Review Of Discussions About Decision Support Issues in Europe and North America at the NATO/CCMS Special Session, and Overall Conclusions

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Abstract

Environmental management of contaminated lands is a complex process requiring a wide variety of decisions encompassing different technical, social, and political questions. Decision support for contaminated land management is an emerging field. Currently, a consensus for the best approach for using decision support does not exist. As part of the special session on decision support at the NATO/CCMS meeting held in Wiesbaden Germany in June 2000, two guided discussion sessions were conducted and one set of questions to the conference participants was prepared. The discussion sections focused on obtaining information on the uses of decision support tools and the strengths and limitations of these tools. The questionnaire focused on gathering information on the use of decision support in the different countries participating in the meeting. This paper summarizes the findings of this information gathering exercise.

1. Introduction

The NATO/CCMS Pilot Study on Remedial Action Technologies For Contaminated Soil and Groundwater Phase 3 is a multi-national forum for the exchange of information on emerging remediation technologies and technology demonstration. The Pilot Study is an activity of NATO Committee on Challenges for Modern Society (Web site: *http://www.nato.int/ccms/info.htm*). The Pilot Study has decided to hold a special session on the subject of decision support, which is the third in a series of special sessions.

2. Technical Background

Environmental management of contaminated lands is a complex process requiring a wide variety of decisions encompassing different technical, social, and political questions. The scope of the problems range from minor contamination of a single site with a single contaminant, to multiple sources of different contaminants on a single site, to management of numerous contaminated sites in terms of sustainable development. The types of decisions that have to be made range from overarching decisions that involve technical and social criteria (e.g., for sustainable development should a particular piece of contaminated land be remediated and redeveloped) to more detailed technical decisions (e.g., how many samples are needed to support decisions on where to remediate).

The breadth in scope and large number of decisions required for contaminated land management has led to confusion as to what decision support means. In a companion paper (Bardos et al ibid.), decision support was defined as: the *assistance for, substantiation and corroboration of, an act or result of deciding; typically this deciding will be a determination of an optimal or best approach*. Although obvious, it is important to point out that decision support is NOT the same as taking a decision. More specifically, decision support is the process of taking experience, data, and problem specific knowledge and the analysis and integration of this information to produce decision knowledge.

Figure 1 illustrates the technical components that go into making decisions for contaminated land management. The problem begins with definition of a technical approach to the problem. Data are collected and managed. The data includes any information used to assess the problem including measurements of contamination and soil and groundwater properties, technical performance of remedial options, and costs of remedial options. The data are utilized directly for decision support in some cases. In most cases, the data are used in models that further analyze the data to provide information necessary for supporting decisions. The outputs from the modeling require interpretation on issues such as are the proper models and parameters being used for the analysis. The decision support variables also have to be interpreted in terms of their adequacy in supporting decisions (e.g., what uncertainties are there in the variables and will these uncertainties possibly lead to a different decision). Figure 1 emphasizes the interdependence and feedback between different aspects of the problems through the two-way arrows. Eventually, the information is used in the decision making process.

Figure 1: Flow diagram of the decision making process.

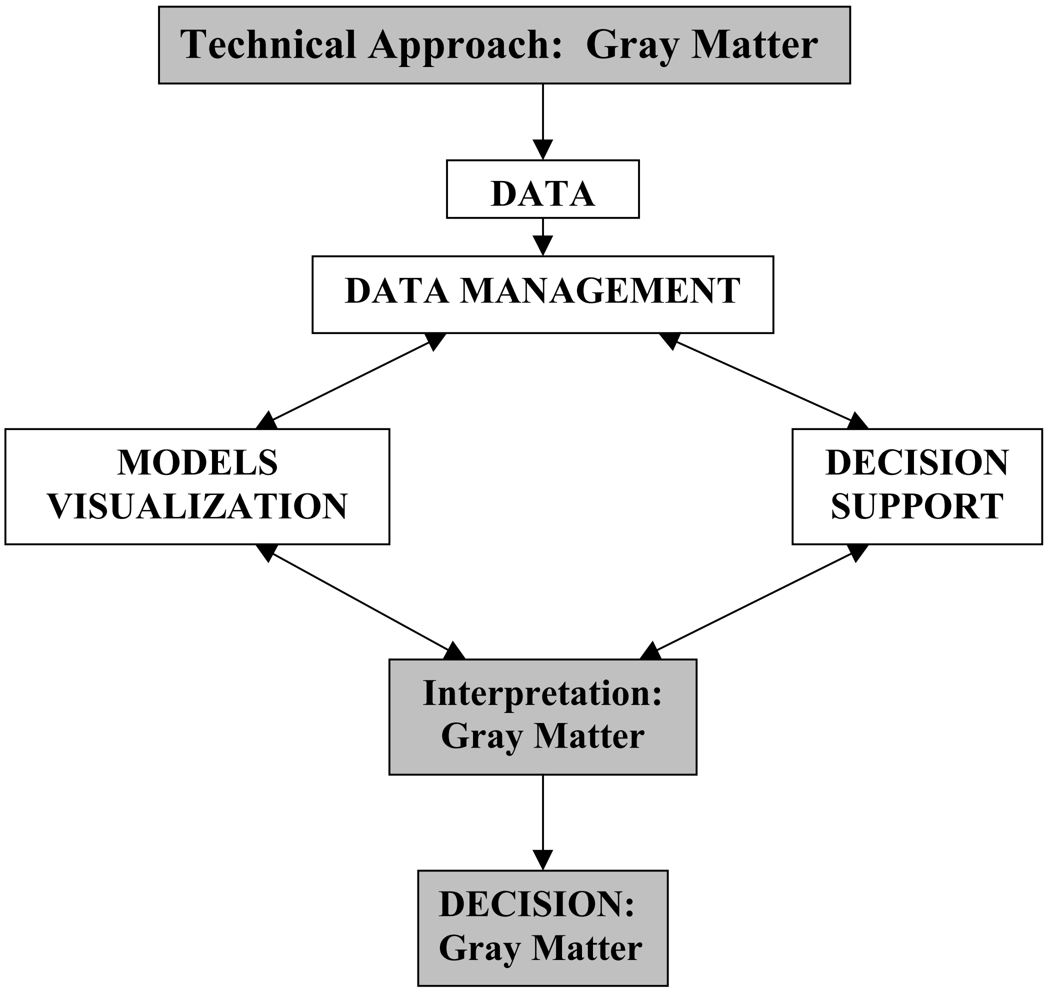

Figure 1 highlights the need for detailed thinking about the problem using gray-shaded boxes that use the term 'gray matter.' Decision support tools and techniques can supplement the decision process but can not replace critical thinking, analysis, and judgement.

A decision support tool was defined (Bardos *et, al., ibid.*) as *anything used as an instrument or apparatus in one's occupation or profession*. Thus a decision support tool (DST) is a product with the aim of supporting decision making; i.e. something that carries out a process in decision support. The DST can be written guidance on how to assemble and analyze information needed to support a decision (e.g., regulatory guidance on risk assessment, sustainable development, cost-benefit analysis, etc.). Alternatively, it can be a software tool that facilitates the data analysis and produces decision knowledge (e.g., costs, risks, etc.). In some cases, the software tools have codified the regulatory guidance to permit relatively easy and more consistent application of the guidance.

Figure 2 illustrates that many decision support tools will be used in addressing contaminated land management. The system boundaries represent the constraints to addressing the problem and include regulations, time, money, and other limitations. Decision tools work within the system boundaries to provide information that supports the decisions. As shown in the figure, some tools will address a single decision (e.g., what region needs to be remediated to reduce human health risks to an acceptable level), while others will address multiple decision variables (e.g., selection of a remedial approach based on economic costs, protection of human health, technical feasibility of the approach, and stakeholder concerns).

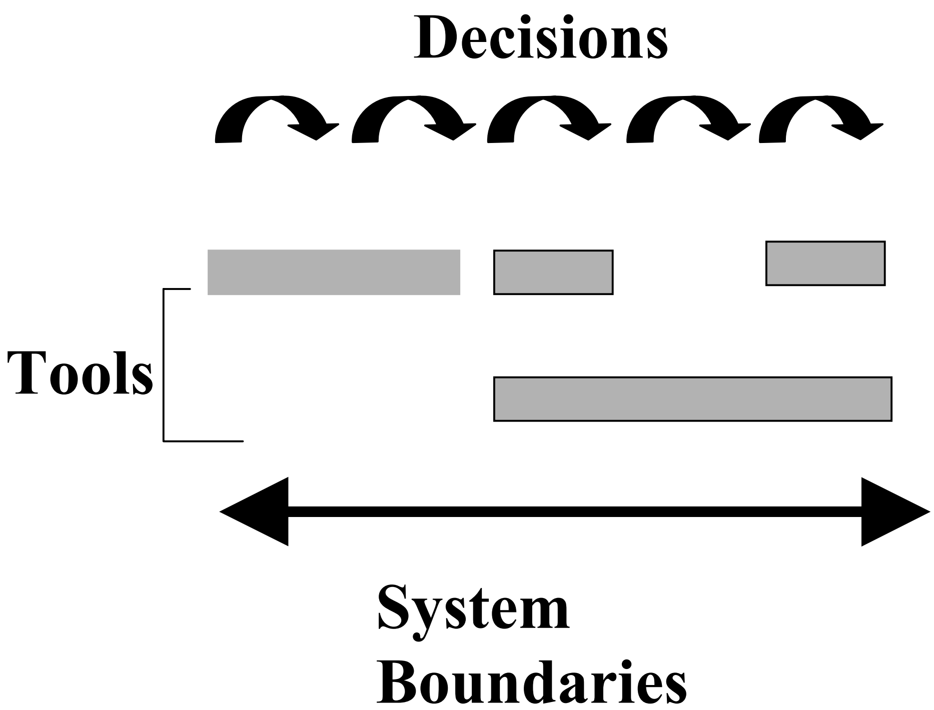

Figure 2: Schematic representation of the relationship between decision tools and decision making.

Also illustrated in Figure 2 is the concept that no single tool addresses the entire process. This is an important distinction, as many people would like a single tool that could address all of the decisions. This would increase transparency and reproducibility of the decision making process. However, because of the breadth and scope of decisions that need to be made this is not practical.

In general, the use of decision support tools and techniques is an emerging field in contaminated land management. While some areas such as human health risk assessment have generally accepted approaches for decision making, many areas such as ecological risk, multi-criteria analysis, life-cycle analysis, and financial risk analysis are only recently emerging as decision support tools. Even for human health risk assessment where standardized approaches to analysis have been developed and accepted, there is still debate over these approaches (e.g., should specialized risk assessments be done for the young and old who may be more susceptible to exposure from contamination).

The fact that there is confusion over what constitutes decision support and decision support tools along with the application of new approaches in this field indicated a need to gather information from the conference participants on their view of the issues in decision support. This was accomplished by holding two discussion sections and asking the conference participants to respond to four questions on decision support.

3. Outline of Discussion Sections

Ing Johan Van Veen led the first discussion section and focused on addressing the following questions

1) Are decision support tools useful?
2) How are DST being used?
3) What is the role of stakeholders in the decision process?
4) What common factors emerge between decision support tools?

Mr. Laurence Davidson led the second discussion section with the intent of determining the advantages and disadvantages of using DST. During the discussion it became apparent that there were many issues that could not be claimed to be an advantage or disadvantage. For example, ease of use of the decision support tools was cited as an issue. Many people wanted tools that were easy to use, while others were concerned that without proper training the easy to use tools could be easily misused. For this reason, a third category, issues in using DST was added.

The list of questions provided to the participants were:

1. How is DS considered in your country as a discipline or technique?
2. How is DS for remediation used in your country (e.g. types of applications, frequency of use? - Always, sometimes, almost never)?
3. In your view how well are information needs for decision making about remediation understood?
4. What is your view of the usefulness of Decision Support for selection of remedial options / risk management? Is DS used to support technology selection?

Participants from Austria, Belgium, Canada, the Czech Republic, Germany, Greece, Italy, Japan, the Netherlands, Norway, Switzerland, Turkey, the United Kingdom, and the United States supplied answers to these questions.

The following summarizes the results of the discussions and responses to the questions. In several cases, there was an overlap between the different discussions and questions. The following reports the findings as they occurred. No attempt was made to consolidate the different thoughts into a more concise manner.

4 First Discussion Section

Are Decision Support Tools Useful?

There was consensus that DST may be useful. This was particularly true of regulatory type guidance on how to conduct analyses to provide decision support knowledge. Several people felt that these types of tools were essential and in some cases are required by national laws. There was less agreement on the use of software tools support different decisions in the contaminated land management process. For example, most people agreed that human health risk assessment tools were valuable and widely used. In contrast, while people could see the usefulness of sample selection based on geostatistical analysis, these types of approaches are not widely used. There were several people in the audience that felt DST could be useful for remedy selection. However, there was a contingent that felt due to the site-specific complexities in the contamination problem and the absence of accurate cost data, use of DST for remedy selection was not particularly useful.

Several people expressed concerns relating to the ease of use of computer software types of DST. Often these tools have a large data base and extensive assumptions built into the process. While this facilitates the analysis, it also can lead to poor use of the tools. Several people felt that easy to use also meant easy to misuse. It was suggested that the use of the tools still requires training and expertise in the different aspects of the analysis. The training should include guidance on the range of conditions over which the tool is applicable. This supports the notion that the tools can not be used to replace expertise, but only to enhance it.

What is the Role of the Stakeholders in the Decision Process?

A stakeholder is any individual or group that has an interest in the particular contaminated land management problem. Stakeholders include federal, state, and local regulators, local businesses, citizens, citizen groups, problem holders, environmental industry, and public health officials (PCCRARM, 1997; SNIFFER, 1999). The different perspectives held by stakeholders often leads to conflict in determining an approach to contaminated land management. In most countries, the problem holder analyzes the problem and suggests a remedy to the regulatory body. Currently, the public and other stakeholders are often informed of the recommendations through public meetings. At this time they may comment on the approach and suggest that improvements may be necessary. For contentious issues, most people agreed that earlier stakeholder involvement would be beneficial to the process. However, there was a concern expressed by several people that this could lengthen the time to make a decision and in some cases be counterproductive. On the other hand, failure to include stakeholder viewpoints can often lead to more severe management problems later. Several suggested that stakeholders must be made part of the decision making process, but they should not be given control of the decision making process. Strong leadership and communication skills were identified as being crucial to dealing with all of the interested stakeholders, but maintaining an ability to actually make decisions.

Stakeholder involvement was viewed as being essential in addressing sustainable development issues. For example, the level of remediation required to return a contaminated site to unrestricted use (greenfield) is more extensive than to restrict the use to industrial applications (brownfield). This additional remediation costs additional money and resources. The choice as to what is the best approach is largely influenced by societal views.

How Are DST being used?

A wide range of applications of DST were mentioned during the discussions. Three major categories of use were identified. The first is written guidance produced by the regulatory bodies. The guidance approach is used in a number of countries to enable a more consistent and defensible approach to contaminated land management. The second approach is use of DST for specific issues at a single site. Examples of these type of approaches include analysis of human health risks, remedy selection, site characterization, and cost-benefit analysis. In most applications, a single decision criterion is evaluated. However, use of multi-criteria analysis (MCA) and life cycle analysis (LCA) approaches are often found. The third category is the use of DST for prioritization among different sites. This is useful for addressing sustainable development issues. In this category, MCA and LCA analysis are commonly performed as these issues cover a wide spectrum of concerns.

Other important findings from the discussion are:

- Human health risk tools are the most widely used of any DST.

- For the most part, implementation of the tools is in the hands of the consultants and other technical specialists. Regulatory staff use them to a much lesser extent and the public and other stakeholders rarely use DST.
- When DST are used they tend to be only a small part of the decision process.

What are the common factors for Decision Support?

A few common themes emerged from the discussion section pertaining to decision support for contaminated land management. These include:

- Many decisions are required for contaminated land management. The decisions range from site and problem-specific questions that are largely based on technical and economic concerns (e.g., what is the best remedy to clean the site) to national questions that are largely based on societal concerns (e.g. prioritization of resources for the management of contaminated land to permit sustainable development). Although the emphasis on the decision variables may differ between different problems, they are interrelated. Site-specific problems can be influenced by societal concerns (e.g., neighbors may object to a technically viable solution such as incineration of wastes because they are concerned over airborne releases).
- Decision support tools integrate data and report results in terms of a decision variable. For example, assume that human health risk is one decision parameter for deciding if monitored natural attenuation is acceptable, or if a more aggressive remediation scheme is required. Many software programs predict the groundwater flow path and rate. While this information is required to analyze a contaminated aquifer, it alone does not address the consequence of the contamination and hence it is not a decision support tool. A decision support tool would take the information from the groundwater flow simulation and integrate it with information on the source strength and duration, contaminant transport processes (for example, removal by biodegradation), and exposure pathways and parameters (e.g., receptor location and use of contaminated water) to estimate human health risks over time.
- Stakeholder involvement is an important aspect of the decision process and helps to achieve a solution for contaminated land management that is acceptable to all.
- Stakeholders may not always agree on an approach for contaminated land management. In this case, the regulators are the mediators between the different stakeholders.
- Risk management and cost-benefit decision support tools are the most commonly used decision support tools.

5. Second Discussion Section

What are the Advantages of using Decision Support Tools?

A major advantage of using DST is that they ensure the decision making process is consistent and reproducible. Specific advantages of DST include:

- Data management can be greatly improved through the use of DST that store the information electronically and permit its use by all stakeholders. Proper data management can lead to improved quality control of data.
- DSTs provide a method to analyze multiple scenarios. Consideration of a range of scenarios can increase the confidence when making a decision.
- DST can be used to optimize the remediation process and lead to lower costs.
- Some DSTs can incorporate uncertainties into the decision framework. Decisions in contaminated land management are always made with some degree of uncertainty.

Addressing this directly can enhance the decision making process. For example, DST can estimate the volume and costs of remediation required as a function of the degree of certainty in achieving human health risk goals (Stewart, 2000) or financial risks (Finnamore, 2000). This permits the decision to be based on the problem holders aversion to failure.

- DSTs provide means to document all parameters and assumptions used in the analysis.
- DST can improve communication between various stakeholder groups.
- DST can be used as an educational tool. For example, the effects of changing parameters on the decision variable can be demonstrated.
- DST can improve the transparency of the process through documenting assumptions and explaining the approach used to reach a decision.

<u>What are the Disadvantages to Using DST?</u>

- Gaining acceptability of the tool with all stakeholders is often difficult. It takes time and effort to educate other stakeholders on the use of a tool. If the tool is perceived to be a 'black box' stakeholders not involved in the application of the tool will not trust the results.
- Decision support tools integrate data and knowledge about a problem to produce results in terms of a decision variable. In performing this analysis, a number of assumptions are made. In reporting only the decision variable, it is possible to lose the rationale behind the assumptions.
- Decision support tools must be maintained to keep current. For example, for remedial options as new cost data are obtained they must be incorporated into the appropriate database for use in the analysis. In addition, human health risk decision support tools often have a database for risk parameters. These parameters are continually being updated to reflect the latest scientific findings.
- Garbage In – Garbage Out. A decision support tool is only as good as the data and assumptions used to perform the analysis. The assumptions include not only those used to develop the DST but also those used in the conceptual model of how to represent the problem. Therefore, the analyst should be trained in the use of the tool and in the approach to represent the contamination problem. This relates to the previously discussed concerns of many that DST can be misused.

<u>What are the Issues in the use of DST?</u>

During the discussion session, it became clear that there were many issues on the uses of DSTs that either have not been resolved or are neither an advantage nor disadvantage. These include:

- The use of many types of DST is in its infancy. In general, DST need to gain acceptance from all of the stakeholders, provide training on how to effectively use them and guidance on when they would be useful.
- The value added by using DSTs needs to be demonstrated. Purchasing a DST, learning how to properly operate a DST and getting other stakeholders to agree that the DST is appropriate for the problem can be expensive and time consuming. If all of this work does not lead to a better decision or more efficient process to reach the decision, use of the DST could be considered inappropriate. Anecdotal evidence was presented at the meeting indicating that in one case, use of a DST saved several million dollars on the remediation project. Situations like this need to be thoroughly documented and subjected to independent peer review.

- Contaminated land management requires good data management practices. The data management system should be independent of the DST. This will allow easier independent analysis by other stakeholders and will lead to better quality control on the data.
- There are gaps between the latest developments in decision theory and their implementation in DST. This is to be expected because the development of the theory generally precedes the implementation in DST. However, it highlights the need to continually maintain and update the DST as new information becomes available.
- Validation/Verification of DST is required but difficult to perform. Validation refers to the demonstration that the DST performs as expected. Validation can be achieved by comparison of DST results with known solutions or with results from other accepted DST. Verification refers to the demonstration that the DST can accurately predict the behavior of the system. Due to the natural variability in contaminated land problems, lack of data, and the need for simplifying assumptions to represent the actual conditions it is generally not possible to verify the DST.
- DSTs are supposed to enhance transparency of the decision process. However, their development requires highly specialized knowledge and skills. For example, DST may implement state-of-the-art models for any or all of the following: geostatistics, subsurface flow and transport, human health risk assessment, ecological risk assessment, economic analysis, and decision theory. This highlights the previously identified need to educate and train stakeholders in the use of DST and the limitations in their use.
- The results from using DST may receive unwarranted credibility through the cloak of scientific rigor. The concern expressed was that if a well-accepted DST is used in the analysis, people will blindly accept the results without critically analyzing the assumptions and parameters. This highlights the need to remember that although the DST may be quite sophisticated in its analysis techniques it is just a tool. The decision process should still be based on thinking.

What are the Issues in Multi-Criteria Analysis (MCA)?

Multi-criteria analysis for decision support of contaminated land management is an emerging technique. In this approach, several alternatives are ranked against a list of criteria. These criteria can include costs, human and ecological risk reduction, societal values for the benefits of remediation, technical feasibility, and so on. From the preceding example, it is clear that each of these criteria will have different measurement scales and may rely on subjective judgement. Each alternative is evaluated against each criterion and given a score. The scores are then normalized to a single scale. Often economic cost is used for the scale. Using the normalized score, each criterion is given a weight to reflect its relative importance to the decision. For example, meeting societal values may be given a weight of 0.3 while meeting ecological values may be given a weight of 0.1. Then, for each alternative, the individual scores for meeting each criterion are multiplied by the weight for the criterion and a total score is obtained. The total scores for each alternative are then ranked to support the decision on selection of an alternative. As MCA is an emerging practice in this field, there is little guidance on how to score the different criteria, normalize to a single scale or select the weights applied to each criterion. This has led to the following issues in the use of MCA.

- Does it make sense to normalize criteria to a single scale? Often everything is assigned a monetary value. Is this the best choice?
- What is the best way to integrate more subjective data (e.g., societal values) with more technical data (e.g. costs or risks)?

- What is the basis for obtaining the criteria weighting factors? Optimally, they would be obtained by consensus among all of the stakeholders.
- How is transparency in the decision process maintained when weights and scoring are subjective?
- Is the process rigorous and robust when using subjective normalization and weighting?

It is clear that there are major concerns about the process of quantifying subjective data and comparison of dissimilar criteria. In order for MCA to become an important tool for contaminated land management these issues will have to be addressed and general guidance on acceptable approaches are needed.

6. Responses to the Questionnaire

How is Decision Support Used in Your Country?

The first two questions provided to the meeting participants were:
1. How is DS considered in your country as a discipline or technique?
2. How is DS for remediation used in your country (e.g. types of applications, frequency of use? - Always, sometimes, almost never)?
The responses often overlapped and contained similar information. Therefore, the discussion has combined the two.

In general, three categories of response to this question were obtained: a) not used at all; b) used in the form of guidance for best practices; or c) used for site-specific problems. In some countries, DS is not widely used. In most countries, DS in the form of regulatory guidance is frequently used and its application is required by some nations. When DS is being used, data management and human health risk assessment were the most frequently used. Multi-criteria analysis and ecological risk assessment are emerging uses for DS. Life Cycle Analysis is being used on a limited basis for special problems. All respondents considered DS to be a technique rather than a separate discipline.

The following example applications were supplied in the responses:
- Regulatory guidance for conducting human health risk assessment or best practices for remediation.
- Prioritization of projects for obtaining state funding, and for social and land-use planning;
- Data management,
- Human and ecological risk assessment,
- As a communication tool for the spatial context for risk and through visualization of data,
- As a method to insure uniform application of regulations,
- To support selection of monitored natural attenuation as a risk management strategy,
- Optimization of remedial technology operation parameters to minimize costs.

How well are information needs for DS understood?

There was a range of perceptions on this issue. Some people believed that information needs were well understood, while most did not. Most people felt that the needs were understood at the thematic level (i.e., contamination data, risk data, etc.) but not at the working level (amount of data required to make a defensible decision). Most agreed that the information needs were well understood by specialists and researchers, less understood by project management and regulators and not understood by stakeholders that are not involved in the analysis process. A few responses identified the following issues in information needs.

- Several areas of science are not well understood. Improved understanding could lead to better decision-making. Areas identified include long-term performance and cost data for remedial techniques, better understanding of subsurface flow and transport, and toxicology data.
- For MCA using subjective criteria such as the value of remediation to society, approaches to quantify the value in monetary terms are needed.
- Data quality needs are not well understood. The impact of natural variability and uncertainties in the data on the decision need to be addressed.

One respondent pointed out that the challenge for decision support tools is to simplify the systems so that data needs are reasonable in terms of the number of parameters and the cost to collect the data. The simplifications have to be balanced against the loss of technical accuracy in the results.

<u>What is your view of the usefulness of Decision Support for selection of remedial options / risk management? Is DS used to support technology selection?</u>

Many respondents felt that DS was useful for initial screening in the selection of remedial options. A few respondents felt that it was also useful in the final selection of a remedy. Those that did not feel DS was useful for final remedy selection indicated that the uncertainties in the cost and performance data were too high for new and emerging remedial technologies to permit use of decision support tools. Most respondents agreed that decision support is useful for risk management, in many countries, guidance is available, and risk assessment is routinely used.

Many respondents generalized the question to express how decision support was most useful in their country. Most respondents felt that decision support was very useful in the form of regulatory guidance to obtain a consistent analysis framework. This helped set the stage for dealing with the different stakeholders in a fair and consistent manner. Other advantages cited for decision support included:

- Improved communication with stakeholders. Visualization of data was acknowledged as an important method of communication.
- Better management, integration and use of data. The use of an overarching data management system that managed the data for all decision support tools can improve quality control and permit greater access to the data.
- Ability to determine key processes and parameters that impact the decision.
- Better transparency to the decision process.

7. Conclusions and Future Directions

Many decisions are required for contaminated land management. The decisions range from site and problem-specific questions that are largely based on technical and economic concerns (e.g., what is the best remedy to clean the site) to national questions that are largely based on societal concerns (e.g. prioritization of resources for the management of contaminated land to permit sustainable development). Although the emphasis on the decision variables may differ between different problems, they are interrelated. Site-specific problems can be influenced by societal concerns (e.g., neighbors may object to a technically viable solution such as incineration of wastes because they are concerned over airborne releases).

Decision Support involves integration of expertise and data, followed by analysis and interpretation of the results to produce outcomes in terms of decision variables (health risk, cost, suitability, etc.). For example, assume that human health risk is one decision parameter for deciding if monitored natural attenuation is acceptable, or if a more aggressive remediation scheme is required. Many software programs predict the groundwater flow path and rate. While this information is required to analyze a contaminated aquifer, it alone does not address the consequence of the contamination and hence it is not a decision support tool. A decision support tool would take the information from the groundwater flow simulation and integrate it with information on the source strength and duration, contaminant transport processes (for example, removal by biodegradation), and exposure pathways and parameters (e.g., receptor location and use of contaminated water) to estimate human health risks over time.

The decision support can be in the form of guidance that provides a framework for performing the analysis or software that has codified the expertise to allow more rapid analysis by many. The magnitude and similarity between contaminated land management problems has led to development of several computer software DST to address different aspects of the problem (site characterization, cost-benefit, risks, sustainable development, etc.).

Regulatory guidance is the most widely used type of decision support. In several countries, adherence to the guidance is required or strongly recommended. For software based DSTs, human health risk assessment and cost-benefit are the most commonly used. Ecological risk assessment and multi-criteria analysis are starting to see more use.

Stakeholder involvement is an important aspect of the decision process and helps to achieve a solution for contaminated land management that is acceptable to all. Stakeholders may not always agree on an approach for contaminated land management. In this case, the regulators are the mediators between the different stakeholders. Effectively integrating the stakeholders into the decision process is a difficult task requiring strong leadership and good communication skills.

The strengths, limitations, and applications of DST have been identified and discussed in this paper. The major strengths identified were the ability to provide a consistent, reproducible process for decision making and the ability to enhance communication between different stakeholder groups. The major disadvantage in using DST was in gaining acceptability of the tool to all stakeholders. This can be a time consuming process. A secondary disadvantage that was cited involved concerns that making the tools easy to use could lead to their misuse. Careful review is required for all results that support a decision.

A number of unresolved issues pertaining to the use of DST were identified. Based on these findings several areas for improvement were identified. Some of the more important areas requiring further development include:

- Improved methods for valuation of criteria and determination of weights for MCA approaches. This includes the need for improved methods and approaches for handling subjective (soft data). Work needs to be done to develop a consistent agreed upon approach to using MCA.
- Improved transparency for the concepts behind decision support to all stakeholders. Greater stakeholder involvement is needed to gain acceptance of DST.
- Improved transparency in the output from DST. Decision support tools often involve abstraction from multiple sources of data and involve complex technical analysis.

- Improved methods for verification of the performance of DST. This is especially true in computationally intensive areas that require extensive experience to use correctly and are often based on data sets that permit multiple interpretations. These areas include flow and transport calculations, geostatistical modeling and optimization of remedy performance.
- Improved methods for understanding the impacts of natural variability and uncertainty on the decision process. Some DST address the role of uncertainty in making a decision, but this is an emerging field that needs further development.
- Critical evaluation of the successes and failures in the use of DST. This evaluation would help to focus future development work.

8. References

Bardos,
Finnamore,
Stewart