentration as a function of time
  -- predictions for treatability studies
  -- economics
  -- optimization of design and operation
    - flow for pump-and-treat and containment
    - transport of contaminants for pump-and-treat
    - in situ remediation
    - monitoring
  -- uncertainty analysis for design and feasibility

* Data requirements
  -- site characterization (remedial investigation)
    - contaminant descriptions
    - contaminant concentrations
    - site geology and geochemistry
  -- process variables
    - decay and reaction rates, etc.
    - partitioning coefficients
  -- remedial design parameters and descriptions
    - flow rates
    - reactant concentrations and dosages
    - phase and component interactions
  -- monitoring data for optimizing operation of remediation and verifying the model

* Model requirements/users
  -- level of sophistication
    - multi-phase?
    - coupled unsaturated and saturated?
    - transport or flow only?
  -- in-house or contractor
  -- versatility
  -- computer environment
  -- training
  -- recommendations for development
  -- effects of regulatory requirements and review

Questions:

Part 1

What types of remediation alternatives are being considered in feasibility studies? Is modeling used to determine their feasibility? If so, what type of remediation alternatives are modeled? what models are used? how are the models selected? is only flow modeled or is transport also modeled? what are the products of the modeling? what are the deficiencies and what improvements are needed?

What level of sophistication of modeling is required to evaluate the feasibility of remediation alternatives? to estimate time requirements and concentrations achieved? to predict costs?

Why aren't models used more often for evaluating feasibility of remediation alternatives? Is data limiting? If so, what data? Are models inadequate? Are there good descriptions and models for incorporating the effects of remedial actions in models? Is it too expensive for the results? Are models unnecessary? Would routines to optimize the effectiveness of remedial alternatives be useful and cost effective?

Should models be developed to optimize the remediation design? estimate costs? predict effectiveness (concentration as a function of time and location)?

Is more research required to determine treatability and provide standard testing to determine remediation process coefficients and analytical descriptions?

Is in situ treatment a viable alternative? Is it being performed now? Is pump-and-treat able to obtain acceptable results in a timely and cost-effective manner?

Is remediation of the vadose zone a problem? Is a model needed to evaluate the transport of contaminants and treatment of contaminants in the vadose zone?

What are the shortcomings in the current methods of evaluating the feasibility of remediation alternatives?

Who needs to use a model in a feasibility study? Is it done in-house or by contractor? On what type of computer should the model run? Is training required to better understand remediation alternatives and the evaluation of their feasibility?

Are models used in feasibility studies also used to predict conditions for treatability studies, design the remediation alternative and adjust operating conditions during the remediation?

Part 2

Have models been used to forecast remediation performance? what models? How accurate have the predictions been? What are the main sources of uncertainty in remediation design? and performance forecasting? Which model parameters need the most re-adjustment, i.e., which are least well estimated a priori or with laboratory experiments? How is uncertainty incorporated in the design process for optimization of the remediation alternative? How is uncertainty quantified?

What methods are available to optimize the arrangement of observation wells (and pumping wells) in order to provide the necessary data to minimize uncertainties, maximize operating efficiency of remediation process and verify the model?

Have models been used to optimize the operation of an remediation system? How can response data provide a feedback to the operation? Are there any quantitative/objective methods to incorporate rapidly new field and laboratory data in model parameter adjustment? or is this subjective art?

What field measurements are necessary and sufficient to reasonably attribute any contaminant disappearance to a specific process, such as dilution, sorption, dispersion, volatilization, and particularly biotransformation?

Do ANY flow or transport parameters measured by bench scale experimentation apply unaltered to field scale simulation or do field heterogeneities preclude their simple application in a model? What is the process of transferring laboratory results to field performance?

Are there any circumstances in which the GW modeling state-of-the-use in the field approaches the possibilities of the state-of-the-art?

Appendix E
List of Attendees

ARMY GROUNDWATER MODELING USE AND NEEDS WORKSHOP

30 March - 1 April 1992

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13. ABSTRACT *(Maximum 200 words)*

This report documents the results of a 1992 U.S. Army-sponsored workshop on groundwater modeling uses and needs in support of contaminated groundwater resources at Army installations. The objectives of the workshop were to determine (a) the extent and specific nature of groundwater flow and contaminant transport models in Army site remediation; (b) requirements for enhanced transfer of groundwater modeling technology within the Army; and (c) needed research and development in groundwater modeling systems. Ninety individuals attended the workshop, representing the Army Environmental Center, various Corps of Engineers offices and laboratories, universities, consultants, and other Federal government agencies.

Workshop participants indicated considerable near-past use of groundwater modeling, with a planned definitive increase in modeling use over the next 5 years. Modeling was considered one of the best tools for synthesis and analysis of the large amounts of biological, geochemical, and hydrogeologic data required for contaminated site remediation. However, Army user expertise in groundwater modeling was deemed to be lagging behind the state of science in general, with a few specific pockets of expertise presented. Thus, training, guidance, and in-Army technical support for groundwater modeling technology were reported as high-priority user requirements.

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Contaminants	Hazardous and toxic wastes	Research and development
Feasibility studies	Installation restoration	Site characterization
Groundwater modeling	Remedial investigation	

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Numerous research and development needs were identified by Army users. These needs fell into the following basic categories: (a) improved use of existing models through coupling to interfaces, visualization, and parameter estimation techniques; (b) increased understanding of subsurface contaminant flow, transport, fate, and remediation processes; and (c) integration of optimization and simulation to allow efficient evaluation of remedial alternatives for design and operation. These research-related items are documented in detail within the report.