INTEGRATING ENVIRONMENTAL RESTORATION MANAGEMENT WITHIN DOE USING AN ALTERNATIVE IDENTIFICATION AND EVALUATION PROCEDURE

A Methodology and a Case History

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ABSTRACT

The process of identifying and evaluating alternative corrective measures is a fundamental integrating part of Environmental Restoration (ER) activities. The process used in the Los Alamos National Laboratory (the Laboratory) ER Program is based on principles and tools from multiattribute decision analysis, a well-developed and proven method for evaluating options in decision situations involving multiple objectives, uncertainty, multiple interested stakeholders in the final decision, and the need for technical input from disparate disciplines. The process provides a methodology that has been extensively developed and reviewed over the past five decades; it provides a methodological structure for incorporating the concepts espoused in the streamlined approach as well as more specific guidelines such as data quality objectives (DQOs). The application of this methodology to the ER Program at Los Alamos is described in this paper.

INTRODUCTION

The regulatory emphasis for cleaning up waste sites under both the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) is the efficient identification and evaluation of alternative corrective measures. For example, Los Alamos National Laboratory's (the Laboratory's) RCRA operating permit requires that the permittee establish site-specific objectives for corrective actions and then develop a workable number of corrective action alternatives to be evaluated based on the site-specific objectives.

Various decision-making aids, such as the data quality objectives (DQO) process, the observational approach, and cost-benefit analysis, have been proposed to structure and streamline the complex process of identifying and evaluating remedial alternatives. However, none of these aids alone accomplishes these tasks. The DQO methodology narrowly focuses on guidance for designing plans for collecting environmental data to support risk-based decisions. However, this is only one aspect of the complex cleanup process. The observational approach provides a general philosophical framework but does not propose a formal quantitative methodology. Cost-benefit analysis requires that all benefits be described in dollars but does not incorporate uncertainties inherent in the complex cleanup process.

This paper shows that decision analysis is an appropriate tool to structure the remediation process and illustrates how a decision analysis structure can be used to incorporate and further quantify the DQO process, the observational approach, and cost-benefit analysis. The paper also presents the decision analysis approach to developing RCRA facility investigation (RFI) work plans at the Laboratory.

STRUCTURING COMPLEX CLEANUP PROGRAMS

Complexity of the Problem

Imposing an all-encompassing structure on large and complicated cleanup programs is difficult for many reasons. One difficulty is that there are many diverse and interested stakeholders in the cleanup process. These stakeholders include the cognizant regulatory agencies--the Environmental Protection Agency (EPA), the State, the Department of Energy (DOE), and the Nuclear Regulatory Commission--each of which imposes requirements and often uses different criteria to determine the acceptability of cleanup efforts. The interested stakeholders also include a diverse public with concerns ranging from property values to long-term health risks. Public demands and regulatory requirements are further complicated by legal issues such as culpability. Finally, in many cases these cleanup efforts must be coordinated with the operations of an active facility.

In addition to responding to the concerns of many stakeholders, decisions must be made in spite of significant uncertainties inherent in the cleanup process. For example, the lack of adequate historical data often makes it difficult to assess the nature and extent of contamination. Remedial alternatives must be identified despite this incomplete information. Furthermore, long time frames are required to determine the consequences of various remedial actions, and these actions must be evaluated before long-term results can be observed. Therefore, mathematical or computer models must be used to determine the long-term fate of the contaminants. These models use geological and hydrological parameters that may be inherently variable and may not be well characterized. Even if the parameters could be specified exactly, the models might not be adequate to describe the very complex transport processes affecting the long-term fate of the contaminants.

Another factor affecting the complexity of the problem is that there are multiple objectives to be satisfied by cleanup efforts. Public health risks must be reduced to acceptable levels, workers performing cleanup operations must be protected, ecological systems must be protected, costs must be controlled in a responsible manner, the facility operations must be maintained, adverse socioeconomic impacts must be minimized, and multiple regulations must be satisfied.

Finally, the cleanup effort requires many different technical disciplines: geology, hydrology, statistics, health physics, toxicology, and chemistry, to name a few. At many facilities, a large number of diverse sites must be investigated. The size of the effort requires a phased approach so that at any given time there are many different phases and many sites within each phase with many different technical disciplines participating. This complexity can lead to serious organizational problems.

Clearly, large, complex cleanup programs need a comprehensive structure to provide a consistent approach for developing objectives, setting priorities, and evaluating alternatives. This structure should formally involve the regulators, the public, facility managers, and technical personnel, and should provide a framework for effective communication. This structure must allow for multiple objectives and incorporate uncertainties. Ultimately, it must provide logical, defensible decisions and an auditable decision rationale.

Cost-Benefit Analysis, DQOs, and the Observational Approach --Aids for Structuring Cleanup Activities

A number of procedures for structuring remedial programs have been proposed. Cost-benefit analysis has a long history as a tool for aiding managers who must make complex and expensive decisions. However, cost-benefit analysis requires that all benefits be evaluated in terms of dollars and does not provide a mechanism for evaluating the impact of uncertainties on the decision-making process, nor does it model the decision makers' aversion to or willingness to accept risks associated with these uncertainties.

More recently, the DQO process has been developed to support decision making. The DQO process is a seven-step procedure for designing plans to collect the environmental data required for making decisions to support health-risk-based decisions. The decisions must be posed in an "if..., then..." format (for example, if the amount of mercury is greater than concentration C, then the area must be kept under institutional control). Thus, the decisions typically involve the comparison of a statistical estimate (an average concentration for example) to a regulatory threshold value. The decisions that the DQO process addresses are tests of hypotheses, and the uncertainty involved in these decisions is modeled through the use of decision errors. The decision errors include accepting the hypothesis when it is false (false negative) and rejecting it when it is true (false positive). These errors can result in failure to remediate when the risk is unacceptable and remediating when remediation is unnecessary. The decision makers degree of unwillingness to make these errors is captured by a discomfort curve. The DQO process provides guidance for designing statistical sampling plans for environmental data and is very useful as a tool to enhance communication between the different technical disciplines, and--in principle if not always in practice--involves the multiple stakeholders in the decision process. The DQO process forces investigators to think carefully about overall goals and objectives, and it provides an "auditable" trail for the assumptions and rationale used in designing the sampling plan. However, the DQO process does not provide an overall structure for the complex cleanup process. It is focused on one objective, public health risk, and supports one aspect of the remedial cleanup effort, the collection of environmental data.

The observational approach provides a framework for the explicit recognition of uncertainty and attempts to streamline the process by developing the probable remedial alternatives early in the process. This approach suggests focusing on the probable remedy, while identifying contingency plans for possible deviations from the most likely scenario. The goal is to stop sampling "as early as possible", that is, when uncertainties are sufficiently reduced to accept the probable remedy. Contingencies are developed for "all reasonable possibilities" and "probable conditions." These guidelines are logical, but reasonable people can and do differ over what constitutes a reasonable possibility and an acceptable level of uncertainty. The problem with the observational approach is that it provides no quantitative modeling structure to make these judgments explicit and defensible.

Decision Analysis as an Integrating Methodology

Decision analysis provides a formal methodology that gives structure to the observational approach, incorporates the DQO process to evaluate environmental risk, and, while recognizing cost as a component of the decision process, identifies other important objectives and includes uncertainties inherent in the remedial process.

Decision analysis directly addresses decision problems involving uncertainty, multiple objectives (and therefore, multiple evaluation criteria), and judgmental or subjective assessments of both technical issues and the decision maker's preferences. This approach contrasts with using an economic social value function or a monetary numeraire to represent personal preferences. The basis for this assessment of evaluation criteria, preferences, and uncertainty is multiattribute utility analysis.

Multiattribute utility analysis and the resulting decision analytic procedures provide a formal, systematic, and logical structure for making decisions involving multiple evaluation criteria in situations with significant uncertainty. The theoretical development for multiattribute utility analysis is based on concepts first proposed by Bernoulli in the early 1700s, and more fully developed in this century by von Neumann's work in economic systems and utility theory, the work of de Finetti and Savage in probability theory, and the many developments in multiattribute utility in the last 20 years, especially those of Raiffa (2) and von Winterfeldt (3). Decision analysis provides a set of procedures for assessing and analyzing preferences, risks, and options and is now an accepted approach for analyzing major public policy issues. Decision analysis has been used by several government agencies, including DOE, and by numerous managers at DOE facilities on a wide variety of problems. For example, DOE Headquarters (DOE-HQ) has used decision analysis in prioritizing budget allocations for environmental activities at DOE facilities.

THE DECISION ANALYSIS PROCESS

The first step of the process is to structure the decision problem by specifying (1) the objectives, (2) a systematic procedure for identifying alternatives to be evaluated against the objectives, (3) the evaluation measures to assess how well any given alternative achieves these objectives, and (4) a structured procedure for considering future-use scenarios that may affect the performance of the corrective measure alternative relative to the evaluation measures.

Step 2 involves screening, based on preliminary evaluation of general alternative corrective measures, using evaluation measures developed in Step 1. This approach eliminates from consideration alternatives that do not meet baseline requirements such as providing acceptable health-risk levels.

In Step 3, combination rules are developed so that evaluation criteria scores for an individual alternative can be combined to give a single measure of performance. This aggregation is consistent with RCRA and CERCLA guidance statements that alternatives must be evaluated on all the decision issues and that tradeoffs should be a featured part of the evaluation.

The combination rules developed in Step 3 are used in Step 4 to compute an overall measure of effectiveness or performance for each of the competing alternatives. This overall measure takes into account the relative importance of the different evaluation measures.

Step 5 is the sensitivity analysis of the entire evaluation process. This analysis attempts to identify those issues that are the most influential in determining the most effective corrective measure.

Finally, Step 6, using the results from Step 5, provides recommendations for further analyses.

DECISION ANALYSIS INTEGRATES DQOS, THE OBSERVATIONAL APPROACH, AND COST-BENEFIT ANALYSIS

Decision analysis provides a systematic procedure for developing the scenarios that are the basis for the hypothesis-test decisions of the DQO process and is thus a natural basis for incorporating DQOs in developing sampling designs. Moreover, the prior distributions used to describe the uncertainty in key measures can be used as a systematic tool for investigating the appropriateness of the "discomfort curves" and their implications for implicit tradeoffs between false positive and false negative errors.

Decision analysis provides the methodology to quantify concepts of the observational approach such as "as early as possible" and "acceptable level of uncertainty." The "as early as possible" concept is quantified using value-of-information assessments. Value-of-information models allow decision makers to estimate the impact of acquiring more data.

As an extreme example, if it is clear that if a corrective measure has been decided upon, gathering more data is a valueless exercise because there will be no impact on the decision. Unless additional data may change a decision, they have no value for the decision- making process and the value-of-information measure is zero. The same logic applies to less-than-extreme cases, in which there is some possibility of changing decisions, but change would occur only if the new data were strikingly different from past observations. If it is unlikely that new data will differ much, the additional data have little or no value. If the decision is changed by the new data, the value of information is the overall performance measure of the new decision minus the overall performance measure of the old decision given the new data. By comparing the value of information with the cost of acquiring the data, more informed decisions can be made about continuing or possibly expanding characterization activities.

Finally, decision analysis is a natural extension of cost-benefit analysis. Decision analysis provides the means to combine and quantify benefits assessed by many different measures. The combination of quantified benefits from multiple objectives can then be combined with or compared with the resources necessary to achieve them. Decisions are made on the basis of this comparison.

Because decision analysis is the underlying methodology used by DOE Headquarters in prioritizing budget allocations for environmental management, the use of this methodology at the DOE facility level is beneficial not only in integrating processes such as DQOs, the observational approach, and cost benefit analysis, but also as a means of integrating facility, regional, and Headquarters concerns in the decision-making process. In the case of the Los Alamos ER Program, the use of a common methodology and structure has made explicit the concerns of facility managers, the concerns of Headquarters, and the points at which these differ. In addition to making evaluation concerns clear, the decision analysis methodology adds further detail by showing the relative importance of these concerns in reaching decisions. This information is the basis for developing an ER prioritization model to be used to identify any SWMUs that should be addressed ahead of schedule (or behind schedule); by coordinating this process with DOE budget prioritization issues it is possible to quickly link the Programs high-priority activities with the budget implications of these priorities and budget allocation requests.

APPLICATION OF DECISION ANALYSIS TO SUPPORT RFI WORK PLAN DEVELOPMENT AT LOS ALAMOS

ER Program at Los Alamos National Laboratory

The Laboratory is one of the oldest and most complex facilities managed by the DOE. It covers a little over 43 square miles. It represents nearly 50 years of uninterrupted nuclear science involving over 50 research sites and one reactor. It has managed its own hazardous waste for the half century is has been in operation.

The Laboratory's ER Program is responsible for characterizing and cleaning up of over 2000 solid waste management units (SWMUs) under the RCRA operating permit. These 2000 SWMUs are organized in 24 operable units (OUs). The ER Program, directed by a program manager, coordinates the work of these 24 geographically defined OUs, each with its own project leader. Each OU has a project team that is supported by 26 technical teams, each with its own team leader. Currently, OUs are in different phases of the RFI process, are run by project leaders with differing technical backgrounds, and employ several different contractors. The size and complexity of the characterization effort presents significant problems for effectively coordinating these activities.

In this complex environment, characterization and remediation investigations of the individual OUs provide the backbone of the ER effort. However, it is important that the overall program be viewed as a unified program of health risk-based cleanup at the Laboratory and not just a collection of related technical activities. Ad hoc or inconsistent integration of the restoration activities will present a confusing picture for regulators, a confusing picture for the public, and will dramatically increase the potential for regulatory delays and cost overruns.

The first phase of the RFI process requires the OU project leaders to begin developing their work plans, which takes about 18 months, involves input from a wide range of technical experts, and uses historical data spanning almost 50 years.

DECISION ANALYSIS PROVIDES GUIDELINES FOR THE RFI WORK PLAN OUTLINE

To provide consistency for RFI work plans across the 24 OUs, the ER Program is using the decision analysis framework to structure work plan development. (1) The first step in the decision analysis process is to specify the remediation evaluation issues that will be used to assess a potential remediation alternative. The identification of evaluation issues is a multi-step process: first, a hierarchy of objectives is developed showing the key concerns for evaluating alternative corrective measures. Then the specific issues associated with each of the objectives are identified so that the future performance of a potential corrective measure alternative can be evaluated against these issues. At the Laboratory, upper-level managers, the ER Program manager, the OU project leaders, the technical team leaders, and other ER Program personnel were interviewed individually and collectively over several months to develop the evaluation issues. These issues, shown in Table I, reflect the major concerns identified in regulations promulgated by EPA and other cognizant federal regulations and, in particular, in the Laboratory's RCRA operating permit. It also includes other issues important to Laboratory operations and ER Program personnel. The issues listed in the left-hand column of Table I are the top-level concerns; the topics in the right-hand column show more specific categories for each top-level concern. These categories can be broken down into even more specific concerns.

These remediation evaluation issues represent Laboratory-wide objectives and provide the logical structure for the RFI work plan outline. Table II illustrates an RFI work plan outline developed to focus data collection efforts on remediation evaluation alternatives. Although the outline does not specify how each OU should address each issue or the relative importance of each issue, which will vary from OU to OU, it provides the basis for evaluating corrective measures and thereby makes Laboratory-wide issues the foundation for data collection at the OU level.

TABLE I

ER Program Evaluation Issues

Evaluation Issues	Specific Concerns
Health and Safety Issues	
Risks to the public and workers from hazardous waste during RFI, CMS, and corrective measures implementation phases	Hazardous waste risks • radiological • heavy metals • chemical Operations risks
Ecological Issues	
Impacts on habitat, biological resources, natural resources, aesthetics, and archaeological resources	Habitat and biological resources • threatened and endangered species • natural resources National Environmental Policy Act and Environmental Impact Statement requirements
Socioeconomic Issues	
Impacts on local economics, social infrastructure, and cultural sites	Economic impacts • property values • employment Social infrastructure • social displacement • services
Managerial Issues	
Contractual agreements, schedule, and budget, and Laboratory mission * *	Schedule Budget Contractual agreements Impact on Laboratory operations
Costs and Resources Requirements	
Present, future and life-cycle costs, and other resource requirements	Life-cycle costs • capital costs • future costs Resource requirements • technical staff • special equipment • area access

Key Variables Help Prioritize Data Collection, Aggregate SWMUs, and Structure Data

Characterization decisions require that investigators specify what data are needed. The data are used to determine the nature and extent of contamination and to support the selection of a corrective measure. Not all data are of equal importance in choosing between competing alternative corrective measures. The important or key variables are those variables that most affect the evaluation measures and thus the selection of a corrective action. These key variables have the highest priority in data collection efforts.

Key variables can be identified using influence diagrams. An influence diagram is derived from a conceptual model for the evaluation measure and shows the dependencies between the many variables involved in determining the evaluation measure. Figure 1 gives an example of an influence diagram for the health impact evaluation measure. The arrows in the diagram show the dependencies between the variables.

The key variables are derived from this diagram by assigning probability distributions to the variables and using a mathematical modeling technique (stochastic networks) to determine those variables that most affect the variability of the evaluation measure. The key variable concept can also be used to aggregate SWMUs. For example, in Fig. 2 the shaded ellipses represent the key variables for the health impact evaluation measure. All SWMUs with the same key variables and the same distributions on those key variables are identified. These SWMU groups must then be treated consistently across OUs, in terms of conceptual models, data collection, and prioritization.

Data archiving can also be guided by identifying key variables. Archival information data bases can be designed with keys that allow easy retrieval of data relevant to the important variables for evaluating corrective measures. This organization provides support for design of data collection activities during RFI and for activities during corrective measures studies (CMS).

TABLE II

RFI Work Plan Outline

Executive Summary
1.0 Introduction
2.0 Background Information for Operable Unit
3.0 Environmental Setting
4.0 Remediation Alternatives and Evaluation Criteria
5.0 Evaluation of Solid Waste Management Unit or SWMU Aggregate
  5.1 First SWMU or SWMU Aggregate
    5.1.1 Background
    5.1.2 Remediation Alternatives and Evaluation Criteria
    5.1.3 Data Needs and Data Quality Objectives
      5.1.3.1 Data for Evaluating Health and Safety Risks
        5.1.3.1.1 Source Characterization
        5.1.3.1.2 Environmental Setting
        5.1.3.1.3 Potential Receptors
      5.1.3.2 Data for Evaluation of Other Impacts (e.g., environmental risks, socio-economic impact,
        costs, schedule and budget impacts)
    5.1.4 Sampling Plans
  5.2 Second SWMU or SWMU Aggregate, etc.
6.0 Proposed No Further Action Units

Plans required by the RCRA operating permit: Project Management, Quality Assurance, Health and Safety, Records Management, Community Relations

BENEFITS OF DECISION ANALYSIS TO MANAGERS OF COMPLEX CLEANUP PROGRAMS

Large, complicated cleanup programs require a structured approach to decisions affecting how individual waste sites at a facility will be cleaned up. From a management perspective, assurances that the methodology used for all waste sites is quantitative and repeatable is necessary to defend cleanup decisions to all stakeholders [i.e., the client (in our case, DOE), the regulators, and the public]. The observational approach is a qualitative decision-making tool to streamline this process for which decision analysis can provide the needed quantitative structure.

There are also compelling reasons to use decision analysis as a management tool both within DOE and at the Laboratory specifically. First, both DOE and the Laboratory are implementing the decision analysis approach at several management levels (e.g., DOE-HQ budget prioritization plan); therefore, its use at the Laboratory is internally consistent with these other efforts. Secondly, the Laboratory's ER Program is large consisting of 24 OUs and numerous personnel, both technical and managerial. Decision analysis can provide a tool to provide a consistent structure to the RFI/CMS process. Most immediately, it can be used to structure site characterization decisions. As the tool is implemented, it will be used to structure remediation decisions.

Decision analysis is giving managers in the Laboratory ER Program specific tools to aid them in thinking systematically about determining overall objectives for the Program, developing from those overall objectives a set of measurable objectives, systematically exploring available alternatives, screening these alternatives, and then logically evaluating the best alternatives in a way that is easily understood by all involved in or interested in the decision. Decision analysis is providing technical personnel in the ER Program a structure within which to develop site characterization plans, using the tenets of DQOs and the observational approach as tools within this consistent decision analysis structure.

SUMMARY

This paper presents a brief introduction to and illustration of the usefulness of multiattribute decision analysis as a quantitative methodology useful for structuring the waste site cleanup process. We have illustrated that decision analysis provides a structure within which the qualitative tenets of both the DQO and observational approach can be addressed. In large complex cleanup programs such as those at DOE facilities, decision analysis provides a logical structure for evaluating cleanup alternatives in a systematic and documented manner across all waste sites. Although only its application to work plan development has been illustrated, decision analysis can provide a structure to the entire site cleanup process.

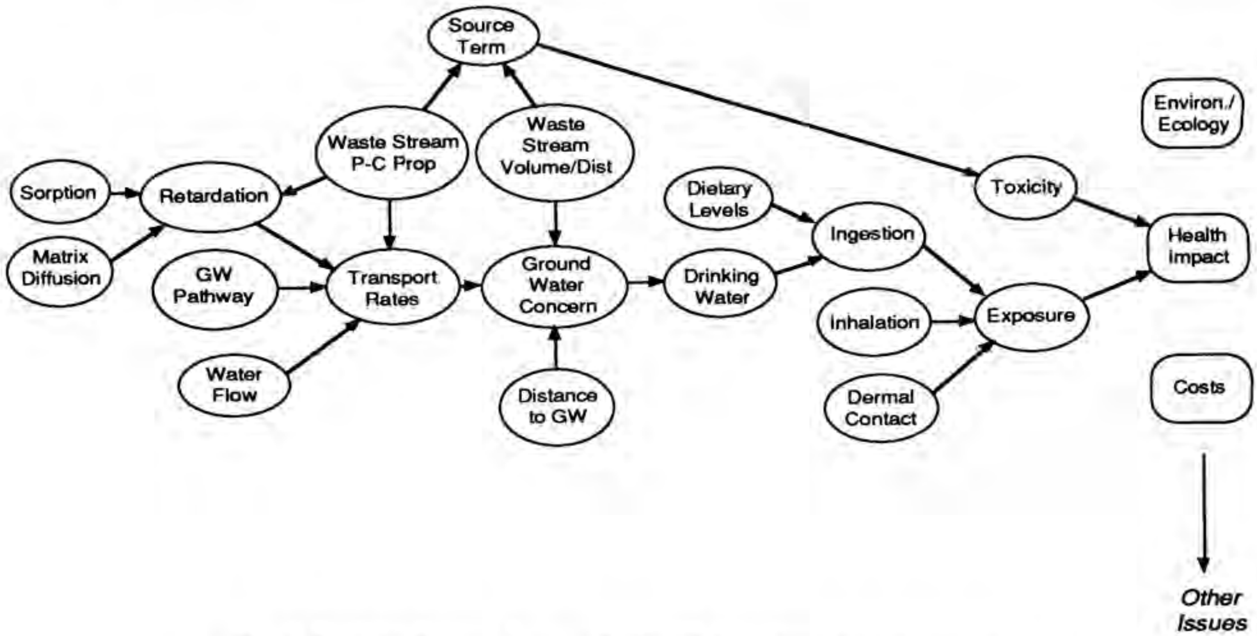

Fig. 1. Partial influence diagram for health impact evaluation measure.

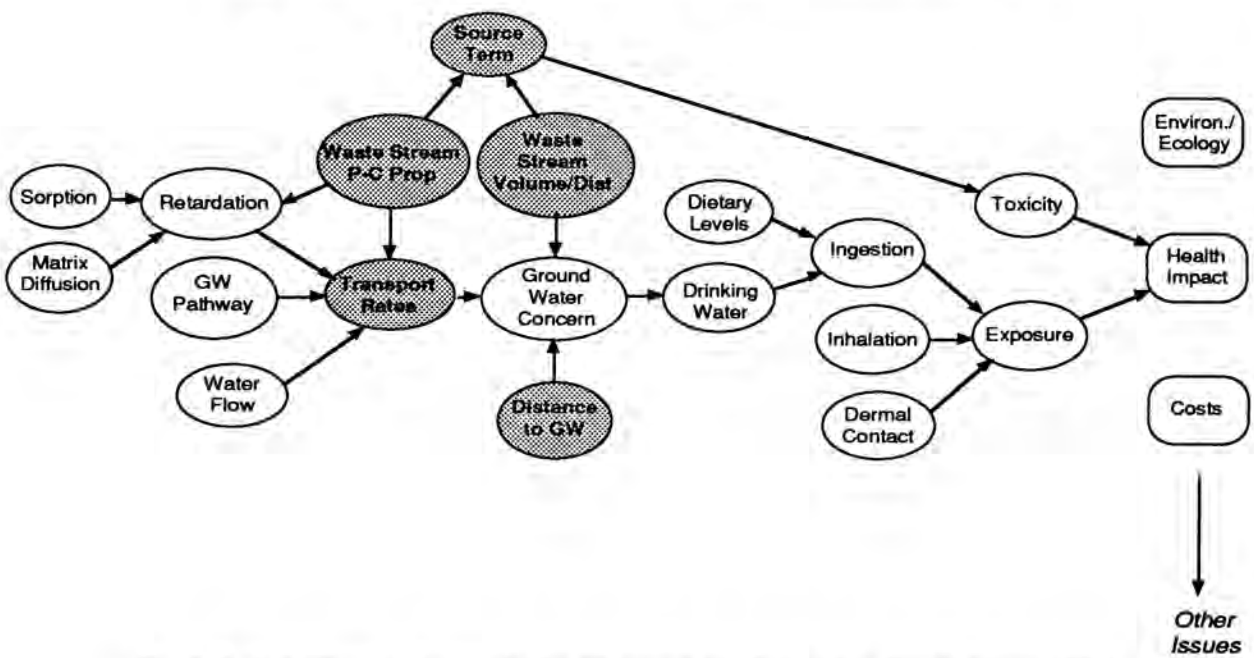

Fig. 2. Partial influence diagram for health impact (shaded ellipses denote key variables).

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