EXPERT MODELING OF ENVIRONMENTAL IMPACTS

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Introduction

Models or diagrams of concepts are important to many types of research. As Stryker (1980) has so aptly noted,

> "Humans respond not to the native world, but to the world as categorized or classified; the physical, biological, and social environment in which they live is a symbolic environment. The symbols that attach to the environment have meaning, are cues to behavior, and organize behavior" (Stryker 1980).

For years, people have used models and diagrams to more easily convey complex ideas and information. More recently, there has been increasing interest in the use of models to describe various environmental impacts, and, even more recently, to aid decision analysis.

Graphical representation is one of the best ways to communicate complex ideas and information. Extensive research has been done in many different areas to condense expert knowledge into easily understandable models. These models are referred to by various names in the literature, including expert systems, influence diagrams, and knowledge maps, although these same terms occasionally are used to mean something else entirely. The common theme throughout these researches is the attempt to define relationships between elements in a system. Knowledge of these systems is often limited to experts and is largely unavailable for utilization by others.

The complex interaction of elements within an environmental system is less complex and arcane. Historically, professionals in charge of activities that impact the environment (engineers, biologists, etc.) have been concerned only about information lying within their area of expertise. This began to change with the passage of the National Environmental Policy Act of 1969. This Act requires an impact assessment of major federal actions that could significantly affect the quality of the human environment, resulting in a document called an Environmental Impact Statement, or EIS (Rosen 1976). The list of items to consider in such an evaluation includes everything from water and vegetation sources to historic and cultural resources. A comprehensive EIS requires a detailed understanding of how all elements in the affected environment relate to each other and how those relationships can be represented to help make decisions about policies that may effect these relationships.

Expert, or knowledge-based, systems first developed in the early 1980s were designed to elicit large amounts of information about a general problem from experts, encode it into a model of the problem, and apply the model to solve individual instances of the problem as they arise (Matzkevich and Abramson 1995:2) – although in many instances these were developed strictly for use in artificial intelligence simulations with computers. Various graphical representations of information were developed to assist with the problem structuring stage of decision-making, presenting relevant information in a visual form and reducing the load on decision-makers short term memory (Browne *et al.* 1997:2). Although these representations, particularly influence diagrams, were originally proposed only as a method for representing decision problems, they have become popular for solving decision problems as well (Shenoy 1994:1), which again involves statistical and computer analysis. In an influence diagram, influences represent causal or quasi-causal relationships between two events or states. A single influence consists of a node-influence-node triad as shown in Figure 1, where the arrow indicates the direction of the influence. In this example, event or state A influences event or state B.

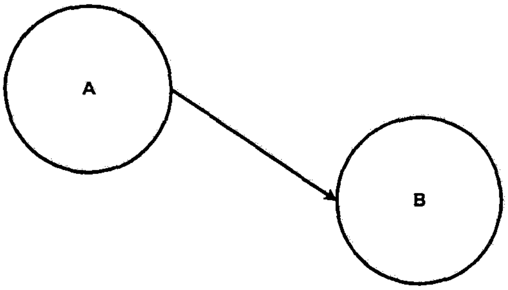


Figure 1. Node-Influence Triad

Although the use of models for predicting and estimating the magnitude of impacts is useful in many applications, there are limitations. Models that address a large number of impact categories become statistically complex when the relationships embodied in them are quantified (Murdock and Leistritz 1980:20). Diagrams with multiple aspects used in decision analysis often have multiple objectives as well, which may conflict (such as socioeconomic and environmental) and thus need to be 'weighted' somehow (Kirkwood 1992:37). The consultation of multiple experts in defining a complex system may also require a weighting of their inputs (Tracz and Wawrzynkiewicz 1993:267). Finally, in complex systems where relationships are poorly understood, quantitative relationships may be impossible to determine. Environmental systems typically fall into this category.

This paper will discuss how an expert model can be used for political decision-making concerning environmental impacts using the example of the Illinois River Basin (IRB) in eastern Oklahoma. Because the Illinois River watershed is a very complex environmental system, our model will be a qualitative, not quantitative, model. Nevertheless, the qualitative model will serve our purposes well, as will be discussed below.

Design of the Expert IRB Impact Model

The IRB expert model was developed for a project entitled "Ecological Risks, Stakeholder Values and River Basins: Testing Management Alternatives for the Illinois River Basin." This four-year project, begun in October 1997, is a joint effort between Oklahoma State University and the University of Oklahoma and is funded by the EPA and NSF under their Water and Watersheds Program.

The IRB expert model represents how various impact processes within the Illinois River basin relate. A visual representation of the expert model was prepared using the flowcharting software program, Visio Standard 5.0.

In the lowest level of the expert model (level 0.0), the political subsystem circumscribes the four other subsystems. The design of level 0.0 is based on the application of disturbance theory (Truman 1951) to the IRB impact management political process. From each of these subsystems, a terminal impact creates a disturbance to stakeholders that, if perceived as severe enough, triggers a demand made on political actors in the political subsystem. These demands, if strong enough, may then stimulate a policy response that is intended to reduce the demand by lessening the perceived subsystem impact. A brief description of the structure of each subsystem is provided later.

The model is arranged as a nested hierarchical structure. At the most basic level (level 0.0), the expert model is a low-resolution representation of the entire IRB impact system. It includes five major impact subsystems: physical (level 1.0), biological (level 2.0), economic (level 3.0), social (level 4.0), and political (level 5.0) (see Figure 2).

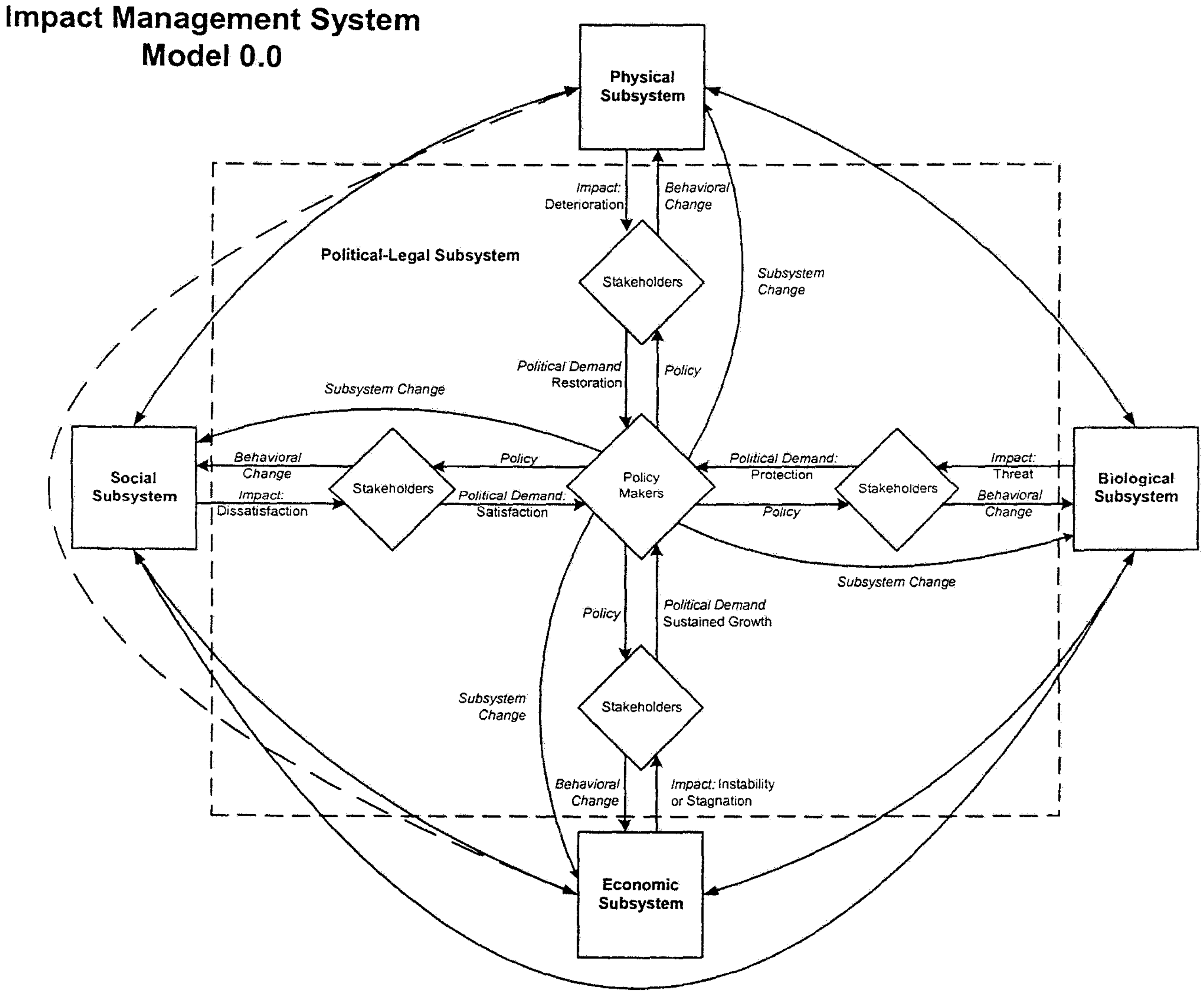


Figure 2. Level 0.0, Showing All Subsystems

These subsystems are not only related to the base level and to higher levels of increasing detail, but also to each other. For example, perturbations in the biological system may influence portions of the economic, physical, and social systems as well, which in turn can trigger stakeholder demands on the political system. The reverse is also true: the polity can respond to political demands by formulating and implementing policy that will effect stakeholder and economic behavior and the physical and biological systems, both directly and indirectly. Thus, the political subsystem can be seen as circumscribing all others. Each of the five major subsystems is then serially elucidated in increasing detail in higher-level influence diagrams (secondary subsystems are numbered 1.1, 1.2, 2.1, etc., and tertiary subsystems are numbered 1.1.1, 2.1.2, etc.). In the entire expert model, 761 influences are identified.

The IRB model was inspired primarily by the work of Ann Bostrom and her associates (Bostrom *et al.* 1992; 1994a; 1994b). An unusual feature of this model, however, is the three-dimensional integration of its five major subsystems and its many sub-subsystems. Most previous mental models have been two dimensional, relating influences within a single system.

The design of the expert model was guided by three performance goals. First, the model had to be usable as a decision support tool. With such a tool, a policy analyst can qualitatively estimate the affects of various policy interventions throughout all subsystems. For example, a policy designed to restore Lake Frances would be seen from the expert model to generate potential secondary impacts affecting water quality, human and ecological health, aesthetics, habitat integrity, and the tourism industry.

Second, the model had to be capable of aiding the design of education programs to correct knowledge deficiencies and misconceptions. Comparisons of lay mental models against the expert model can identify misunderstandings that may be amenable to education.

Third, the model must be capable of aiding conflict assessment. By determining which knowledge deficiencies and misconceptions exist, it is possible to identify conflicts that are due to differences in knowledge. For example, a resident may see no need for a policy regulating the use and monitoring of septic tanks to prevent releases of pollutants to groundwater if he or she does not know if or how they could affect water quality. Moreover, knowledge of misconceptions can be compared against value differences (discovered by using other research techniques) to determine whether extant conflicts are due to knowledge or value conflicts, or both. This information is essential to fashioning and legitimating a policy that will be widely accepted among stakeholders.

IRB Model Construction and Validation

Due to its size, we developed special symbols to navigate the model. The outcome of each subsystem is represented by a square, found on the main page of each subsystem and on model 0.0.

A double circle node on the diagram indicates a 'drop down' – meaning that more influences located on other pages lead to that node, the identity of which is indicated by the numbers in the circle. Given that it is not possible to place all 761 influences on a single sheet of paper, we were forced to use multiple pages. This necessitated the use of 'drop down' nodes to vertically nodes across pages.

Some influences are presented on more than one page. An example is flooding, which affects many different aspects of the basin. These nodes were represented by a circle within a square and are called 'link nodes.' The numbers of the pages where the 'link node' can be found are shown in the node.

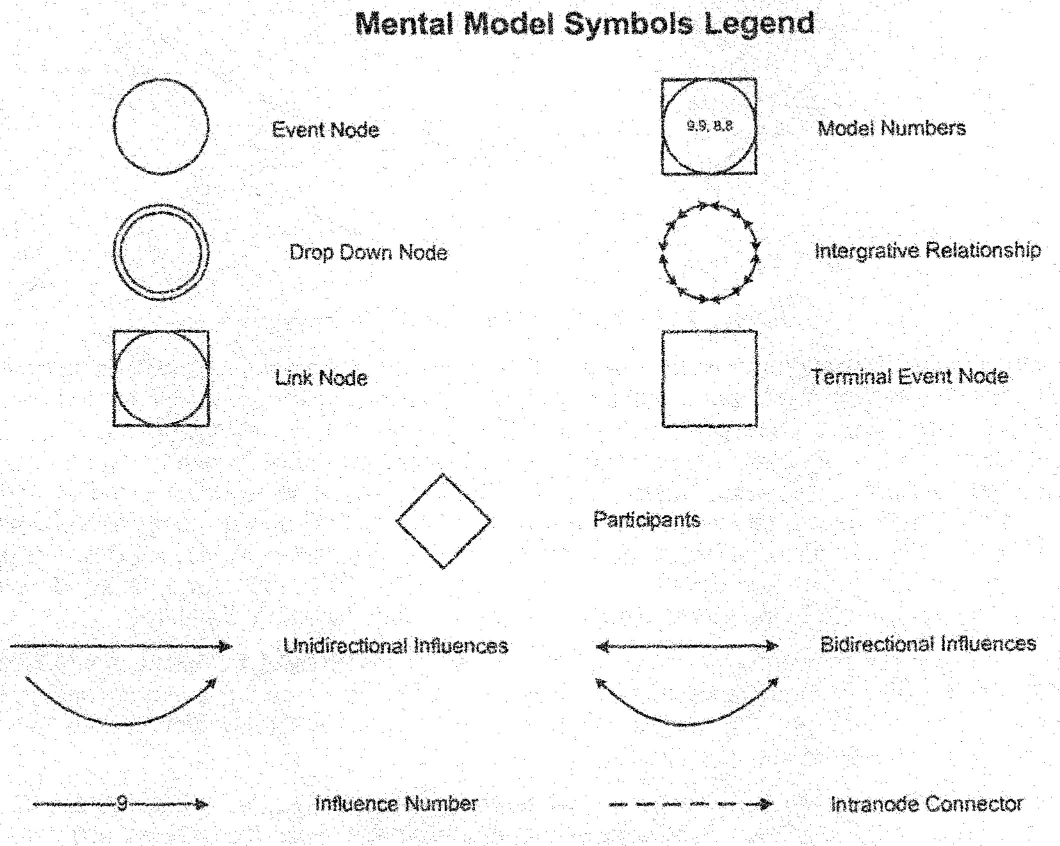


Figure 3. Symbols Legend

Based on knowledge possessed by members of the research team, a preliminary model that included most of the major elements of the five subsystems was developed. This preliminary model was then submitted to various experts for review and revision.[1] The experts revised the model in several ways, including adding new nodes, adding links between existing nodes, and clarifying definitions of existing links. Experts were selected from the U.S. Army Corps of Engineers in Tulsa, the Oklahoma Department of Environmental Quality, the Oklahoma Water Resources Board, the Oklahoma Scenic Rivers Commission, the Oklahoma Conservation Commission, the University of Oklahoma Health Sciences Center, the University of Oklahoma in Norman, Oklahoma State University in Stillwater, and Northeastern Oklahoma State University in Tahlequah. These experts were chosen because of their expertise in their respective fields, their familiarity with the Illinois River basin, and their willingness to contribute.

Physical Subsystem

The physical subsystem is the smallest of the five subsystems with only 58 influence links. The primary level of the physical subsystem (model 1.0) shows 'stream channel deterioration' as the terminal adverse impact (disturbance), which is influenced by stream channel aggradation (sedimentation) and stream channel degradation (erosion) processes. Both processes are presented in more detail within the secondary levels within the physical system. Erosion/sedimentation processes in turn are influenced by activities such as gravel mining, timber harvest, livestock access to waterways, general vegetation removal, addition of vegetative debris to waterways by beavers, gravel roads construction and maintenance, and the collapse of the dam at Lake Frances.

Biological Subsystem

The biological subsystem is considerably more complex, with 168 influence links. Figure 4 shows the base level of this subsystem (level 2.0).[2] This complexity is due to the myriad interactions involved in any ecosystem as large as the Illinois River watershed. The terminal adverse impact (disturbance) in this subsystem is a threat to public health or the environment. The subsystem is divided into human health and ecologic health, both of which are affected by nearly the same activities (an exception is drowning due to recreational activities, which affects only human health). The primary factor affecting both human and ecologic health is water quality, which is influenced by many other factors that are described in secondary and higher levels within the biological subsystem. Such factors include toxic contamination, decrease in the concentration of dissolved oxygen, solid waste disposal, and habitat destruction. Toxic contamination, in turn, is affected by several factors such as urban runoff, pesticide use, hazardous waste handling, underground storage tanks, animal feeding operations, and municipal wastewater treatment discharges. Dissolved oxygen levels are affected chiefly by algal blooms, which consume large quantities of oxygen. Algal blooms are caused by excessive nutrient loading (eutrophication). Algal blooms and the level of dissolved oxygen are also affected by the temperature and turbidity of the water. There are many sources of nutrient loading in the Illinois River basin, including animal wastes, fertilizers, septic systems, wastewater treatment effluents, and natural vegetative decay. Non-toxic, non-nutrient solid waste also affects water quality, although it usually exerts only an aesthetic effect. Litter from various sources is the main contributor to this type of pollution, along with debris from construction and gravel mining. Habitat destruction is influenced by many factors, such as deforestation, removal of vegetative debris from waterways, overgrazing by cattle, sedimentation, and toxic contamination.

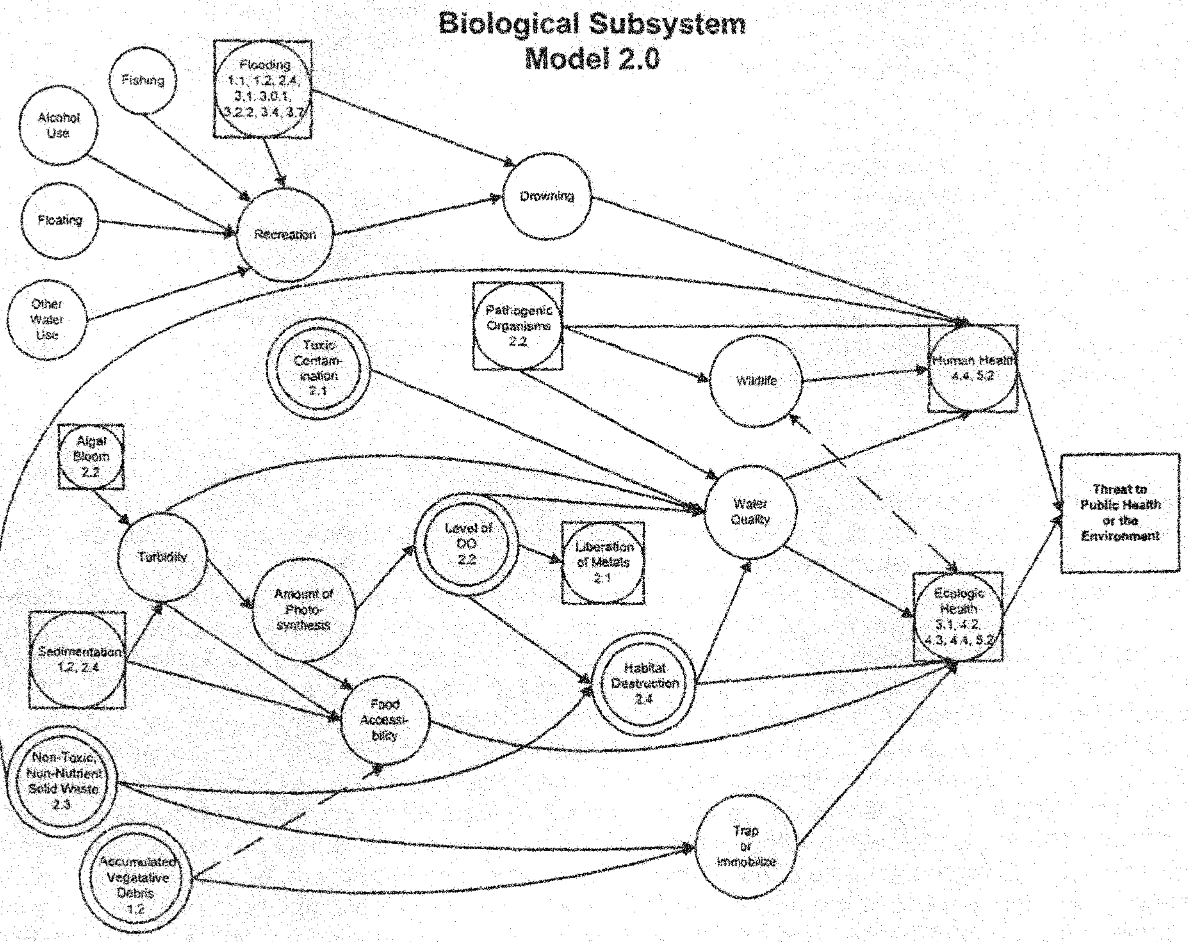
Economic Subsystem

The economic subsystem is a large and complex system, with 179 influence links. The terminal impact in this system is instability or stagnation of the economy. Influences on the economy include the triad of employment, wages, and taxes (which are shown in an integrated relationship) and the various sectors of economic development in the basin. Economic development is divided into five sectors: tourism,

[1] Experts who assisted in validating the model were: Biological Subsystem: Robert Lynch (OUHSC) and Gary Vandenbos (NEOSU); Physical Sybsystem: Baxter Vieux (OU) and John Simms (NEOSU); Economic Subsystem: Keith Willett (OSU) and Edwin Rossman (USACE); Social Subsystem: Edwin Rossman (USACOE), Ed Fite (OSRC), Mike Yuan (USACE), Lowell Caneday (OSU); Political Subsystem: Ed Fite (OSRC), John Hassell (OCC), Glen Jones (ODEQ), and Dean Couch and Derek Smithee (OWRB).

[2] Due to space limitations, no other base subsystems or higher level subsystems are shown in this paper.

recreation and commercial, residential, industrial, agricultural, and nursery. Each of these are influenced by demands for that type of development, which, in turn, is affected by factors such as development costs, development income, consumer's net income, and population of the area. Other influences on economic development include the quality of exploitable natural resources, policy maker preferences, and public infrastructure. Public infrastructure consists of both structures and services, such as roads and bridges, water and electric supplies, wastewater treatment, law enforcement, and emergency medical



response.

Figure 4. Level 2.0, Showing the Base Level of the Biological Subsystem

Social Subsystem

The social subsystem is also a large subsystem, with 159 influence links. The terminal impact in the social subsystem is dissatisfaction with quality of life. This outcome will occur if stakeholders' perceived quality of life is less than expected. Factors that influence quality of life judgments are scientific and educational valuation of the area, recreational satisfaction, cultural preservation, aesthetic quality, and the psychosocial state of the stakeholder. Aesthetic quality includes factors such as sights, sounds, odors, and degree of solitude. Cultural preservation includes spiritual valuation and archaeological and historic site preservation. Recreational satisfaction includes type and availability of activities, visitor displacement and succession, and park conditions. The psychosocial state of the stakeholder is influenced by a variety of factors including cultural norms and traditions, community and political values, and demographic characteristics.

Political Subsystem

The terminal outcome of the political subsystem is policy that affects the other subsystems. This subsystem has 197 influence links. Influences to policy include the level of policymaker and stakeholder dissensus, policy maker and stakeholder preferences, legal and knowledge constraints, and interest group pressures. Legal constraints are dealt with in detail, particularly with agencies that regulate land use, water use, and water quality in the basin, as well as agencies that provide incentive programs for establishing vegetated buffer zones along waterways in the basin.

Problem Analysis and Modeling

As discussed above, models have been used to assist decision-making in many different aspects, such as education, exploring relationships between causal elements, and predicting changes in outcomes as a result of policy intervention. Our model is particularly suited to assist in problem analysis because it addresses nearly all of the aspects of the problem analysis process.

The first step in problem analysis is to understand the problem. This was the original intent of most models, that is, representing complex systems in a manner that can be easily comprehended. Such a model can help both policymakers and stakeholders to better understand the problem. In the Illinois River Basin study, this goal was accomplished by using the model as a basis for a computer visualization program, which will be distributed for use as an educational tool to facilitate understanding for both policymakers and stakeholders. In addition, the model can be used as an assessment tool to gauge others' knowledge of the problem (Bostrom *et al.* 1992; 1994a; 1994b). This was accomplished in the Illinois River Basin study by using the model as a tool to interview various stakeholder groups in order to gauge their understanding of the concepts and issues included within the model.

Another step in policy analysis is to choose and explain relevant policy goals and constraints. A portion of the model described herein is devoted to describing existing policy, which explains policy constraints. The model can also be used in choosing relevant policy goals. A policy analyst can locate a specific issue on the model and identify the aspects that influence – and are influenced by – that issue. By clearly showing relationships, the model will better inform the policy analyst as to what goals they should seek to instigate change in the system.

Similarly, the model can help the policy analyst to identify and assemble feasible policy alternatives. The analyst can explore where policy interventions can be made so that policy efficacy can be assured. In addition, the analyst can visualize how the intervention could produce effects that are propagated throughout the system. In this way, the chances of neglecting to consider secondary and higher level effects are reduced.

The model can also assist in the type of decision analysis used in risk characterization. Risk characterization involves two main processes – analysis and deliberation (National Research Council 1996). In brief, this process involves the analysis of data, which frames deliberation. That deliberation then determines what further analysis needs to be done, which frames further deliberation, and so on. In essence, the model can serve as the initial analysis. (The model can also be used for additional analysis of the knowledge that stakeholders have about the issues in the model, as discussed in the Bostrom *et al.* papers).

In the Illinois River Basin study, a computer visualization utilizing this expert model is in the final stages of development for utilization by both policymakers and stakeholders. This visualization uses a slightly simplified version of the expert model and contains interactive diagrams of the model as well as pictures, diagrams, and charts to explain the concepts included in the model. The visualization also contains spatial maps and GIS data, which will be linked to relevant concepts within the expert model. The visualization will be completed in early 2001 and distributed for use on a compact disc. It will also be used during policymaker meetings to facilitate understanding and deliberation. This application of the model will help achieve the first performance goal of the model, which is to be usable as a decision support tool and help a policy analyst qualitatively estimate the affects of various policy interventions throughout all subsystems.

The fully developed model can then aid deliberation in several ways. It can educate deliberants about the system as well as make explicit the areas of potential policy intervention. The deliberants can also better understand the potential secondary and tertiary impacts of any policy intervention by using the model. Finally, the model can frame further analysis by showing what specific type of analysis can be (or needs to be) done.

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