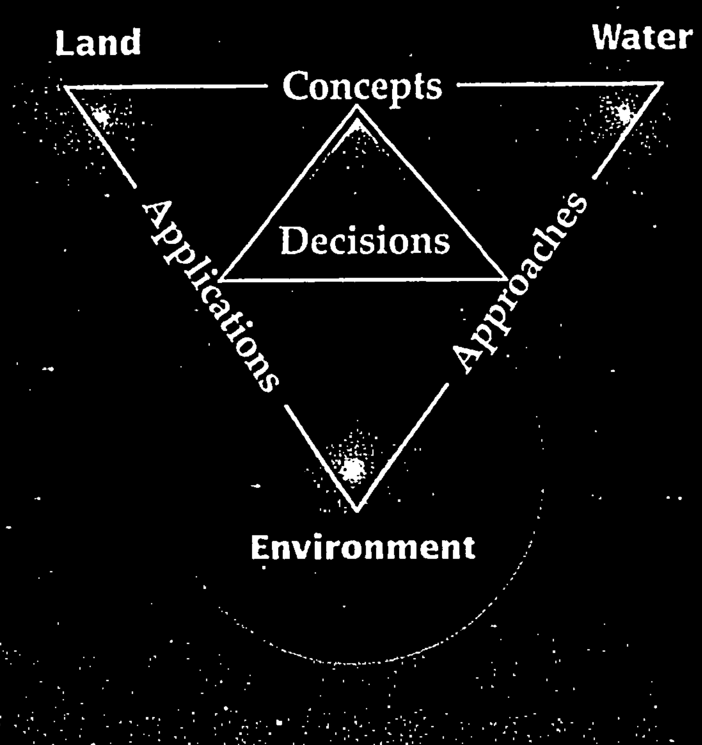
# Multiple Objective Decision Making for Land, Water, and Environmental Management

Proceedings of the First International Conference on Multiple Objective Decision Support Systems (MODSS) for Land, Water, and Environmental Management: Concepts, Approaches, and Applications

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# Chapter 11

# Managing Environmental Cleanup Risks as a Multiobjective Decision Problem

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## Abstract

This paper describes Federal Facility cleanup programs, such as those being conducted by the Departments of Energy (DOE) and Defense (DOD), from the perspective of a risk management decision problem. Our intent is to describe the risk management decision process and the technical risk assessment procedures to help define the design and operational requirements of multiobjective decision tools for risk management decision making. We also present the case for using human health and ecological risk assessments as a mechanism for integrating a strong technical component into the decision-making process.

The role of science and risk assessments in the environmental decision-making process will likely be governed by the ease with which complex technical relationships, data, and statistical uncertainties are interpreted and used by the decision maker. This interface between the scientist or risk assessor and the risk manager is ideally suited for the use of decision analysis tools that provide a common basis for integrating, synthesizing, and valuing the scientific and policy information. Two limitations to implementing decision support systems for risk management applications are dynamic risk assessment models, particularly for ecological risk assessments, and supporting databases, particularly on the fate and effects of hazardous contaminants.

## Introduction

Large, federally funded environmental cleanup programs are projected to cost several hundred billion dollars over the next several decades (Abelson, 1990; 1992; 1993; Breshears et al., 1993; U.S. Department of Energy, 1991; Congress of the United States, 1991). The primary purpose of these programs is to manage risks to human health and the environment from contaminants that have been released as a part of normal operations and accidents. It is widely recognized (Abelson, 1990; 1992; 1993; Breshears et al., 1993; Levin, 1992; Cowling, 1992; Loucks, 1992; Russell, 1992; Schindler, 1992) that risk-based decision making must be used in these programs to set priorities for addressing problems and to select cost-effective solutions that ensure protection of health and the environment.

Lessons learned from the National Acid Precipitation Assessment Program (NAPAP) suggest that the role of science in the environmental decision-making process is largely governed by the ease with which complex technical relationships and data can be interpreted and used by the decision maker (Levin, 1992; Cowling, 1992; Loucks, 1992; Russell, 1992; Schindler, 1992; Breshears et al., 1993). If the results of the research are difficult to interpret and use as a part of the decision process, decision makers will often heavily rely on other, mostly nontechnical, criteria in making decisions. Examples of nontechnical criteria would include some environmental guidance and regulations (arbitrary safety factors are often built into regulatory standards), social-political factors, and costs. Complete reliance on nontechnical criteria for decision making can lead to overly conservative and costly decisions that may or may not reflect the real problems and risks. Moreover, management actions that have a weak technical basis, can enhance the risks to receptors (i.e., the cure is worse than the disease).

This paper describes the large Federal Facility cleanup programs, such as those being conducted by the Departments of Energy (DOE) and Defense (DOD), from the perspective of a risk management decision problem. Our intent is to describe the risk management decision process and the technical risk assessment procedures to help define the design and operational requirements of multiobjective risk management decision tools (Lane et al.. 1991; Ascough, 1992). We also present the case for using human health and ecological risk assessments as a mechanism for integrating a strong technical component into the decision-making process.

## Cleanup Programs, Risk Assessments, and Decision Making

Calls for ensuring a sound scientific basis for decision making (Abelson, 1990; 1992; 1993; National Research Council. 1989) have come to the forefront over the last few years because of the projected several hundred billion dollar life cycle costs of the environmental restoration programs currently being conducted by DOE and DOD (McGuire, 1989; Pasternak and Cary, 1992). These programs consist of three phases including an initial phase to characterize the types and concentrations of contaminants in biotic and abiotic receptors at a site and the transport processes that mobilize the contaminants. Existing data and additional field sampling serve as the basis for completing this phase. In the second phase, all relevant data are used to conduct a technical assessment of the risks to both humans and ecosystems. State and federal regulations mandate these assessments to ensure

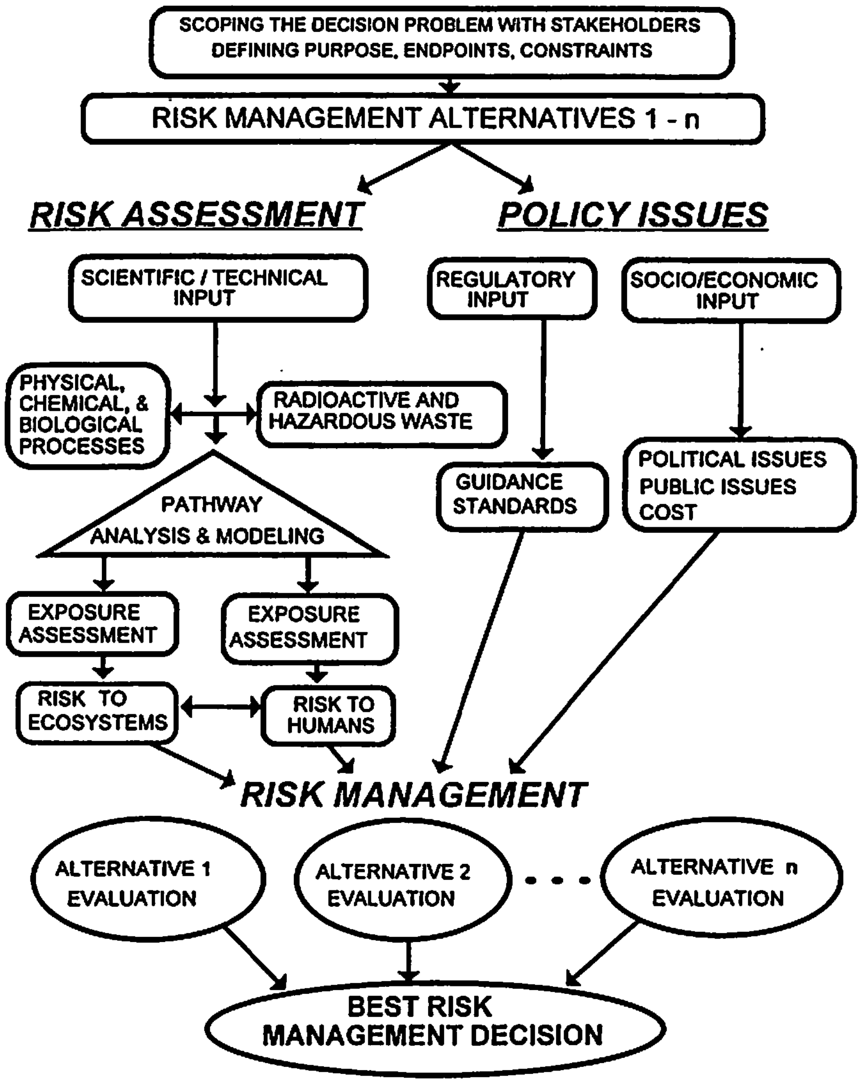


**Figure 11.1 Decision process to manage risks.**

that human health and the environment are protected from site contaminants (Harwell, 1989; Bartell et al., 1992; Suter, 1993). If the calculated risks are acceptable, then the risk manager has technical justification for no further action at the site. If the risks are unacceptable, then a third phase is implemented to remediate the site until potential risks are reduced to acceptable levels.

## The Decision Process to Manage Risks

The general types of information that comprise the decision process to manage risks are presented in Figure 11.1. We find this perspective generally consistent with comments of Levin (1992), Russell (1992), Cowling (1992), and Loucks (1992), based on their experience with NAPAP. Figure 11.1 illustrates the three major factors to be considered in evaluating risks and risk management alternatives. They are (1) scientific and technical input, (2) regulatory requirements, and (3) political, economic, and social input. These factors must initially be considered in concert with all stakeholders to define the overall problem, specify the time and economic constraints associated with political and public policy issues, specify the management alternatives to be considered, and any other constraints to the decision process.

Subsequently, a risk assessment for each risk management alternative should be driven by scientific and technical input and should be relatively independent of regulatory, political, economic, and social considerations except when necessary to clarify a scenario (Figure 11.1). Risk management alternatives might range from doing nothing to remediate the site to eliminating the contaminants via soil removal.

After completing the assessment, scientific input is still required by the risk manager to help interpret the results of the assessments and the corresponding statistical uncertainties in the risk estimates. This interface between the scientist and risk manager is an ideal venue for the use of decision tools that provide a common basis for integrating, synthesizing, and valuing the scientific information.

As shown in Figure 11.1, the scientific information is just one component of the overall decision problem. The risks associated with a particular risk management alternative must be integrated with regulatory, political, social, and economic factors to derive an overall valuation, or "score", for the particular alternative. The "best" risk management decision is obtained by comparing the "scores" from all of the alternatives and then selecting that option (Figure 11.1). The technical risk assessment should represent our best science, while the risk management component should represent our best judgment based on both scientific and policy issues.

The multiobjective nature of the risk management decision process is readily apparent from Figure 11.1. For example, minimizing costs may not be compatible with the best technical solution or applicable regulatory standard. Likewise, management actions taken to protect humans from exposure to contaminants may enhance risks to components of ecosystems. For example, physical disturbances to remove contaminant sources may reduce risks to humans but completely destroy associated ecosystems, including rare and endangered species.

## Components of the Technical Risk Assessment

Conducting a technical risk assessment requires some knowledge about the physical and biological makeup of the contaminated site and the environmental processes that are important in the cycling of energy and materials (Figure 11.1). Examples of the latter would include herbivory, carnivory, natality, mortality, erosion, precipitation, water balance, etc.

Depending on the contaminant(s) that are present and the current and future land use practices, information is also needed on the distribution and transport of the contaminants of interest, including concentrations in soils, water, air, biota, foodstuffs, and on the key ecological processes that mediate contaminant transport to receptors. Ideally, lack of key information would be identified very early in the characterization phase of the program so that sampling could be designed to fill knowledge gaps.

Sources of information on the structure and function of the environment and on contaminant distribution and transport are then used in risk assessment models, of varying complexity, to predict the distribution of the contaminant(s) and to estimate exposures and risks to human and ecosystem receptors (Figure 11.1).

Models play a central role in risk assessments due to the need to make projections about the fate of contaminants in the environment and potential changes in exposure of the organisms of interest with time. Seldom are enough data available to answer questions about contaminant fate and effects, particularly over long timeframes. The risk may increase with time if the chance of exposure is greater in the future than it is at present such as might happen when containment strategies for storing toxic wastes fail or restrictions on access to contaminated sites are removed. In contrast, the risk may decline in the future if the contaminant undergoes biological or radioactive decay, if it becomes sequestered, or if transport pathways change through natural processes.

Generally, two levels of modeling are conducted to support risk assessments. Screening level models incorporate conservative assumptions that can be used to rapidly and, relatively, inexpensively evaluate contaminated areas to determine the need for further action. If the screening level assessment identifies potential risks, another, less conservative procedure is used to better represent the dynamic processes and pathways leading to exposure of receptors. This graded approach to risk assessments reduces the costs by avoiding more intensive data collection and analysis for sites that pose little risks to human health and the environment.

Screening models often use analytical solutions based on the assumption of equilibrium conditions and constant coefficient equations. For example, the concentration of contaminant in vegetation (y) is a function of concentration of contaminant in soil (x), or $y = f(x)$. The advantages of using screening level models are that they are simple to use because they do not require extensive knowledge of transport processes, input parameters, or driving variables. Moreover, the conservative assumptions typically eliminate the need for an uncertainty analysis. The disadvantages are that they do not identify transport processes, cannot easily account for changes with time, or accommodate nonequilibrium conditions. They provide worst case estimates rather than realistic estimates of exposure with no estimate of how likely the worst case may be.

The dynamic, or simulation, model can be used if the screening level assessment demonstrates that the site presents a nonnegligible risk to the environment. Dynamic models provide time-dependent simulation of environmental processes and contaminant behavior as a function of multiple inputs and losses. The advantages of dynamic models are that they can more realistically represent transport processes, time-dependent events, and long-term dynamics of the system. They are also more amenable to evaluating consequences of remediation alternatives and provide realistic rather than conservative estimates. Their disadvantages are that they require a better understanding of the system, including rate constants, time-dependent processes and events, and supporting databases. Moreover, risk estimates have uncertainties associated with them that can complicate the interpretation of results. Perhaps one of the biggest disadvantages of dynamic risk assessment models is that they have been developed for very specific purposes. This means that models may have to be developed on a site by site basis, a time consuming and costly endeavor.

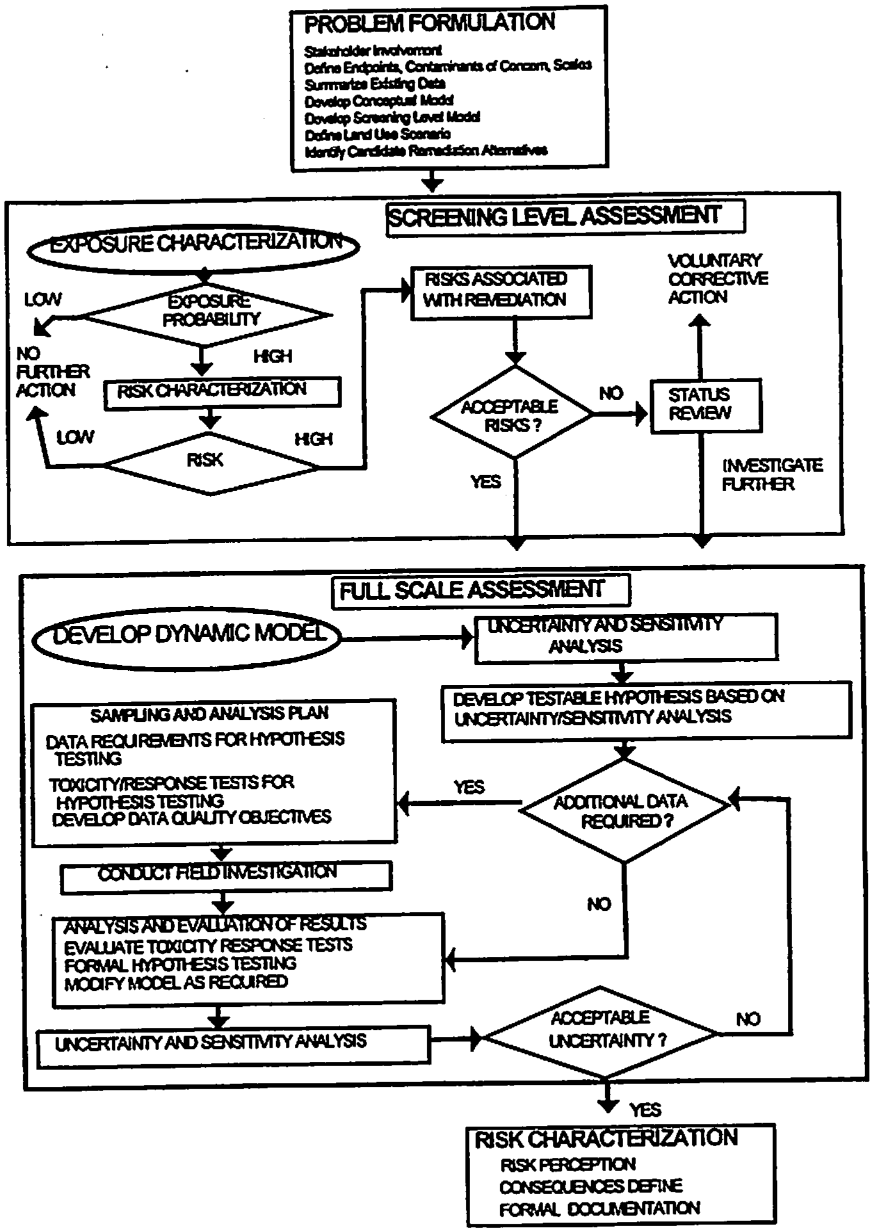


**Figure 11.2 Decision logic for conducting risk assessments.**

## Decision Logic for Conducting a Technical Risk Assessment

The decision logic presented in Figure 11.2 presents a generic approach to conducting a risk assessment at any contaminated site. The approach is consistent with the goals of the U.S. Environmental Protection Agency's Framework for Ecological Risk Assessment (U.S. EPA, 1992) and the National Council on Radiation Protection and Measurement's (1987) guidance for human health assessments. Typically, risk assessments are conducted in three phases that include a problem formulation phase, a technical risk assessment phase (including screening and full scale assessment), and a risk characterization phase.

## Problem Formulation

During the problem formulation phase, a conceptual model is developed that reflects all relevant information and data needed to define and scope the decision problem. For example, the study area and site contaminants are identified and described, contaminant toxicity profiles developed from the literature or special studies, existing data are summarized (including contaminant concentrations in soils and biota and environmental relationships that influence the fate and effects of the contaminants), and measurement and assessment endpoints are established. Perhaps the biggest weakness of the risk assessment process is the lack of good quality data to support risk assessment modeling

The selection of assessment and measurement endpoints for ecosystem components are based on several criteria including (1) social relevance, (2) biological relevance, and (3) susceptibility to the stressor (U.S. EPA, 1992; Suter, 1993). Species that are economically or culturally important, such as mule deer, elk, pronghorn, squirrels, nut crops, etc., that are harvested by humans or have other social or cultural significance are possible candidates for an ERA. There is opportunity at this phase to collect supplementary on-site data to fill in major information gaps. The supplementary information required will be largely driven by the data needed to conduct the screening assessment.

## Screening Level Assessment

In this phase, predictions of exposure to receptors are made with the screening level model, taking background concentrations into consideration. A decision is made as to the probability of exposure of receptors to above background concentrations of site contaminants. If the probability is low, the site is targeted for no further action. If the exposure is above background levels, then the predicted concentrations are compared to the toxicity profiles of the contaminants (developed in the problem formulation phase) to determine the probability of an effect. If the probability of effect is low, the site is again targeted for no further action. If the probability of effect is not low, then the full scale assessment is triggered to use a dynamic pathway model to evaluate exposures and risk.

## Full Scale Assessment

The full scale assessment is designed to allow us to better quantify that risk and its associated uncertainty. This is accomplished through the development and application of a dynamic pathway model that better reflects our understanding of fate and effects of the contaminants at the site. The working hypotheses from the conceptual model provide a framework for developing the pathway model. The pathway model, after uncertainty and sensitivity analysis drives the development of a set of testable hypotheses about the site and its potential impact on human health and the environment.

The results from the pathway analysis provide the means for making risk estimates, usually with large uncertainties in those estimates. Uncertainty and sensitivity analyses of the model quantifies that uncertainty and provides information about where the effort would be most profitably applied to reduce it. Depending on the sources and levels of uncertainty, the procedure may be repeated until the risk estimates are of an acceptable quality. The assessment then proceeds to the risk characterization phase.

### Risk Characterization

This is the final phase of the technical risk assessment and includes evaluation of the final risk estimate and its probable consequences. Probable consequences of risk are determined by scientific personnel and then presented to the risk manager and other stakeholders. Formal documentation describes the risk estimates, the process used to arrive at them, their associated uncertainty, and the potential human health and ecological consequences.

## Summary

The primary purpose of several on-going, government facility cleanup programs is to protect public health and the environment from harmful effects of contaminants that were intentionally or accidentally released as a part of operations over the last several decades. Risk assessments are legally mandated for these programs and provide a framework for integrating science into the decision-making process. These assessments are structured around prediction models that use knowledge about environmental processes and the fate and effects of contaminants to predict immediate and long-term harm to humans and ecosystems.

Generally, two levels of modeling are conducted to support risk assessments. Screening level models incorporate conservative assumptions that can be used to rapidly and, relatively, inexpensively evaluate contaminated areas on the need for further action. If the screening level assessment identifies potential risks, another, less conservative procedure is used to better represent the dynamic processes and pathways leading to exposure of receptors. In either case, the models should have a firm scientific basis, have parameter values available, and take into account the interactions of subprocesses that influence contaminant fate and effects.

The scientific information is then integrated with regulatory, political, social, and economic factors to derive an overall valuation for the particular cleanup alternative. Iterative use of the process provides evaluations of multiple risk management alternatives from which the best alternative can be selected. Two limitations to implementing decision support systems for risk management applications are dynamic risk assessment models, particularly for ecological risk assessments, and supporting databases. particularly on the fate and effects of hazardous contaminants.

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