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Opinion Makers Section

MCDA and Environmental Problems

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Choosing or ranking environmental management strategies can be a complex and difficult problem, yet it is among the most important decisions an environmental manager will make. Natural and human-made ecosystems are complex: they may contain multitudes of species and a variety of landscapes, they may be simultaneously straining under the pressure of human development, and analyses of them can be highly uncertain. Amidst all this uncertainty, the manager must balance competing forces to find a resource-efficient, technically supportable, and effective management strategy.

These issues were discussed during a NATO Workshop at Thessalonica (Greece) last April on "Environmental Security in Harbors and Coastal Areas: Management Using Comparative Risk Assessment and Multi-Criteria Decision Analysis".

It should be pointed out before entering into the details of choosing environmental management strategies and MCDA that it was very difficult in many circumstances to adopt a common language among environmental managers, experts and operations researchers working on the field of MCDA.

Traditional environmental management approaches (such as management of contaminated sites, natural resource management, etc.) often do not provide a clear and systematic decision *rationale*. The uncertainties that exist in monitoring and simulating data, especially given the practical limitations of technical expertise, schedule, and finances, mean that some level of uncertainty is unavoidable when managers commit to selection of a single management option (alternative). This uncertainty is difficult for managers to quantify and systematically incorporate into decisions. Modeling is often used to justify implementation of a single management option, but modeling inter-comparisons have revealed a large degree of uncertainty in model predictions even for simple ecosystems. For example, Linkov and Burmistrov (2003) report differences of up to seven orders of magnitude among model estimations of radionuclide concentrations in a strawberry plant sprayed with contaminants under well-controlled conditions.

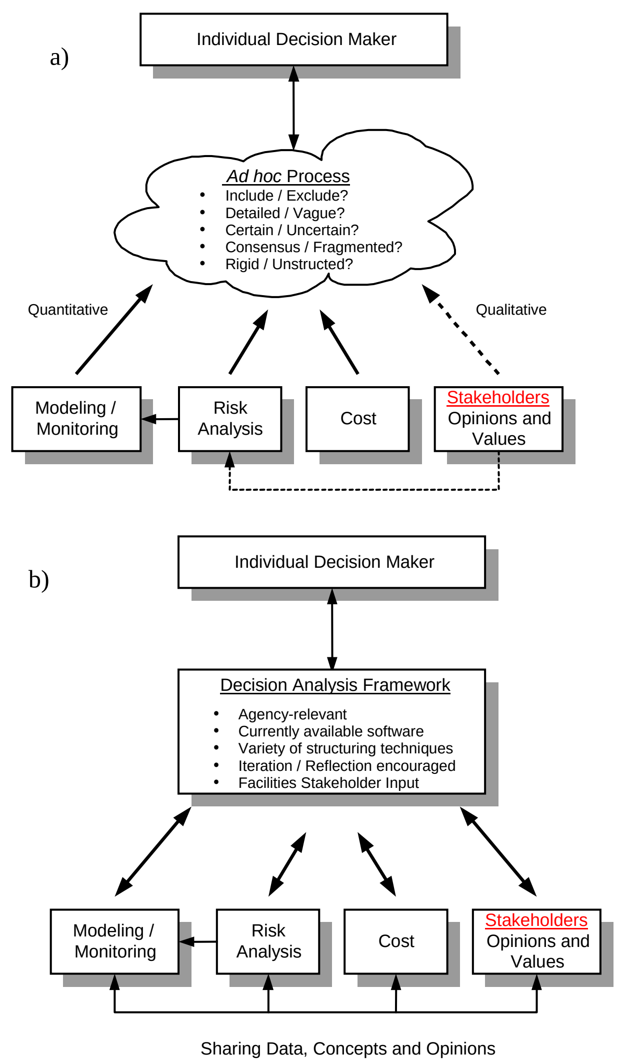

Figure 1: Current (a) and evolving (b) decision-making processes for contaminated sediment management.

In response to these decision-making challenges, some regulatory agencies and environmental managers have moved toward more integrative decision analytic processes, such as comparative risk assessment (CRA) or multiple criteria decision analysis (MCDA). These methods are designed to raise awareness of relationship that must be made among competing project objectives, help compare options that are dramatically different in their potential impacts or outcomes, and synthesize a wider variety of information (Figure 1b).

CRA has been most commonly applied within the realm of environmental policy analysis. Andrews et al. (2004), for example, distinguish between CRA use at macro and micro scales. At the macro scale, programmatic CRA has helped to characterize regional and national environmental priorities by comparing the multi-dimensional risks associated with policy options. U.S. government agencies at various levels have logged significant experience with policy-oriented, macro-level CRA. International CRA applications are reviewed in Tal and Linkov (2004) and in Linkov and Ramadan (2004). At smaller scales, so-called micro-CRA studies have compared interrelated risks involving specific policy choices, such as chemical *versus* microbial disease risks in drinking water. In these micro-scale applications, the CRAs often have specific objectives within the broader goal of evaluating and comparing possible options and their risks. Bridges et al. (2005) discuss micro-scale applications of CRA in more detail.

Central to CRA is the construction of a two-dimensional decision matrix that contains project options' scores on various objectives or criteria. However, CRA lacks a structured method for combining performance on criteria to identify an "optimal" project option. MCDA methods and tools, on the other hand, do provide a systematic approach for integrating risk levels, uncertainty and valuation. MCDA helps decision makers evaluate and choose among options based on multiple criteria using systematic analysis that overcomes some of the limitations of unstructured individual or group decision-making. Although almost all decision analysis methodologies share similar steps of organization in the construction of the decision matrix (often the end result of the CRA process), there are many MCDA methodologies which each synthesize the matrix information and rank the options by different means. Yet, taken by themselves, few MCDA approaches are specifically designed to incorporate multiple stakeholder perspectives or competing value systems.

Fortunately, MCDA tools can be naturally linked with an adaptive management paradigm for efficient applications to environmental problems. Adaptive management explicitly acknowledges the uncertainty in managers' knowledge of a system. As a consequence of this uncertainty, adaptive management holds that no single best policy can be selected, but rather a set of options should be dynamically tracked to gain information about the effects of different courses of action. Adaptive management concepts were introduced more than twenty years ago, but their implementation to date has been primarily limited to a few large-scale projects in long-term natural resource management, where uncertainty is so overwhelming that optimization is not possible. Even though managers of smaller projects are confronted with the same problems and often have to go through the frustrating experience of changing their management strategy when it fails our review shows that the field of environmental management is far from accepting and using adaptive management approaches. Although adaptive management is recognized and even recommended by many state and government agencies, adaptive management applications vary widely in their implementation of the concept and there is no framework that robustly incorporates adaptive management in environmental practice.

Yet despite the promise of adaptive management, current environmental management practice has not widely accepted and utilized adaptive approaches. While adaptive management has been recommended by many state and government agencies, applications vary in their implementation of the concept, and there is no framework that robustly incorporates adaptive management in environmental practice.

Recent papers (Linkov *et al*., 2004; Kiker *et al*., 2005; Linkov *et al*., 2005, Linkov et al., 2006) introduce a structured framework for selecting the best management strategy. This proposed framework (Figure 2) is intended to provide a road map to the environmental decision-making process. Having the right combination of people is the first essential element in the decision process. The activity and involvement levels of three basic groups of people (decision-makers, scientists and engineers, and stakeholders) are symbolized in Figure 2 by dark lines for direct involvement and dotted lines for less direct involvement. While the actual membership and the function of these three groups may overlap or vary, the roles of each are essential input into the decision process. Each group has its own way of viewing the world, its own method of envisioning solutions, and its own societal responsibility. Policy- and decision-makers spend most of their effort defining the problem's context and the overall constraints on the decision. In addition, they may be responsible for the final decision and subsequent policy implementation. Stakeholders may help define the problem, but they contribute the most in helping to formulate performance criteria and contributing value judgments for weighting the various criteria. Depending on the problem and regulatory context, stakeholders may have some responsibility in ranking and selecting the "final" option. Scientists and engineers have the most focused role in that they provide the measurements or estimations of the desired criteria that determine the success of various options. While they may take a secondary role as stakeholders or decision-makers, their primary role is, to the best of their abilities, to provide the technical input necessary for the decision process.

The decision-making process is in the center of the figure. While it is reasonable to expect that the process may vary in specific details among regulatory programs and project types, emphasis should be given to designing an adaptive management structure so that participants can modify aspects of the project to suit local concerns while still producing a structure that provides the required outputs. The process depicted in Figure 4 follows two basic activities: 1) generating management options, criteria, and value judgments and 2) ranking the options by applying value “weights”. The first part of the process generates and defines choices, performance levels, and preferences. The latter section methodically prunes non-feasible alternatives by first applying screening mechanisms (for example, overall cost, technical feasibility, or general societal acceptance) followed by a more detailed ranking of the remaining options by decision analytical techniques (AHP, MAUT, decision rules approach, verbal analysis, multi-objective mathematical programming, outranking based methods, …) that apply the various criteria levels generated by environmental tools, monitoring, or stake-holder surveys.

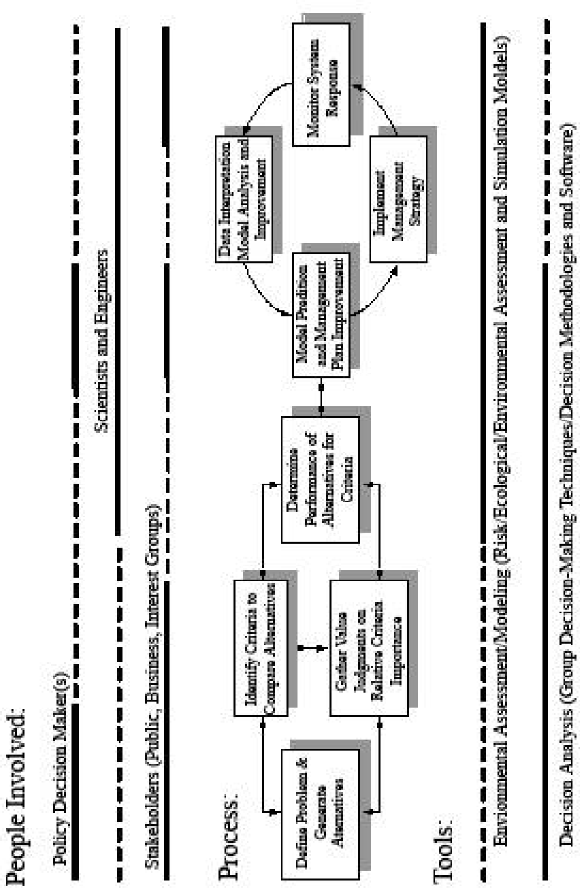

Figure 2: Adaptive decision framework. Solid lines represent direct involvement for people or utilization of tools; dashed lines represent less direct involvement or utilization.

As shown in Figure 2, the tools used within group decision-making and scientific research are essential elements of the overall decision process. As with the involvement of different groups of people, tool applicability is symbolized by solid lines (direct or high “utility”) and dotted lines (indirect or lower “utility”). Decision analysis tools help to generate and map preferences of stakeholder groups as well as individual value judgments into organized structures that can be linked with the other technical tools from risk analysis, modeling and monitoring, and cost estimations. Decision analysis software can also provide useful graphical techniques and visualization methods to express the gathered information in understandable formats. When changes occur in the requirements or the decision process, decision analysis tools can respond efficiently to reprocess and iterate with the new inputs. The framework depicted in Figure 2 provides a focused role for the detailed scientific and engineering efforts invested in experimentation, environmental monitoring, and modeling that provide the “rigorous” and defendable details for evaluating criteria performance under various options. This integration of decision tools and scientific and engineering tools allows each to have a unique and valuable role in the decision process without attempting to apply either type of tool beyond its intended scope.

As with most other decision processes, it is assumed that the framework in Figure 2 is iterative at each phase and can be cycled through many times in the course of complex decision-making. A first-pass effort may efficiently point out challenges that may occur, key stakeholders to be included, or modeling studies that should be initiated. As these challenges become more apparent one iterates again through the framework to explore and adapt the process to address the more subtle aspects of the decision, with each iteration giving an indication of additional details that would benefit the overall decision process.

In summary, using adaptive management and multiple criteria decision analysis gives structure to the decision-making process and allows the manager to learn about the system being managed and modify the management strategy based on new knowledge. Such a framework could be of great assistance to managers, saving them both time and resources as it helps them to understand the relationship involved between different management options and to make justified, intelligent selections.

This article is based on our recent publications cited below. We would like to thank our co-authors Drs. Seager, Gardner, Ferguson, Belluck, Benjamin and Mr. Satterstrom and Varghese for their help and support.

REFERENCES:

Andrews, C.J., Apul, D.S., and Linkov, I. (2004). Comparative risk assessment: past experience, current trends and future directions. In: I. Linkov and A. Ramadan, eds., *Comparative Risk Assessment and Environmental Decision Making*. Kluwer, Amsterdam.

Bridges, T., Kiker, G.,(2005), Cura, J., Apul, D., Linkov, I.. “Towards Using Comparative Risk Assessment To Manage Contaminated Sediments". Levner, E., Linkov, I., Proth, J.M., eds. "*Strategic Management of Marine Ecosystems*,” Springer, Amsterdam.

Linkov, I. and Burmistrov, D. (2003). Model uncertainty and choices made by modelers: lessons learned from the International Atomic Energy Agency Model Intercomparisons. *Risk Analysis 23*:1335-46.

Tal, A. and Linkov, I. (2004). The role of comparative risk assessment in addressing environmental security in the Middle East. *Risk Analysis* 24:1243.

Linkov, I. and Ramadan, A. (2004). *Comparative Risk Assessment and Environmental Decision Making*. Kluwer, Amsterdam, 436p.

Linkov,I., Varghese, A., Jamil, S., Kiker, G.A., Bridges T., and Seager, T. (2004): Multi-criteria decision analysis: framework for applications in remedial planning for contaminated sites. (Chapter in Linkov, I., Ramadan, A., (Eds) “Comparative Risk Assessment and Environmental Decision Making ” Kluewer, Amsterdam 2004.

Kiker, GA, Bridges TS, Linkov, I, Varghese, A, and Seager, T. (2005). Application of Multi-Criteria Decision Analysis in Environmental Decision-Making. Integrated Environmental Assessment and Management 1(2):1-14.

Linkov,I., Sahay, S., Seager, T.P., Kiker, G.A. and Bridges T. (2005): Multi-Criteria Decision Analysis: A Framework For Managing Contaminated Sediments. Proth, J.M., Levner, E.and Linkov, I. (Eds) “Strategic Management of Marine Ecosystems” Kluewer, Amsterdam.

Linkov, I., Satterstrom, K., Kiker, G., Bridges, T., Benjamin, S., Belluck, D. (2006, in press). From Optimization to Adaptation: Shifting Paradigms in Environmental Management and Their Application to Remedial Decisions. *Integrated Environmental Assessment and Management*.