The Use of Models In Great Lakes Decision Making

An Interdisciplinary Synthesis

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Executive Summary

The Use of Models in Great Lakes Decision Making:

An Interdisciplinary Synthesis

Computer models have been used since the 1970s in several areas including pollution control, fish stocking, and water level regulation, and their uses range from increasing the understanding of a system to serving as decision support tools. Models are of value when they increase the likelihood that choices will be based on the best available science and when they facilitate the selection of policies that achieve goals in the most efficient and effective manner. However, even good models can lead to bad decisions when they constrain creativity, preclude options that are outside the purview of the model, make predictions that are irrelevant, generate results in a spatial or temporal scale different from the scales of concern, or when the uncertainty bounds are too large or inaccurately communicated. In today's era of participatory decision making, models must provide stakeholders with easy-to-access data, improve the stakeholders' understanding of the model's meaning, help participants understand system dynamics, and thereby promote meaningful discussion among stakeholders.

To examine how computer simulation models have been used in decision making processes, the research team interviewed thirty-five people and reviewed several documents in relation to four case studies in the Great Lakes in which models were an important feature: Phosphorus loadings (1970s); PCB Mass Balance (1980s); Lake Ontario Fish Stocking (1990s); and Water Level Regulation in Lake Ontario and the St. Lawrence River (2000s).

The four cases represent examples of the increasing demands being placed on models, modelers and managers by trends in environmental protection and natural resource management toward :

(1) ecosystem-based management and ecological forecasting

(2) increased meaningful public participation and collaborative decision-making

(3) adaptive management, where decisions are made, results monitored and policy reevaluated

(4) sustainability, i.e., the inclusion of environmental values and ecological understandings in decision processes previously dominated by economic values.

These four trends guarantee that models will play increasingly important roles in environmental management because decisions require not only a thorough understanding of ecosystem components (indicators), but they require an ability to interpret indicators in the context of policies in multiple frameworks.

This Synthesis Paper describes and evaluates how models have been used in decision making, their strengths and weaknesses as decision tools, the way they have enhanced or undermined decision processes, and ways their use can be advanced. For our purpose we developed three indicators of success:

- Deliberative effectiveness: Is the model used in ways that improve the effectiveness of deliberations among participants in the exercise?
- Explanatory effectiveness: Is the model used in ways that improve participants' understanding of environmental and policy systems and improve their ability to participate in an informed way?
- Policy relevance: Is the model used in ways that are relevant to the actual policy decision being made?

In this, we are not evaluating the success of the models or the decision-process with regard to their ultimate impacts on the physical environment but rather are analyzing how the actors themselves regarded the case in terms of our criteria of effectiveness. Thus, evaluating success is less about judging whether specific environmental goals were reached and more about whether a shared understanding of the problem resulted. Our cases give examples of when this work has been done effectively and others when it has failed.

We focus primarily on how the modelers, scientists, managers and stakeholders experienced the *process* of using models to support policy decisions and what their experiences suggest for designing future processes. The following matrix of three functions (descriptive, predictive and heuristic) and three modes (system parameterization, interest clarification and participant education) is typical of how models can and have been used in environmental policy decision processes.

Modes/functions	**Descriptive**	**Predictive**	**Educational**
Parameterize system	Describe system parameters and their relationships	Predict system responses to change	Improve understanding of the system. Organize and synthesize data about the system.
Clarify interests	Describe relationship between natural system and social systems	Predict impacts of decision	Demonstrate potential trade-offs
Communicate	Describe cause/effect relationships	What-if scenarios, develop shared vision of possible future	Explain limits, constraints and possibilities

We found that in aquatic ecosystem management, the best outcomes result when there is open communication (and greater understanding) throughout the modeling process between the modelers who carry out the modeling itself and the resource managers, policy makers, and citizens who implement policy and management frameworks and live with the results of these decisions. If this meaningful interaction does not occur, if users are not intimately involved in the modeling process from problem specification to model development to management application, there is a strong possibility that the model will be inconsistent with the management questions being asked. It is also likely that the data and resources available to calibrate and confirm the model will not be available or that other programmatic constraints will interfere with the modeling process.

Some specific findings include:

- Planning and managing the modeling *process* is as important as focusing solely on decreasing output's uncertainty.
- Managers need to provide clear direction, while modelers must be careful not to promise more than can be delivered.
- Model objectives and complexity should be decided up front and agreed upon between modelers and managers.
- Ambiguity at the beginning of a process can undermine chances for success.
- Models should and can constitute spaces for participatory deliberation and education.

Based on the lessons learned from the four case studies and the insights on modeling and decision making found in the literature, we developed a conceptual framework to provide a prototype for designing future processes. The framework defines five distinct stages of the process and six ongoing management considerations. The process of utilizing computer models to support decisions is visualized as a spiral, with problems and modeling applications proceeding from the results of previous turns of the cycle and new problems and applications feeding into the next turns. "Short circuiting" often occurs when the results of one of the stages triggers a relapse to an earlier stage.

The stages in the integrated modeling and decision making process are:

(1) Problem Definition and Process Planning

(2) Refining the Approach

(3) Building the Model

(4) Application and Decision Making

(5) Adaptive Management

In addition, we found that there are several overarching management concerns that involve: communication (among managers, modelers and data providers), participation (from the beginning of the modeling process), complexity and uncertainty (agreed upon and defined by all participants), evaluation (throughout the process), documentation, and assuring continuity of resources (to validate the model and monitor the system).

As the tools of modeling become more powerful and more widely available, the greater potential they have to contribute toward improving environmental decision making, the more significant role they play in the decision process and the more important it is to plan and manage the *process* of using models. We would also encourage model developers, decision makers and managers to share their "lessons learned" in the literature that documents model process development, success, and effectiveness.

Interviewee Coding

CASE STUDY	*DESCRIPTION*	*ALIASES*
LOSLR Study	ETWG member. Engineer. Interested in modeling.	CE
	PIAG member. A broker between the public and the Study Board. Scientist/ Modeler.	BP
	Member of the Mohawk community working with fisheries.	YT
	Educator. Reviewed the material used by PIAG to engage the public.	BN
	ETWG member. Biologist, used to working with simple models. Worked in assembling the 1999 plan of study.	CLC
	Study Board member. Scientist, working for a government Agency.	SB-1
	Study Board member representing the Akwesasne community. Scientist working with fisheries.	AM
	Study Board member. Scientist working for the Army Corps of Engineers.	SB-2
	PFEG member. Modeler, working for the Army Corps of Engineers.	MA
Fisheries Management	Modeler. Scientist working several years with Fisheries.	MF
	Modeler. Task Group Member. Scientist working for several years with fisheries.	TG-1
	Scientist acting as a broker between the fishing community and managers/modelers.	PE
	Modeler. Task Group Member. Scientist working for several years modeling and monitoring Fisheries.	TG-2
	Charter Boat Captain. Engineer used to working and building computer models.	BC
	Sport Fisherman.	FS
	Modeler, assisting the development of the SIMPLE model.	SMC
	Modeler concerned with Fisheries and predator-prey dynamics. Modeler of the RISK model.	MR
	Sport Fisherman and Charter Boat Captain. Lawyer.	FSC
Eutrophication Modeling	Modeler, scientist. Several years experience in Great Lakes modeling.	MOA
	Decision maker working for a US Federal Agency (EPA). Actively involved in Mass Balance Modeling.	EPM-1
	Decision maker working for a US Federal Agency (EPA). Actively involved in Mass Balance Modeling.	EPM-2
Eutrophication and Mass Balance Modeling	Scientist working for Environment Canada. Involved with Mass Balance modeling and marginally involved in LOSLR Study evaluating the option plans.	CLP
	Modeler. Participated in Mass Balance and Eutrophication modeling.	MEM
	Modeler. Participated actively in the modeling in LOSLR Study, Mass Balance and Eutrophication. Participated marginally with the Fisheries management modeling effort.	GR
	Decision maker. Working at International Joint Commission.	IJC
	Scientist, data provider for the eutrophication modeling	EGP

CASE STUDY	DESCRIPTION	ALIASES
Mass Balance	Working for the Great Lakes Industry group. Scientist and business administrator, working in policy issues in the Great Lakes.	IP
	Chemist/Modeler. Focuses on determining through model prediction discharges of the manufacturing industry (private sector) to comply with government regulations.	CM
General Decision Making / Modeling	Modeler / Scientist. Research focuses on toxics and water quality.	MS
	Scientist. Founder of an organization that creates spaces for dialog between managers, modelers and scientists.	MN
	Scientist concerned with policy development and public participation. Worked in government position and in academia.	GU
	Decision Maker, with a long history working with US government. Expert in the Great Lakes regulation system.	QA
	Scientist/ Decision maker, several years working in the Great Lakes	SGL
	Modeler mainly concerned with fisheries and adaptive management in the Great Lakes	AM
	Scientist/Modeler, concerned with the misuse of models in the economic arena	NCE

Acronyms

EPA: Environmental Protection Agency
ETWG: Environmental Technical Working Group
GLWQA: Great Lakes Water Quality Agreement
IAGLR: International Association of Great Lakes Researchers
IERM: Integrated Environmental Response Model
IJC: International Joint Commission
LaMPs: Lakewide Management Plans
LOSLR: Lake Ontario Saint Lawrence River
MKB: Model Knowledge Base
NRC: National Research Council
NYS DEC: New York State Department of Environmental Conservation
OM: Open Modeling
OMNR: Ontario Ministry of Natural Resources
PCBs: Polychlorinated biphenyls
PFEG: Plan Formulation and Evaluation Group
POS: Plan of Study
RAP: Remedial Action Plans
RPO: Regulation Plan Options
RSC: Royal Society of Canada
SAB: Science Advisory Board
SB: Study Board
SIMPLE Model: Sustainability of Intensively Managed Populations in Lake Ecosystems
SVM: Shared Vision Model
SVP: Shared Vision Planning
TSC: Toxic Substance Committee
TWG: Technical Working Group

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Chapter 1

Introduction

This synthesis paper represents policy inquiry in its broadest sense. Policy science dates back to a progressive movement in the first part of the 20th century that advocated for reliance on technical expertise rather than political power in making government decisions that affect the broad public (Fischer, 1990). Harold Lasswell is often credited with being the founder of public policy research (Fischer, 2003). In *The Policy Orientation* (Lasswell & Lerner, 1951), a book Lasswell co-edited, he called for reforming democratic practice and bringing it into the modern technological era. The research strategy of what Lasswell termed the "policy sciences" has had two tracks: one is the study of how policy gets made, and the second is the provision of information about social and natural conditions to policy-makers in the form most useful to them. The use of mathematical models of aquatic systems in making management decisions that affect them is an advance in the latter task of policy science (getting information to policy-makers).

During the 1960s and 1970s, government decision making and policy research took a technocratic turn, placing greater emphasis on rationality and efficiency than on democracy. Some of the tools used were computer models. Modeling began with a movement, initiated by Forester in the 1950s, called system dynamics which is concerned with non-linear processes and feedback mechanisms whose important elements can be translated into computer language (Van den Belt, 2000; Cockerill et al., 2007). Most models have been created by a technical elite who have an understanding of mathematics and computer languages (Felleman, 1999).

Good models can lead to good decisions when they improve the understanding of a problem and the efficiency of the decision process. Models are of value when they increase the likelihood that choices will be based on the best available science and when they facilitate the selection of the most efficient and effective policies. However, even good models can lead to bad decisions when they constrain creativity, preclude options, produce predictions that are irrelevant, generate results in a spatial or temporal scale different from the scales of concern, or when the uncertainty bounds are too large or inaccurately communicated. Furthermore, it may have been good enough for modelers in the past to provide technical support to technocratic managers, but in today's era of participatory decision making, models must do more. They must provide stakeholders with easy-to-access data, improve the stakeholders' understanding of the model's meaning, help participants understand system dynamics, and thereby promote meaningful discussion among stakeholders.

Robinson (1992) pointed out that, "while the need for better data and models to support environmental decision making is generally recognized, the need for new approaches to how those data and models are used in the policy-making process has received less attention" (p 1). Improving the modeling process itself by making better, more accurate and complete models will only go so far if we do not also design better decision processes in which the models are used. In our analysis of four cases, we focus primarily on how the modelers, scientists, managers and stakeholders experienced the process of using models to support policy decisions and what their experiences suggest for designing future processes. The following matrix of three functions (descriptive, predictive and educational) and three modes (system parameterization, interest clarification and participant education) categorizes how models can and have been used in environmental policy decision processes.

Modes/functions	**Descriptive**	**Predictive**	**Educational**
Parameterize system	Describe system parameters and their relationships	Predict system responses to change	Improve understanding of the system. Organize and synthesize data about the system.
Clarify interests	Describe relationship between natural system and social systems	Predict impacts of decision	Demonstrate potential trade-offs
Communicate	Describe cause/effect relationships	What-if scenarios, develop shared vision of possible future	Explain limits, constraints and possibilities

Early models used in the Great Lakes and elsewhere usually focused on only one or a few processes, such as the phosphorus loadings models used during renegotiation of the Great Lakes Water Quality Agreement in the 1970s (Modeling Task Force, 1987). Often these models were developed by a single authoritative entity with the technical expertise to design and construct the model and the political power to enforce management decisions (Lund & Palmer, 1997). Advances in computer technology have since allowed modelers to create increasingly complex programs that simulate a broad range of biological, physical, chemical, economic, and social variables often within a single modeling system (Palmer, 1998; Wind & de Kok, 2002). Contemporaneously, the public's increasing familiarity with computer systems has allowed a wider range of stakeholders and decision makers to readily interact through model interfaces (Heidtke et al., 1986; Loucks, 1995; Watkins & McKinney, 1995). As technology has made it feasible to address ever more complex problems in systematic ways, not surprisingly, the problems decision makers attempt to address through models have grown in complexity.

The tendency is to ask predictive models and decision support systems to inform more and more decision processes. This raises a number of significant concerns about the effect of modeling on the quality of the decision process. The best outcomes of the use of models result when there is open communication and greater understanding throughout the modeling process between the modelers who carry out the modeling itself and the resource managers, policy makers, and citizens who implement policy and live with the results of these decisions. If this meaningful interaction does not occur, if users are not intimately involved in the modeling process from problem specification to model development to management application, there is a strong possibility that the model design and application will be inconsistent with the management questions being asked. It is equally likely that the data and resources available to calibrate and confirm the model will not be available or that other programmatic constraints will interfere with the modeling process (DePinto et al., 2006). There will be a strong possibility exists that one of two outcomes will result: (1) the model may frame the public policy process rather than the other way around or (2) the managers and stakeholders may become confused and disgruntled and therefore largely ignore the model forecasts in their decision process.

Models clarify the cause-effect relationships that contribute to the problem being addressed. Models approximate how the system of interest will respond to change, including management action. But how models are structured, the data they use, what relationships they simulate, how the output is visualized, and how uncertainty is communicated, all affect the way stakeholders perceive the scientific and democratic legitimacy of the decision process. These perceptions then greatly affect the ability of managers and policy makers to effectively and efficiently solve environmental problems.

This Synthesis Paper reports on four case studies of the use of computer models to inform decision making in the Laurentian Great Lakes of North America. From these case studies and a review and synthesis of the relevant literature, we present a conceptual framework for understanding the process of using models in environmental decision making. We describe and evaluate how models have been used in decision making, their strengths and weaknesses as decision tools, the way they have enhanced or undermined decision processes, and how their development and use can be advanced.

We focus on the following indicators of success:

- **Deliberative effectiveness:** Is the model used in ways that improve the effectiveness of deliberations among participants in the exercise?
- **Explanatory effectiveness:** Is the model used in ways that improve participants' understanding of environmental and policy systems and improve their ability to participate in an informed way?
- **Policy relevance:** Is the model used in ways that are relevant to the actual policy decision being made?

When simulation models first emerged as decision support tools, most natural resource policy was explicitly utilitarian and efficiency-oriented; the goal was to maximize the net social benefits of resource management with the least cost to society. Thus, modelers were given the charge to create tools that would reliably compare alternative management actions in terms of costs and benefits. This was largely a systems analysis and engineering challenge for the modelers and an accounting challenge for the decision makers. These decision-support tools estimated dollar costs of management actions measured against the estimated dollar benefits.

The right decision was the one that yielded the greatest net benefit (benefits minus costs) to society. Typically, the results of the analysis were presented to a government agency - usually the same one that had contracted for the model. There was little if any perceived need for what we would call "stakeholder involvement" or "public participation." *Deliberative effectiveness* was, in these cases, mostly a matter of sound project management and communication of results. It was a process by experts for experts. *Explanatory effectiveness* could be measured by whether the managers/stakeholders understood the model output. *Policy relevance* was determined by whether the managers used the modeling results in their final decision. Changes in how we think about environment and society have greatly complicated these relationships.

The need for objective, science-based methods to analyze and compare policy choices drove the development of mathematical descriptions of system behavior, or models, toward applications in environmental management. Clearly, the more reliable and accurate the models, the more confident decision makers can be in their choice of action. Given this role, modelers have designed their models to produce or translate results into metrics that are meaningful to decision makers (Karplus, 1983; Walhs, 1993; Simonovic, 1996; Palmer, 1998; Chen et al., 2004). These metrics largely determine the design of the model and are themselves determined by the policies that drive the decision process.

Traditionally, there have been concerns that models could and would be used not to inform deliberative decision making in a fair and transparent way but would instead be used to bolster, justify and legitimate policy choices that had already been made in the shadows based on other political and economic considerations (Robinson, 1992; Modeling Task Force, 1987; Nelson, 1977; DeSario & Langton, 1984). Although our research suggests that some participants suspected and complained of deliberate misuse of models and modeling, there was no evidence of such manipulation. However, deliberate misuse is only one way that things can go wrong. More often, problems stem from a lack of communication or misunderstandings, failure to plan the decision process to best utilize the functional capabilities of models, and lack of meaningful participation by stakeholders at critical stages of the process, particularly in the articulation of policy goals (EPA-SAB, 2006; Glaser & Bridges, 2007; Jakeman et al., 2006). Too often, agencies take their policy objectives for granted. They may be articulated in the agency's stated mission or legislative mandates, but stakeholders can and often do hold contrary opinions about what the decision makers' objectives should be (Koontz et al., 2004). Unless the policy objective of the decision process is clear, well-communicated, and shared by the participants, the likelihood of dissatisfaction with the model and the decision process is great.

It has been obvious for a long time that there is more to improving the use of models as decision-support tools than getting the technology right (Robinson, 1992; Nelson, 1977; Ingram & Schneider, 1998). The policy process must also be thoughtfully designed, a step that seems to have been lacking in those cases where significant dissatisfaction has been expressed (e.g., Lake Ontario fisheries and Lake Ontario-St. Lawrence water levels management). This is why the "terms of reference" for the decision process as a whole, for the modeling components, and for the relationship between the two are so important. Too often, however, policy objectives remain obscured or multiple, and sometimes conflicting policy goals are articulated without clear priorities (Smith & Koontz, 2003).

In addition to applications in classic cost-benefit analyses or as tools to guide and communicate scientific research, our case studies demonstrate that models are used in other types of decision making processes (see also van den Belt, 2004; Peterson et al., 2004; Smith & Koontz, 2003). The roles that models play have expanded largely in two directions: first, to organize data and communicate scientific findings from scientists to managers (Day & Hall, 1977; Scavia, 1977; DePinto et al., 1986), and second, to test alternative management scenarios by simulating system responses to management activities (Chen et al., 2004). Model results are no longer a static summary or "answer" delivered to a decision maker (Felleman, 1999). Instead, models can now be conceived, constructed, and modified as one portion of a group process and collaborative decision making toolbox (van den Belt, 2004; Peterson et al., 2004; Palmer, 1998). Full assessment of their use requires, therefore, much more than the traditional methods of verification and validation or evaluating the outcomes of decisions.

The cases we selected also represent examples of the increasing demands being placed on models, modelers and managers by trends in environmental protection and natural resource management. These trends are toward 1) ecosystem-based management and ecological forecasting; 2) increased meaningful public participation and collaborative decision making; 3) adaptive management, in which decisions results are monitored and policy is regularly reevaluated; 4) sustainability, that is, the inclusion of environmental values and ecological understanding in decision processes previously dominated by economic values. These four trends all but guarantee that models will continue to play increasingly important and diverse roles in environmental management.

Case Studies

This Synthesis Paper focuses on experiences in the Great Lakes, but we believe the results should be relevant anywhere. We chose to study the Great Lakes because the principal investigators have worked mostly on the Great Lakes and because the Great Lakes have been one of the most modeled aquatic systems in the world (Modeling Task Force, 1987). Modeling applications include setting phosphorus limits in the Great Lakes Water Quality Agreement (Task Group III, 1978; Modeling Task Force, 1987), assessing the movement of toxic chemicals into the lakes and through aquatic food chains (DePinto et al., 2004; Schottler & Eisenreich, 1997; Trudel & Rasmussen, 2001), adjusting stocking levels in Lake Ontario (Jain & DePinto, 1996), and evaluating water regulation plans for Lake Ontario and the St. Lawrence River (Manno, 2003; Limno-Tech Inc., 2005). These are the four case studies that form the major component of this Working Paper:

(1) Phosphorus-eutrophication models in support of U.S.– Canada Great Lakes Water Quality Agreement objectives, 1972-1980.

(2) PCB mass balance models in support of the Lake Ontario Lakewide Management Plan, 1996-2004.

(3) Bioenergetic models and predator-prey models in support of the New York Department of Environmental Conservation's stocking decisions including stakeholder participation in response to a sharp decline in forage fish populations, 1992-93.

(4) Integrated Environmental Response Model and Shared Vision Model in support of the multi-stakeholder decision process for recommending changes in the outflow regulation plan for the Moses-Saunders Power Project on the St. Lawrence River, 2002 to present.

We chose these four cases because they:

- Span a time period of increasing technical sophistication from the early 1970s when computer simulation models served as nascent decision support tools to the present day when technological advances allow output visualization and user interfaces that can engage a variety of stakeholders.

- Represent examples of the increasing demands placed on models, modelers, and managers by trends in environmental protection and natural resource management toward ecosystem-based management and ecological forecasting. They call not only for greater public participation and collaborative decision making but also for continuous learning in a process where decisions are made, results monitored, and policy regularly reevaluated and possibly reformulated. The need for sustainability -- which calls on decision makers to consider the relationships between environmental quality, economic prosperity, and equity -- poses a further challenge represented in these case studies as well.

- Demonstrate an increasing level of public and stakeholder participation in Great Lakes decision making over time. The eutrophication (1970s) and mass balance models (1980s) did not include citizen participants while the fish stocking exercise (1990s) included stakeholder participation during the later portions of the first modeling exercise, and the Lake Ontario-St. Lawrence River study (2000s) was designed to include stakeholder participation throughout the process.

- Represent high-profile ongoing activities in Great Lakes aquatic resource management (water quality, fisheries harvest, and water level management).

- Deal with some of the significant stressors to the Great Lakes system: nutrients, persistent toxic substances, fish management, water levels, and water flows.

- Two of the authors were familiar with each of the cases and in some were directly involved, making detailed case studies feasible.

Methods

We[1] conducted thirty-five extensive open-ended interviews, twenty eight with people directly involved in the modeling and decision making process in one or more of the case studies. These included modelers, agency personnel, and participating stakeholders. An additional seven individuals were interviewed because of their knowledge and experience with the Great Lakes cases and/or with modeling and decision making. A draft of our findings was sent to all interviewees allowing them to correct any errors of fact or omission. In addition, we organized a panel discussion with ten panelists from the U.S. and Canada, at the 49th Conference of the International Association of Great Lakes Researchers (IAGLR) entitled *Computer Models in Great Lakes Decision Making*. The interviews were recorded with the consent of each interviewee; the panel discussion was also recorded. The interviews and panel discussion were transcribed. These transcripts constitute the main source of data for the case studies along with the public documents produced during each of the case processes. We also conducted an extensive literature review related to modeling and decision making.

Interview transcripts were analyzed identifying themes and patterns based on our indicators (relevance, explanatory effectiveness, and deliberative effectiveness) in a constant comparative process within each interview transcript and then among transcripts. For our analysis, we have adopted a technique called "interpretive policy analysis," based on the work of Dvora Yanow, to organize and analyze the cases (Yanow, 2000). Instead of asking directly "were the right decisions made," we asked our informants the same question but in many different ways, for example, "What happened during and as a result of the decision process, and why did it happen that way?" From the details of these answers, we constructed the storyline of our cases. The informants' explanations of motives (their own and those of others), the narratives they tell, and their interpretations of actions and outcomes reveal how they made sense of their experience and how that might affect their interactions with decision processes in the future.

This kind of research starts with the knowledge that everything associated with these cases is socially constructed. The way participants think about these things (or artifacts) and the meaning these artifacts have for each participant has been constructed through an iterative social exchange. People learn from each other, and in complex ways they make sense of artifacts, both formally through education, passively through advertising and propaganda, and informally through social interaction and observation. Each person involved in these cases -- whether modeler, scientist, bureaucrat, angler, business person, or activist -- lives a set of experiences by which the problem and the possible solutions are understood. These meanings have both rational and emotional content and greatly affect beliefs and assumptions about appropriate behavior toward and communication about nature and natural resources, all of which can greatly affect the outcomes of decision making.

In this regard, to evaluate success is less about judging whether specific environmental goals were reached and more about whether a shared understanding of the problem resulted. In other words, models should be seen as powerful tools in a process of socially constructing shared understanding of the problem and its possible solutions. Our cases give examples of when this work has been done effectively and others when it has failed.

Arriving at shared understanding is a necessary prerequisite for making collaborative decisions, but it is not a guarantee that the resulting management actions will necessarily solve the problem. And even when problems are resolved effectively, they may recur again in the future or morph into new problems. Still, the experience of working together to achieve mutual understanding sets the stage for future successes in the overall policy goal of preserving and protecting the Great Lakes ecosystem. The ecosystem is in constant flux; therefore, the best outcome of "successful" experiences in modeling would be the creation of an informed, engaged constituency and a culture of collaboration in the Great Lakes.

Organization

This Synthesis Paper describes and assesses how models have been and are used in decision making, their strengths and weaknesses as decision tools, the way

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[1] Most interviews were conducted by Manno and del Granado, some by del Granado alone and some by del Granado and Cloyd.

they have enhanced or undermined decision processes, and how their development and use can be advanced. Chapters 2-5 present an interpretative analysis of the case studies consisting of a brief history of each case, the main reasons for choosing the case, followed by an analysis of the experiences and views of participants. Chapter 6 begins with a classic cyclical model of the policy making process and expands on it to highlight the primary points of interaction between modeling and decision making. This modeling/decision cycle is fleshed out by examples from the four case studies and the literature. Chapter 7 presents the conclusions and recommendations that we believe follow from our research.

Chapter 2

Phosphorus-eutrophication models in support of U.S. - Canada Great Lakes Water Quality Agreement objectives, 1972-1980

This was the greatest victory and the greatest demonstration of the ability to deal with an environmental problem for such a large ecosystem across the international boundary (QA).

There was absolutely no question that the eutrophication models really drove the science that went into the policy of the '72 [Great Lakes Water Quality] Agreement, and to me that is a tremendous success …The model was scientifically sound and identified the level of phosphorus that would reduce algal blooms in the lake. The back calculations were done to determine what the load limit needed to be, and the money was there because of public pressure (GR).

During the late 1960s and early 1970s, nuisance algal blooms caught the attention of residents, beachgoers, anglers, and visitors across the Great Lakes region, as algal mats washed up on beaches, rotted, and fouled the air (DePinto et al., 2006). In the Great Lakes region and throughout Canada and the U.S., the public demanded action. Newly created environmental agencies in both countries were responsible for developing policies for dealing with the crisis. The International Joint Commission (IJC) informed the two federal governments about the severity of the issue, and Canada and the U.S. began negotiations that eventually led to the Great Lakes Water Quality Agreement (GLWQA) of 1972, which required both countries to protect water quality by targeting the causes of degradation.

Benthic Algal growth in Lake Ontario
Photo Courtesy of Gail Krantzberg

By the mid to late 1960s scientists were largely in agreement that phosphorus was the limiting nutrient for phytoplankton growth in freshwater systems. However, there was little understanding of how to apply this knowledge to improving water quality in systems as large and complex as the Great Lakes. When the 1972 GLWQA was signed, Canada and the US agreed to set water quality objectives and recommend control measurements for phosphorus discharges (Final Report of the Phosphorus Management Strategies Task Force, 1980). In order to meet water quality objectives, scientists, managers, and decision makers needed to determine both the level of phosphorus reduction required and the most politically and economically feasible ways to meet these load reductions. The scope and complexity of such an environmental problem required dealing with complex, interactive processes: phosphorus inputs from air deposition, direct water discharges, and land run-off; jurisdictional issues arising from the involvement of two sovereign nations made up of eight states and two provinces; and a burgeoning environmental movement spurred on by the Cuyahoga River catching fire and reports that Lake Erie was dead. By any name, eutrophication was a major political and economic challenge.

The 1972 GLWQA established 1 mg/liter as the target load for all Great Lakes (Modeling Task Force, 1987). This load limit was based on the scientific knowledge of the relationship between phosphorus loading and eutrophication (limited to the loading from point sources), and it was thought to be achievable with the water treatment technology of the time.

In 1978, the IJC and the two countries undertook a review of the GLWQA . This review included evaluating phosphorus target loads using additional years of data and a better understanding of the relationship between phosphorus loading and eutrophication. Task Group III of this review process was charged with five technical objectives:

(1) To prepare a report based on 'acceptable' total phosphorus loadings to each lake

(2) To provide the best estimates of current phosphorus loadings from each country and each major source

(3) To present means for controlling phosphorus and the cost of pursuing them

(4) To develop several phosphorus loadings levels and treatment strategies for each lake

(5) To determine the dissolved oxygen level and other water quality objectives would be compatible with the proposed phosphorus loading (Report of Task Group III, 1978).

Task Group III developed a number of models of varying complexity to achieve these objectives (Scavia, 1977; Report of Task Group III, 1978). Five different models were used, and results were compared to find areas of agreement and variance. The Vollenweider loading plot model looked at the correlations between chlorophyll a, in-lake phosphorus, and phosphorus loadings. The Chapra model used phosphorus loadings as the main variable in a mass balance model (Scavia, 1977). Manhattan College developed three mass balance models for phosphorus and nitrogen: one for Lake Ontario, one for the Saginaw Bay system of Lake Huron, and one for Lake Erie. Finally, the Bierman model was a mass balance model for nitrogen and phosphorus that also calculated the concentration of five functional groups of zooplankton and phytoplankton. Due to the amount of data required for this last model, the Bierman model was only used in Saginaw Bay (Report of Task Group III, 1978). Although some of these models had already been developed as part of a burgeoning academic interest in environmental modeling, the Task Force's 1980 report noted that this was the first time the models' results would be used to inform management decisions (Final Report of the Phosphorus Management Strategies Task Force, 1980).

The models demonstrated that reducing phosphorus in municipal effluent to 1 mg/liter would not be enough to achieve desirable water quality. Non-point sources had also to be controlled. Task Group III recommended significant reductions (to 0.5 mg/liter) for sewage plants discharging into the most affected waters (Lake Ontario, Lake Erie, and Saginaw Bay) and reducing or eliminating the phosphorus in all commercial and household detergents (Report of Task Group III, 1978).

In addition to the work of Task Group III, the U.S. and Canadian governments asked the IJC to study how dispersed (non-point) sources of phosphorus and other pollutants contribute to the problem of eutrophication. Under this Reference[1] , the IJC created the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG), considered the first effort to include broad public participation in a Great Lakes policy process (Botts & Muldoon, 2005). PLUARG and Task Group III produced separate estimates of total phosphorus loadings to the Great Lakes, in some cases using different data sources (Final Report of the Phosphorus Management Strategies Task Force, 1980). PLUARG focused on non-point phosphorus sources such as agricultural and urban run-off and recommended strategies to manage these sources (DePinto, 1986). Using the recommendations of both Task Group III and PLUARG, Canada and the United States adopted Annex 3 to the GLWQA, which included five points:

(1) Municipal effluent discharge of 1 mg/liter for Lakes Superior, Huron, and Michigan (upper lakes) and 0.5 mg/liter discharge for Lakes Erie and Ontario (lower lakes)

(2) Regulation of industrial discharges

(3) Reduction of non-point sources in the upper lakes to the greatest extent possible and by 30% in the lower lakes

(4) Reduction of phosphorus in detergents to 0.5% by weight

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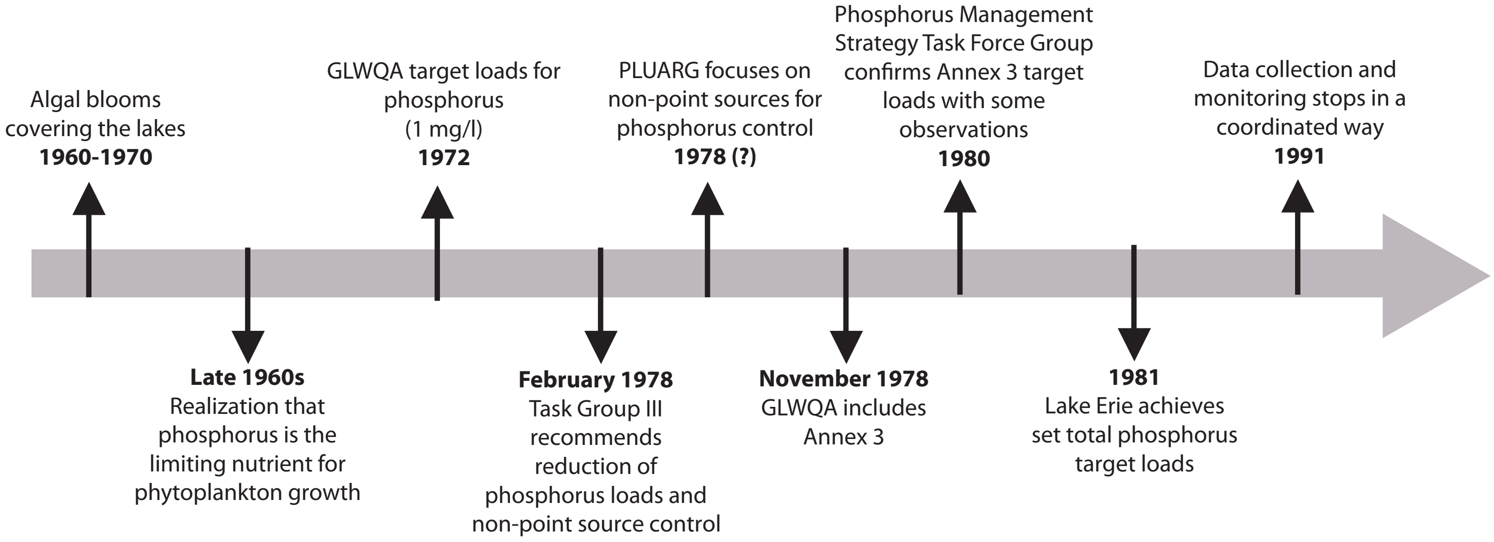
1. One of the functions of the IJC is to conduct research at the request (Reference) of the two Parties to the Boundary Waters Treaty. The ongoing Reference related to the GLWQA constitutes a significant portion of the IJC's work, and the IJC has formed two international boards to assist it in this function: the Great Lakes Water Quality Board and the Science Advisory Board. To assist PLUARG, the Science Advisory Board and the Water Quality Board created a joint task force called the Phosphorus Management Strategies Task Force (DePinto, 1986).

Figure 1. Historical context and timeline for the Eutrophication modeling effort



Key:
GLWQA: Great Lakes Water Quality Agreement
PLUARG: Great Lakes Pollution from Land Use Activities

(5) Maintenance of research and monitoring for phosphorus loads (DePinto, 1986).

The loads recommended by Task Group III and subsequently published in Annex 3 of the 1978 GLWQA were “tentative” total phosphorus target loads, subject to confirmation 18 months after the release of the 1978 Water Quality Agreement in November 1978 (figure 1). In fact, they were revised and confirmed even earlier by the Phosphorus Management Strategy Task Group in its 1980 final report (Final Report of the Phosphorus Management Strategies Task Force, 1980). After a detailed analysis of the models used by Task Group III, the Phosphorus Strategy Task Force recommended developing phosphorus management strategies that would target loads as a range: ±30 percent for Lake Erie’s load (11,000 ton/yr) and a ±20 percent for Lake Ontario’s (7,000 ton/yr). The Task Force had three reasons to recommend the target loads being set as a range: 1) statistical analysis of the residual error between observed in computed values, 2) differences in target loads projected by the various models, and 3) elements which were not included in the models, but which may affect the target loads (Final Report of the Phosphorus Management Strategies Task Force, 1980).

According to the Phosphorus Management Strategies Task Force, two elements were not explicitly addressed in the modeling efforts of Task Group III. First, the models were structured to analyze pelagic open-lake water areas, not the near-shore littoral areas that are the most visible sectors and which have different light, nutrient concentrations, and circulation patterns (Final Report of the Phosphorus Management Strategies Task Force, 1980). The interview data indicates that the state-of-the-art technology in the late 1970s was unable to distinguish between open-lake and littoral water conditions, and that this limitation was explained in the Task Group III Report. However, the results from Saginaw Bay and the western basin of Lake Erie could have been considered near-shore because these areas share many characteristics with shallow near-shore areas (Bierman, personal communication, 06/28/07). The second unaddressed element, highlighted by the Phosphorus Management Strategy Task Force, was the variability of phytoplankton community composition. These species vary seasonally and over time could produce changes in the ecological characteristics of their habitat. Nevertheless, the report acknowledges that “the state of the art of eutrophication modeling has not yet [in 1980] developed to the degree which permits adequate definition of this phenomenon” (Final Report of the Phosphorus Management Strategies Task Force, 1980, p. 43).

This phosphorus reduction effort is widely recognized as a major environmental success, and many believe that the modeling played a major role in the regulatory and policy measures that emerged in the GLWQA (Modeling Task Force, 1987). Algal blooms in the open water largely disappeared and water clarity and quality improved. Lake Ontario showed visual signs of recovery, and Lake Erie achieved its total phosphorus target loads (TP) in 1981. However, and perhaps because of these successes, coordinated data collection and monitoring stopped in 1991. Since then, algal blooms have again plagued near-shore areas and zones of severe oxygen depletion have reappeared in Lake Erie's western basin, leading scientists to once again study phosphorus loadings (DePinto, 2006).

What can we learn from the experiences of the phosphorus modelers in the 1960s and 1970s? How can we draw from those experiences to develop recommendations for those who may set up participatory decision making processes in the future? We were able to interview several of the scientists and modelers who worked on these early models and who are still working on the Great Lakes.

The case is interesting and informative for the purposes of our analysis for several reasons, including:

- It was a turning point in thinking about the effects (or lack of effects) of human activity on large lake systems.
- It was an early example of mobilizing the ecosystem modeling community to develop and use their tools to inform management decisions in response to a large scale environmental problem.
- It required significant coordination and collaboration between the new government environmental agencies and university-based modelers to apply what had previously been academic exercises to real-life problems.
- It set the tone for future binational scientific collaboration associated with the GLWQA, helping to establish an epistemic community in the Great Lakes that became a model for science-based environmental decision making around the world for many years.
- Academic scientists interacted directly and through their models with environmental managers.
- It was formulated, supported, and understood as both a decision-support process and an effort to further develop modeling skills and practice.
- It relied on and supported the development of several different models and approaches to modeling, allowing them to reinforce, correct and build on each other. It provided modelers and managers with experiences on which to build criteria and decide questions about appropriate model complexity, quantification and communication of uncertainty, documentation, and methods of model validation.
- It was seen by the participants at the time and by many independent scholars since as a success story for the relationship between modeling and decision making, although its lessons have yet to be fully learned.

As one of the modelers explained:

> *They essentially compared the model predictions with what they found in the lake after they had implemented what the models told them they should implement. That is called post-auditing, when you actually go back and check how good the model was at predicting response with the response of the system to a management action. That is the kind of thing you want to do if you are going to be doing any adaptive management because you want to find out where you blew it, if you blew it (GR).*

This case demonstrates a clear role for models in science-based governance. Modelers were asked to apply the latest understanding of the eutrophication process in their models and to use available data on phosphorus, chlorophyll *a*, water levels, and temperature to simulate the conditions in the Great Lakes that were leading to nuisance algal blooms. With the major causal relationships described and variables and equations parameterized, modelers were in a position to answer an important question for the policy-makers: what should the target phosphorus loads be? The clear articulation of the problem (eutrophication), the goal (the elimination of nuisance algal blooms), and the means to achieve the goal (setting water quality objectives in terms of phosphorus concentration and establishing the target loads needed to achieve the objectives), along with public

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2. Stakeholders should be understood as members of the public that hold an interest in the issue.

support that generated the necessary political will, allowed modelers to contribute to solutions. With the target loads tested by a series of models, the managers were in a much better position to engage in the political process of allocating the necessary reductions. The political leaders, the general public, and the scientists had arrived at a shared understanding of at least the main structure of the problem and its potential solutions:

It was a common goal [in] that everyone, even the general public, had a discussion about streams catching on fire and Lake Erie being dead. That really raised the public awareness quite a bit, and so the legislators were responding to their constituencies and giving the resources necessary for the scientists to do their work. So, maybe you need a crisis [to get] the decision makers acting with the science (GR).

Agency commitments and early successes in modeling meant that the modeling teams were supported throughout the process of model development. The models were improved through evaluation of past model results and comparisons to the conditions in the lake after management actions, in some cases years after, to see how well the predictions matched actual conditions:

In general, these models actually did very well in terms [of] essentially forecasting how the system will respond. This is really an advanced state of the science and state-of- the- art decision support because it gives you a lot of confidence in the use of the models for that purpose (GR).

Participants pointed to the use of multiple models and regular communication between the modeling teams as a highlight of the process. The models ranged from strictly empirical (describing observed relationships without a theoretical examination of the causal relations) to complex, process-oriented models. Such a large-scale multiple-model exercise has not been repeated; perhaps this is a major reason for the experience being remembered as a boost for both Great Lakes management and the underlying science of modeling and water quality.

They were using three or four different models at the same time, on the same problem and running them together. And they were using a whole suite of models to actually come up with targets. And I think that is an important lesson that we forgot over the successive decades. Having multiple models is really important because there are all kinds of uncertainties with models. Each of them has different kinds of uncertainties and different issues, and if you can get a whole suite of models with very different perspectives and get the same results, you'll get more faith in the forecast (MOA).

The Great Lakes were at the center of attention in the rapid emergence of politically expressed environmental awareness in both Canada and the United States. The pollution problem was visible and noxious, providing the political will to support the science and modeling exercises and to pass a number of environmental laws:

So there was that lining up of managers and science with money because of the interest in environmental movements. You've identified that you have to reduce the loads to that certain level to end up with that kind of concentration in the water. When you think of the complexity we are dealing with today, it was relatively simple then. Phosphorus is the limiting nutrient; the model says this is what we ought to do; the money was there for the improvement, so many things worked very well (IJC[3]).

Indicators

Deliberative effectiveness

Discussions were facilitated by the application of a multiple model approach: five models were developed to address the eutrophication issue, and at least three were applied in each lake. Similarities and differences in model results were discussed by modelers in Task Group III and then by the participants in the Phosphorus Management Strategy Task Force. Models increased deliberation about the causes of eutrophication and demonstrated the need for further advances in mathematical modeling for addressing scientific and management questions.

Explanatory effectiveness

It is clear that even though public pressure sparked the effort to reduce algae blooms and their causes, the public was not involved in the research process or in the final decision. This was not a case of public participation in the process of modeling or decision making. Certainly the result of the process was that people involved had a better understanding of the system, but there was also a lack of understanding or not enough attention paid by the decision makers to the limitations of the models and their result for near-shore conditions.

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3. Decision maker working at the IJC.

Policy Relevance

The eutrophication modeling effort advanced the use of technology (modeling) in management decisions, further developing skills and tools for modeling in the Great Lakes. However, there is little evidence or discussion of how the model results were actually used in the decision making process.

There was a disconnection between the objectives for eutrophication control in Annex 3[4] of the GLWQA and what the models looked at relative to phosphorus loads. The models were aimed only at open-lake (pelagic) issues, largely because modelers did not have the computer power necessary to do analysis at a finer scale (needed for the littoral sectors). However, the objectives in Annex 3 mention near-shore effects of eutrophication ('nuisance' algae blooms), effects readily visible to the public near the shoreline area. These models did not address that issue.

Models were successfully post-audited for open water and chlorophyll…They computed a target load in order to achieve the water quality objectives for basically open water chlorophyll and phosphorus concentrations. When they went back and looked after they had achieved those target loads, they found that the chlorophyll and phosphorus responded the way the models [said they] should have responded, almost. … So they were successful at what they were designed to do… In retrospect, the models did not address all the desires of the decision makers at the time …The main reason was that we didn't have the technical expertise or the computer power to do the kind of things that would have been necessary, that we could do now but we couldn't do then [1970s]. We can do near-shore fine scale models now, but we couldn't do it then, we didn't have the computer power… And we are still seeing near-shore eutrophication conditions (GR).

A question that remains unanswered is whether there was communication between the modelers and the decision makers regarding the limitations of the model and why these limitations were not pointed out in the 1978 review of the Great Lakes Water Quality Agreement, despite their being mentioned in the Task Group III report.

Modelers did not foresee some currently relevant issues, such as *Cladophora* returning to Lake Erie or changes in the lakes' chemical composition due to invasive species. This is yet another reason for considering this case, as modelers and decision makers can now see results over a nearly 40 year period. The modeling process is regarded as successful, the policy emerging from the process was implemented successfully, and phosphorus loads were reduced. Yet in the mid 1990s, the Great Lakes experienced similar problems with eutrophication (although to a lesser extent). Thus, an important question raised by this case study relates to the sustainability of decisions in which early successes were achieved, but were followed by unanticipated ecosystem changes.

Monitoring and auditing efforts declined once there was a sense that the eutrophication problem was solved and as the focus on water quality shifted to chemical pollutants. In the early 1990s, EPA and Environment Canada made the decision to declare the eutrophication problems resolved and subsequently to stop monitoring phosphorus loads. In 1991, the IJC gave its last report on phosphorus loads to the lakes. The only lake where some monitoring continued was Lake Erie.

Recommendations

Financial and technical support for the models and mechanisms for continued evaluation and modification of the models (ongoing monitoring) slowly leaked away as other, more pressing problems confronted managers and policy makers in the Great Lakes. This points to the need for an institution that catalogs and when possible, updates models used for Great Lakes management. If such a body had existed in 1991, it would have allowed modelers to quickly add features to models in order to

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4.The goals of Annex 3 are: (1) Restoration of year-round aerobic conditions in the bottom waters of the Central Basin of Lake Erie; (2) Substantial reduction in the present levels of algal biomass to a level below that of a nuisance condition in Lake Erie; (3) Reduction in present levels of algal biomass to below that of a nuisance condition in Lake Ontario including the International Section of the St. Lawrence River; (4) Maintenance of the oligotrophic state and relative algal biomass of Lakes Superior and Huron; (5) Substantial elimination of algal nuisance growths in Lake Michigan to restore it to oligotrophic state; and (6) The elimination of algal nuisance in bays and in other areas wherever they occur. (June 2007 http://www.epa.gov/glnpo/glwqa/1978/annex.html) The goals of Task Group III are: (1) To prepare a report based on the latest information on 'acceptable' total phosphorus loadings to each lake, (2) To provide the best estimates of current phosphorus loadings from each country and each major source, (3) To determine what control possibilities exist and what would be the cost of pursuing them, (4) To develop for each lake several phosphorus loadings levels and treatment strategies, and (5) To determine what dissolved oxygen and other water quality objectives would be compatible with the proposed phosphorus loading.

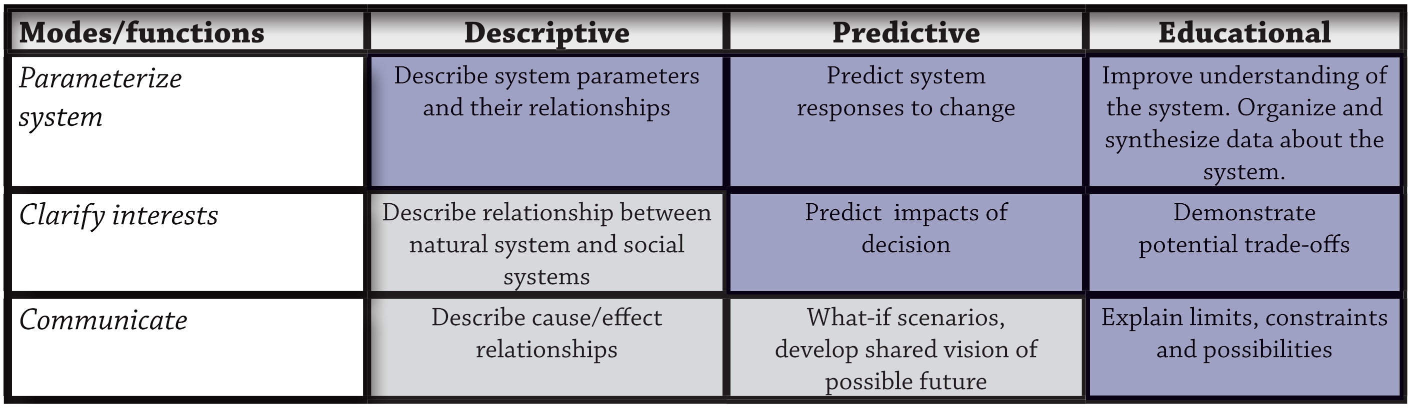
account for changes in near-shore conditions. A new initiative in this direction is the Great Lakes Observing System, under the International Ocean Observing System, which is an attempt to catalog, operationalize, and improve models in the Great Lakes region.

An important aspect of this case study and a way to engender confidence on the decision makers' side is to construct multiple models with different approaches and levels of complexity. If these models point to the same conclusions, they will build confidence in the modeling effort and the decisions they support.

Given that management questions are sometimes difficult to determine *a priori*, determining the appropriate level of complexity is an art, not a science. Thus building a range of models or at least beginning with a simple model and then building complexity as needed is a useful strategy. In this case, the task group's decision to commission several models led to decision makers having more confidence in the results. Still, there was a disconnect between what decision makers thought they were getting in terms of predicting the conditions in both near-shore and offshore environments and what the models were actually delivering.

During the problem specification stage, it is important for modelers to use those specifications to determine the degree of model complexity and resources needed to support this level of complexity. Modelers must then be able to communicate these needs back to the managers and decision makers in terms they will understand, such as the human and financial cost of the effort. This type of back and forth communication between managers, decision makers, and modelers helps control expectations and reduces (hopefully, avoids) misunderstandings.

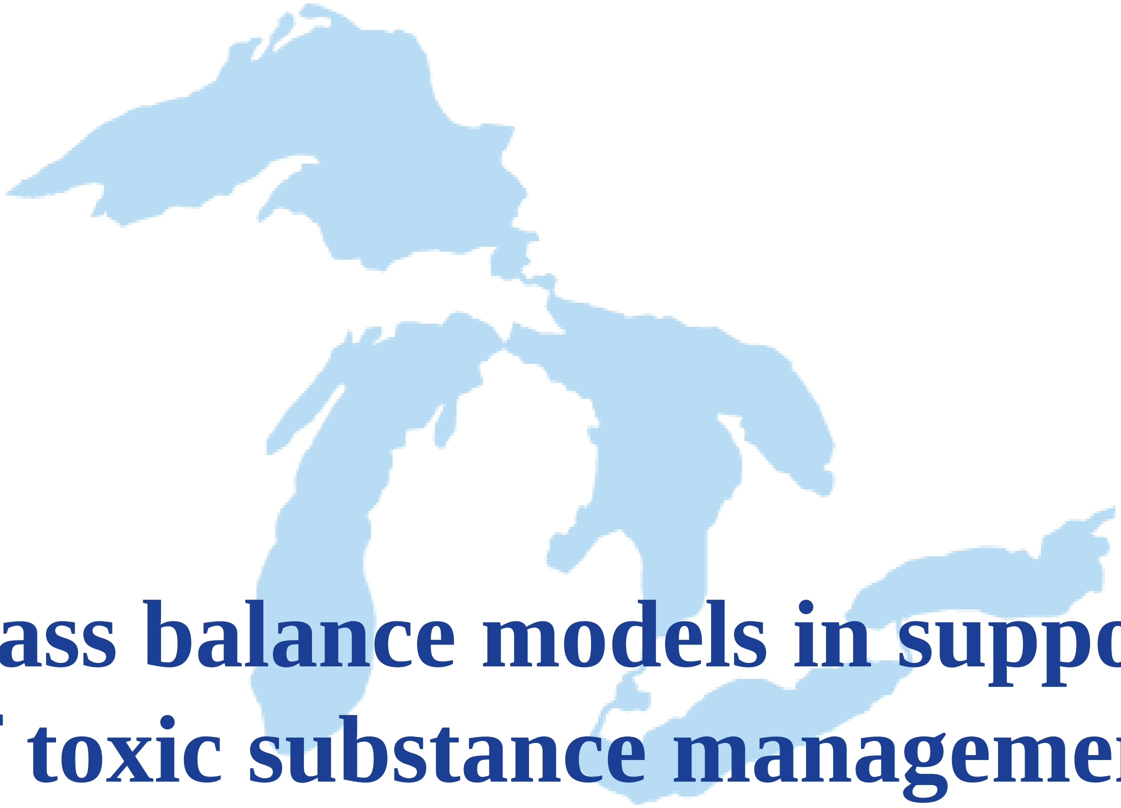
Figure 2: Phosphorus-eutrophication models: *Functions vs. Modes Matrix*



Modes/functions	**Descriptive**	**Predictive**	**Educational**
Parameterize system	Describe system parameters and their relationships	Predict system responses to change	Improve understanding of the system. Organize and synthesize data about the system.
Clarify interests	Describe relationship between natural system and social systems	Predict impacts of decision	Demonstrate potential trade-offs
Communicate	Describe cause/effect relationships	What-if scenarios, develop shared vision of possible future	Explain limits, constraints and possibilities

Areas in gray represent the functions and modes where we conclude that the models performed well, while those in blue represent the functions and modes where this modeling effort could have been improved. Better communication was needed between modelers and decision makers to explain the limitations of the models, especially in terms of calculating loads based on the data and responses in pelagic water sectors. Although reflected in the Task Group III report and then highlighted in the Phosphorus Management Strategy Task Group, these limits were not addressed further and became evident problems as changes in the ecosystems led to near-shore eutrophication.

Chapter 3



Mass balance models in support of toxic substance management and Lakewide Management Plans, 1986-present

In the early 1970s, numerous scientific reports documented health problems in Great Lakes wildlife, including lip and liver tumors in bottom feeding fish, cormorants with crossed beaks, and reproductive problems in several species of colonial birds (figure 3). Although it is difficult to link human health effects directly to Great Lakes environmental conditions, health officials and the general public were concerned that people were also in danger. In 1971, the first Fish Consumption Advisories recommending limits on the amount of fish consumed were issued by state and provincial governments in the Great Lakes. Large, long-lived fish such as popular sport fish had accumulated high levels of toxic chemicals, including polychlorinated biphenyls (PCBs) used in many industrial applications and in almost all electrical transformers (Government of Canada & United States Environmental Protection Agency, 1995). An environmental toxicant, PCBs, were widely dispersed in the environment and known to be one possible cause of the health effects seen in Great Lakes wildlife.

In 1977, the production of PCBs was banned (Travis & Hester, 1991). After the IJC Science Advisory Board created a list of priority pollutants that included PCBs, the Great Lakes Water Quality Agreement was revised in 1978 to add a new focus on toxic chemicals, particularly those that persist in the environment and accumulate in top predators. By the 1980s, technology had evolved making it possible to accurately measure very low levels of chemicals in tissue. Progress had been made solving the problem of eutrophication, but species populations were rebounding in the lakes only to face threats from toxic compounds. As a result, environmental groups, federal and state management agencies, and the IJC shifted their attention to reducing the levels of persistent bio-accumulative toxic chemicals in the Great Lakes. With the successes of the phosphorus reduction efforts still fresh in their minds, they wished to repeat the achievement, including the contributions of modelers and modeling, in developing policies regarding toxic chemicals.

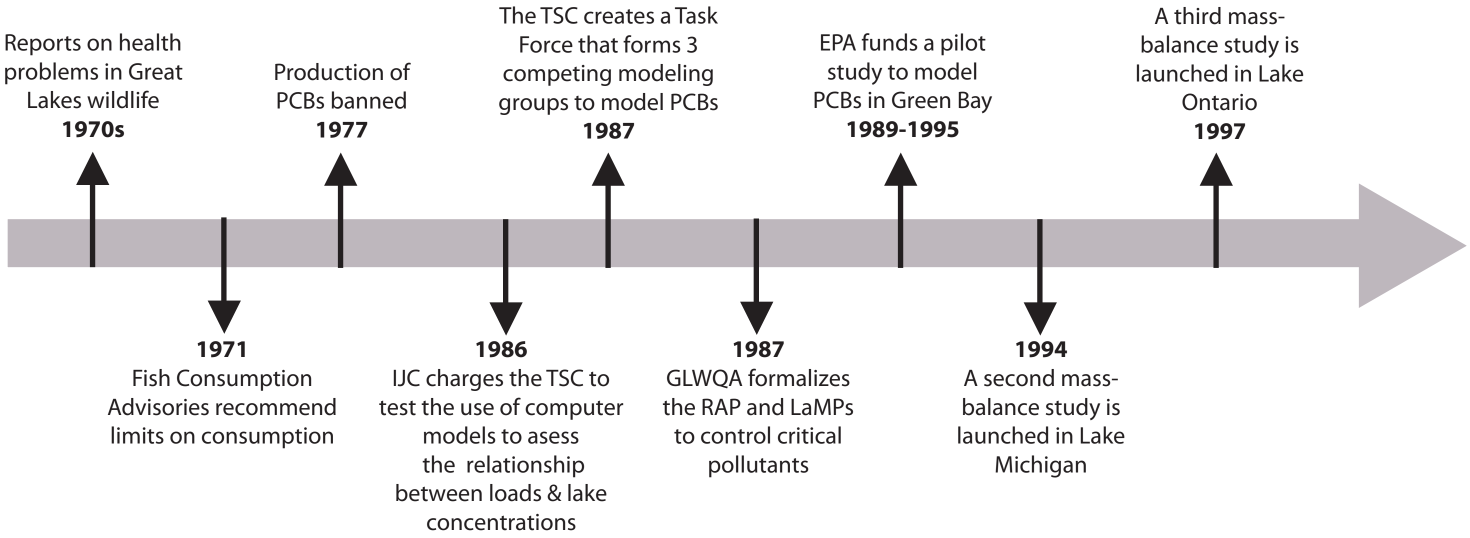
In 1985, the IJC's Water Quality Board organized a two-fold process to address chemical pollutants. The first step focused on identifying and evaluating human health effects of critical pollutants in the Great Lakes. The second step focused on quantifying, evaluating, and eliminating the sources of these critical pollutants. The Water Quality Board formed the Committee for the Assessment of Toxic Chemicals (Toxic Substance Committee), which recommended the development and use of computer simulation models "to provide the Board and other Great Lakes resource managers with the capability to test the impact of various management alternatives" (Report to the Great Lakes Water Quality Board by the Task Force on Chemical Loadings of the Toxic Substances Committee, 1988, p. 1).

In 1986, the IJC's Water Quality Board charged the Toxic Substance Committee to test the feasibility of using computer simulation models mainly to establish a relationship between chemical loads and their concentrations in the Great Lakes, including source identification and quantification via mass balance models. The Committee formed a Task Force that requested three different modeling groups to "prepare separate reports on modeling the fate of PCBs in Lake Ontario" (Report to the Great Lakes Water Quality Board by the Task Force on Chemical Loadings of the Toxic Substances Committee, 1988, p. 2). The three modeling groups were: (1) Rodgers and co-workers from Limnotech, Inc. (2) Connolly and co-workers from Manhattan College and (3) Mackay from the University of Toronto.

In 1987, the University of Toronto organized a workshop to compare the results of these modeling groups; the workshop concluded that models were useful in identifying data gaps, improving monitoring strategies and understanding the likely environmental impacts of regulatory decisions. In the same year, the Great Lakes Water Quality Agreement review formalized the Remedial Action Plan (RAP) process through which the U.S. and Canadian governments committed to preparing RAPs for the 42 Areas of Concern (AOCs) designated as the most polluted areas in the Great Lakes. The 1987 amendments to the GLWQA also included commitments to develop Lakewide Management Plans (LaMPs) for controlling critical pollutants. (Government of Canada & United States Environmental Protection Agency, 1995)

Two years after the Toronto workshop, EPA funded a pilot project to model the fate and transport of toxic chemicals in Lake Michigan's Green Bay with an emphasis on PCBs (1989-1995). In the pilot study, EPA collaborated with several other agencies. In 1994, following apparent success in Green Bay, a second mass balance study was launched for the entire lake. In 1997, a third mass balance study began, this time in Lake Ontario and in cooperation with the New York State Department of Environmental Conservation (NYSDEC).

Figure 3. Historical context and timeline for the Mass Balance (PCB) modeling effort



Key:

PCBs: Polychlorinated biphenyls
TSC: Toxic Substance Committee
GLWQA: Great Lakes Water Quality Agreement
RAP: Remedial Action Plan
LaMPs: Lakewide Management Plans

The case is interesting and informative for the purposes of our analysis for several reasons, including:

- This was the first large-scale effort to repeat the successes of the phosphorus reduction efforts, but its consequences in terms of management decisions were very different.
- Mass Balance Modeling of toxic substances was seen as a way to provide scientific and management support to the agencies and local communities charged with the task of initiating new Remedial Action and Lakewide Management Planning efforts. Subsequently the early efforts in Green Bay were seen as skills development for the TMDL program.
- The PCB mass balance project was meant to establish protocols and practices that could be used for modeling the fate and transport of other toxic chemicals in the Great Lakes.
- Although initiated under the binational Great Lakes Water Quality Agreement, Canadian environmental agencies did not actively participate in developing the strategy and models.
- Some of the modelers and managers had previously participated in the eutrophication modeling process and tried to apply lessons learned from that experience, particularly in organizing regular opportunities for modelers and managers to communicate.
- There were several public meetings during the stages of the Green Bay Mass Balance modeling work to present results of the work.
- The tools and techniques for measuring and reporting PCB concentrations including standards for setting and reporting levels of detection in different media can vary considerably among agencies and laboratories, complicating the reliability and increasing the uncertainty of PCB mass balance model results. The projects contributed greatly to development and standardization of analytical techniques and quality assurance/quality control protocols for toxics.
- The case exemplifies the need for collaboration between federal and state agencies in setting objectives and implementing management actions.

- The process of developing mass balance models has continued over the past twenty years via the TMDL process, creating many opportunities to learn from the experience.

In the other three cases that we reviewed (eutrophication, fisheries, and water levels), most of our interviewees emphasized successes and problems related to the policy decisions being made and how the models were used in the process. In this case, however, the emphasis was on the modeling itself: the peer review, the quality assurance plan and especially the ongoing involvement of the management agencies in the model development. As reported, during the Lake Ontario mass balance modeling effort:

New York State [DEC] and the EPA would periodically review the model and the model report and provide written comments and questions and suggestions to the modelers. And then they would also have workshops with the modelers that were involved. We would have workshops that involved a wider range of government agencies staff that would include managers. I think some of those were very useful in that there were some model simulations that didn't match some field observations, and when we had all the people in the room, we were able to identify some potential discrepancies between the model output and the field data, …so I think that was useful (EPM-1).

Similarly in a previous mass balance modeling in Lake Michigan, the process and model development were open for an extensive peer review.

In the management structure of the Lake Michigan Mass Balance, there was a modeling work crew that was created where the modelers literally sat at the table with the rest of us and the management structure to identify for us what their data needs were going to be, data quality needs, data management needs. So the process that we undertook then was to go ahead and develop our plan with a lot of people's input… That work plan [Lake Michigan Mass Balance Model] was peer-reviewed. We sent that out to hundreds of people, and we got hundreds of responses back, and then we built everything we could in and went back out again to everybody, and we got some better comments, and so after we did that about once or twice, we felt fairly confident. It also served another purpose. It worked in our favor because it had gone out to the public interest groups (EGP).

The modeling was being supported and directed by the U.S. EPA, but water quality permitting programs, the policy tool most likely to be affected by the results, are managed by the states under the U.S. Clean Water Act. It was important to get the states involved, but there was some reluctance from the state management agencies:

I think that New York State maybe did not feel like they had been included in the development of the model. The EPA was funding it. Once the model was developed, EPA [came] to New York State and said, 'We have this model; we want you to take this and set permits.' The New York State people were like, 'Wow, can we trust this model? And how did it do this? Is it calibrated?' So I think there was some reluctance for them to use it because ultimately it was New York State's responsibility to do this regulatory activity. I think that created some friction, and I think it was overcome at different stages, but definitely it was the issue at one point (EPM-1).

There was some public influence on the modeling process, particularly in framing questions that the model might be able to inform through scenarios:

Some of the input that we got was used for developing the scenarios that the models were going to run. People were asking questions like, 'When can we eat the fish?' Some of the input we got from the public we were able to factor into the design in terms of the scenarios that we were going to run (CLP).

Although there were many toxic chemicals of concern in the Great Lakes, PCBs took on particular importance because fish consumption advisories were driven largely by the presence of PCBs in fish tissue. Thus, the question became 'what can we do to bring PCB levels down to the point that we can eliminate the consumption advisories?':

The way the decision went [about which substance to focus on for the mass balance work] was because we looked to see what was driving fish advisories, which kinds of chemicals. Basically we knew that PCBs were driving fish advisories in the lakes, so that was an obvious one (EGP).

One of the most important outcomes of the modeling exercise was to show that the policy options then available to the agencies (removal of PCB contaminated sediments in Areas of Concern, further reductions in allowable concentrations of PCB in wastewater discharges, adoption of a policy of zero discharge) would not result in bringing the waters of the Great Lakes into compliance with Great Lakes Water Quality objectives for several decades. Both countries had already adopted policies that were likely to bring about significant reductions: a ban on production and new uses of PCB and removal and treatment of PCBs from hazardous waste sites. Great Lakes environmental activists were pressing for government action in the form of stricter regulations and aggressive remediation of contaminated sediments, particularly in industrial harbors and embayments, but the model results suggested that enormous sums of money could be committed with little or no impact on the environment: the vast majority of PCBs that were ever going to be in the system were already there, thus the rate of the system's recovery was not driven by new inputs but rather by the ability of the system to process historical inputs.

[The models] pointed out that if we eliminate all external loadings of Lake Ontario tomorrow, it will still be twenty years before fish get to the protocol concentration because of the legacy of PCBs. That was kind of a shock for the decision makers, believing it and understanding it. The other thing that they didn't like hearing was that the three biggest sources [were atmosphere, upstream and sediment]… none of which is there anything they could do about it. They wanted to hear, 'Just track down and shut off the point sources and you solve the problem for PCB' (GR).

So the thing that I tried to emphasize when I spoke to the public is that whatever we do, you are not going to see a response in a year or two. It is going to be ten or twenty years (EPM-2).

The fact that [the model] could tell us it is going to take twenty years or fifty years, we didn't feel there was anything else that we could do on our side to accelerate it. What else could we do? We are already doing everything we could do in terms of PCBs (CLP).

Wisconsin DNR was willing to spend a billion dollars forcing industries to clean up PCBs, [but] the results of mass balance showed that virtually no PCBs were coming out of industry. Well, it did come out of industry, but it came out 23 years before that, so it changed the perspective there (EGP).

The U.S. EPA made a major financial commitment to the mass balance modeling, mostly because the phosphorus models had been so successful in driving the policy response in the earlier eutrophication case:

A lot of that regulatory work that was done [in the Great Lakes] had basically been set off as a result of the modeling activity from the early phosphorus models that were run with the predictions. And that is why probably in the mid to late '80s [there was] the realization that the modeling construct worked. That moved GLNPO to develop the Green Bay Mass Balance project to step it up from nutrients into toxics, basically PCBs … We took confidence from the phosphorus stuff. I remember some of the discussions internally within GLNPO at the time saying, 'Okay, it worked for us for phosphorus,' and [after] multiple meetings and discussions, that is when the decision was made to step this up for PCBs for the Green Bay Fox River system (EGP).

There was certainly recognition that the structures of the PCB and phosphorus problems in the Great Lakes were different. There is no evidence from our interviews that there was an understanding that the problem structure could or should be a consideration in how the modeling and policy making processes should be undertaken.

The phosphorus issue for Erie was a very visible thing because you had the dead fish, you got the algae, you got the smell, the taste, and odor problems. It was a very real issue that brought a lot of people from all different levels together to say, 'We better fix this.' There is a shift that takes places when we talk of toxins because in most cases, you can't see those PCB molecules (EGP).

Initially, the EPA wanted to begin the toxic mass balance modeling project in Lake Ontario, the lake with the highest PCB concentrations. Such a project would require cooperation from the Canadian management agencies, but the Canadian managers believed that the process would require too many financial and human resources to address a pollutant whose point sources had already been reduced:

From our view, it was sold on the basis for guiding or informing management decisions in terms of managing PCBs in the lake. We [Environment Canada] had a lot of discussions internally, and we were very careful to say that we were not going to be tied to whatever the model tells us because we didn't see much utility (CLP).

How managers perceived the regulatory context can greatly affect the approach to modeling. As the mass balance approach moved to New York, there were clear questions about the value of the modeling approach:

Recently there is the Great Lakes Water Quality Initiative (GLWQI), which requires the States to adopt very low standards for PCBs, essentially non-detect, so when the subject for the need to do a TMDL for Lake Ontario would come up, New York State would say 'Why do we need this model and the TMDL because we adopted the GLWQI approach, and we have extremely low numbers, so we are not going to gain anything from using the model approach to setting limits.' So that was New York State's approach and this was five years ago … But I think overall, New York State now *thinks the model was very useful in understanding mass balance and PCBs in Lake Ontario. [It] helps us explain why it is taking so long for the Fish Consumption Advisories, why they are still in play (EPM-1).*

Unlike the phosphorus case, where the models helped the environmental policy-makers decide what needed to be done, in the PCB case the governments did not take immediate action. One possible explanation for this is that resources available for Great Lakes work had declined by the time the modeling process was completed:

We [EPA] are looking at using the results of the mass balance to help drive some of the decision making. The timing was such where we got a fantastic information base out of the mass balance but unfortunately, [with] the conditions we have right now in the Great Lakes basin, the resources aren't necessarily there to take full advantage of it (EGP).

While there appeared to be limited application of the modeling output for developing new policy initiatives, the model has had a significant influence on policy by discouraging ambitious and costly PCB programs that may have accomplished little. The experience likely contributed to the shift away from toxic chemicals as the central concern of the Great Lakes water quality community by the 1990s:

I think it [the model] did [influence policy in Lake Ontario], because it showed that PCB sources within the Lake Ontario basin are relatively minor, basically inconsequential to the levels in fish flesh in Lake Ontario. So it basically told us that there was not as much of a need to try to control those sources. If the model had shown that if we could turn off PCB sources on the Genesee River, the Oswego River and Black River, if we could do that, the fish will be safe to eat in five years, then I think we would have definitely devoted our attention to getting those last remaining sources. But basically it said that even if we turn off all the sources in the Niagara River, you would have almost no change because the sources in the bottom sediments were controlling fish flesh (EPM-1).

I think there is proof of concept out there for models. I think models work because, like I said about the Green Bay Mass Balance, some wrong decisions could have been made. For Lake Michigan, we could have made some decisions that may not have been the right decisions. Yeah, you may spend a couple of million dollars doing the modeling exercise, but at the end of the day, we may be many many million dollars ahead of the game by doing the right remedial programs or regulatory programs. (EGP).

In addition, the mass balance programs in Green Bay, Lake Michigan, and Lake Ontario led to a great deal of experience in modeling large ecosystems. Because the science and technology of modeling large ecosystems apparently progressed far more as a result of the mass balance experience than the measurable recovery of the Great Lakes from toxic contamination, some observers believe that the intention of the effort was largely academic.

Although less money was available for modeling in Lake Ontario, the team developed an innovative "building block" approach that built data collection according to funding availability.

We called [the Lake Ontario mass balance] the "mini" mass balance. We didn't have any where near the $15 million we spent in Green Bay. The idea was to start small, start simple, and build over time as resources allowed and as data could be collected to support the model. It was a good way to go, and actually our first year of our work was [spent] reviewing the modeling that had been done (GR).

An important aspect of the mass balance modeling experience was testing the concept of mass balance modeling as a tool for pollution management. The initial modeling in Green Bay was done as a "proof of concept," where the primary object was to determine whether models could profile the behavior of toxics in large lake systems. The outcome of the modeling exercise was a confirmation that modelers could in fact model such systems. The three-model 1986-1987 modeling exercise described above, called by some the "battle of the models," asked whether models could be used to investigate the fate of PCBs in the lakes. The battle of the models suggested that such an approach was feasible.

The Green Bay study was the definitive test. It was driven by scientific research questions. Management questions did not, in general, drive the design or the development of the model. Most of the $15 million spent on the Green Bay mass balance study went towards analytical chemistry, measuring PCB concentrations in water, sediments, and biota. Such expense probably would have not been necessary if the modelers' only goal was a management objective: to determine PCBs loads that would reduce PCB concentrations in fish to a certain acceptable level. However, the cooperative agreement to develop the Green Bay mass balance model required a peer reviewed proposal, which was reviewed on its scientific merits rather than its management objectives.

Conclusions

The Green Bay modeling effort provided valuable insights into mass balance modeling. The effort was subsequently repeated at a broader scale for Lake Michigan and Lake Ontario. The clean up of PCBs in Green Bay represented half a billion dollars in spending, thus the modeling expenditure of $15 million could be justified by the scale of remediation decisions at stake. Furthermore, successive modeling efforts in other lakes and rivers could be developed for a fraction of this original cost, including, the mass balance model for Lake Ontario.

While the mass balance approach has the potential to be applied to other chemicals, it has not been used in this way to date. There have been no other whole lake mass balance studies for non-PCB toxics in the Great Lakes system. For example in the Lake Michigan study, other chemicals of concern such as atrazine and mercury were not included or only partially analyzed. Oftentimes, data regarding the inputs and background levels of these chemicals in the water was not available and thus mass balance could not be modeled. As in the eutrophication study, this lack of coordination between efforts and opportunities points to the need to institutionalize and operationalize models so they can be monitored and improved and their applications extended to new areas of interest.

The Green Bay and Fox River mass balance models were used extensively for making remediation decisions in that system, yet this is not what they were originally designed for. The models turned out to be of great benefit to the managers, although they were initially developed as a research project. Thus in this case study, we observed an important role for research and development (R&D) and its potential for providing products for future management uses.

Indicators

Deliberative Effectiveness

The Green Bay mass balance modeling exercise, as it extended into Lake Michigan and then Lake Ontario, added a dose of realism about the ability of management actions to reduce in-lake concentrations and levels of contaminants in fish. The extensive deliberation among modelers, scientists, and managers meant that by the time results were presented, confidence in them was high and thus deliberation on policy was not diverted to questions of scientific validity as happened in our Fisheries and Water levels management cases. The modeling process clearly helped guide scientific deliberations about the behavior of the system and the effects of PCBs in it. The process contributed to discussions about the state-of-the-art technology, human understanding of pollutants in water systems, and the feasibility of models to represent this behavior. In addition, this modeling process contributed to deliberations on the Lake Ontario Lakewide Management Plan.

There is some evidence, however, that by investing large resources into understanding the fate and transport of PCBs, a class of compounds already banned in the Great Lakes, the EPA diverted attention and resources away from keeping other potentially harmful pollutants out of the lakes. Public policy on PCB management had already been set at zero discharge. Public deliberation needed to be focused on achieving zero discharge rather than on determining how long detectable levels of PCBs would remain in the open water.

Explanatory Effectiveness

Mass balance models highlighted the importance of contaminants already in the system (legacy contaminants) in planning for remediation activities. This disappointed those who had hoped that reducing or eliminating point sources would solve the problem but provided a better understanding of how the system processes pollutants.

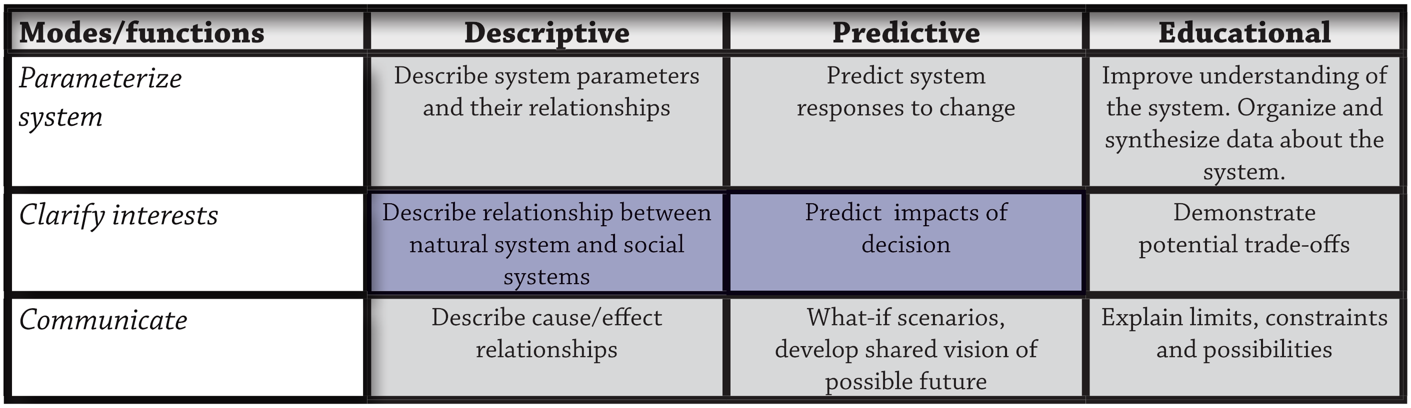
Policy Relevance

The value of this modeling exercise is the demonstration of how important the historical control of PCBs point sources might have been. This modeling effort demonstrates the value of controlling the point sources of emerging chemicals given the possibility that these chemicals may have a long legacy, similar to that of PCBs. Furthermore, this modeling exercise demonstrated that the system was responding to historical PCBs loads through sediment feedback and ongoing non-point source loads that had not been addressed, such as atmospheric loads and landfill leaching.

Functions vs. Modes Matrix

The following matrix of three functions (descriptive, predictive and educational) and three modes (system parameterization, interest clarification and participant education) represent a summary of the most relevant uses and functions of modeling ventures for this synthesis paper. In this section we compare the performance of the PCB mass balance modeling against the matrix of functions and modes.

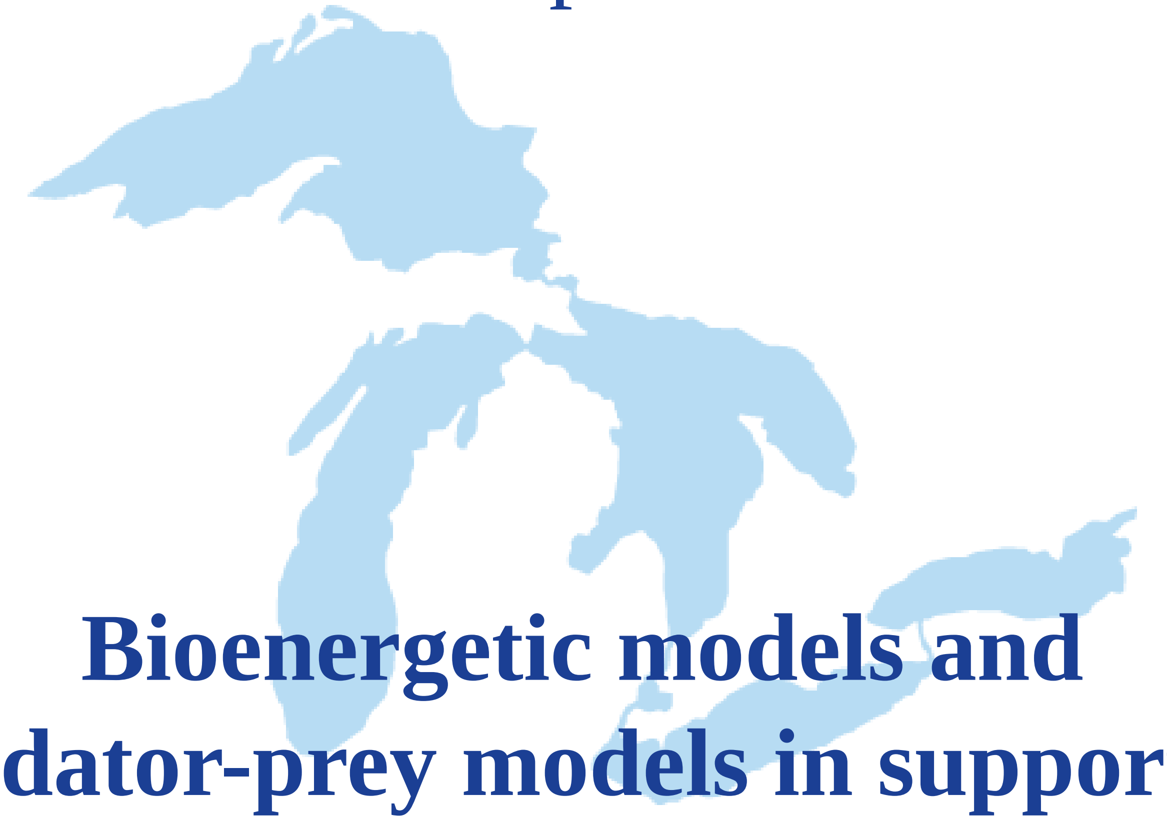
Figure 4: Mass balance models: *Functions vs. Modes Matrix*



Modes/functions	**Descriptive**	**Predictive**	**Educational**
Parameterize system	Describe system parameters and their relationships	Predict system responses to change	Improve understanding of the system. Organize and synthesize data about the system.
Clarify interests	Describe relationship between natural system and social systems	Predict impacts of decision	Demonstrate potential trade-offs
Communicate	Describe cause/effect relationships	What-if scenarios, develop shared vision of possible future	Explain limits, constraints and possibilities

The areas where the PCB mass balance modeling effort fulfilled its performance goals are represented in gray. The modeling exercise was conceived as a scientific exercise to increase the understanding of the behavior of PCBs in the system, and it did. The modeling exercise made scientists aware of the importance of PCBs in the sediments and made them realize the tradeoffs between costs and benefits of implementing remediation plans. Nevertheless, some interviewees argued that the modeling captured funding that could have been used elsewhere and that the benefits of the modeling from a managerial point of view could have been greater. The areas where models could have been improved are represented in blue. For instance, models could have been used for (and may still be developed for) chemicals other than PCBs. Regardless of their limited application, the models increased the understanding of the causes and effects of new discharges of PCBs in the water and the realization that legacy contamination of the sediments by PCBs was the real problem.

Chapter 4



Bioenergetic models and predator-prey models in support of stocking decisions in Lake Ontario, 1992-2000

In the early 1990s, fisheries biologists and resource managers reported that ecosystem trends suggested the possibility of a future crash of salmonid populations in Lake Ontario. These findings raised alarms within the two agencies responsible for managing the Lake Ontario fishery: the New York State Department of Environmental Conservation (NYSDEC) and the Ontario Ministry of Natural Resources (OMNR). The warning came from both agency- and university-based scientists, and it was informed by an increased scientific understanding of the complex food web relationships that determine the size and condition of Ontario's large predator fish.

Historically, Lake Ontario supported three top predatory fish: Atlantic salmon (*Salmo salar*), lake trout (*Salvelinus namaycush*), and burbot (*Lota lota*) (Christie, 1973). Deforestation, pollution, algal blooms, commercial over-fishing and changes in diet (producing thiamine deficiency) reduced the population of Atlantic salmon (Ketola et al., 2000). Over time, several exotic species entered and expanded throughout the system via canals, ballast water, and other means, further threatening the native fishery. These invaders included alewives (*Alosa pseudoharengus*), rainbow smelt (*Osmerus mordax*), and sea lamprey (*Petromyzon marinus*). Sea lamprey parasitism contributed to the collapse of lake trout populations, and in the absence of predators, the alewife and smelt populations increased to the point that die-offs due to food competition were common throughout the 1960s and 1970s. From the 1960s through the 1980s, lake trout, Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), brown trout (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*) were stocked to fill the ecological and economic gap left by the extirpation of the original populations of Atlantic salmon and lake trout. Sea lamprey control programs allowed recreational and commercial fishing to rebound in Lake Ontario. However, it was generally believed that the salmonids did not reproduce well in the wild, and that stocking was required to maintain the fishery. By the 1980s, this had become regular practice (Government of Canada and United States Environmental Protection Agency, 1995).

By the 1980s, researchers and managers were discussing the sustainability of Lake Ontario's recreational fishery and the capacity of the system to maintain the numbers of fish being stocked at that time, especially given the reduction in nutrient loads to the system (a successful response to the pollution control programs of the 1970s and 1980s). Fishery managers' concerns became urgent when the collapse of Lake Michigan's Chinook salmon fishery[1] was linked to a decline in prey (alewives). Prompted by these events, in 1992 the Lake Ontario Committee (LOC) of the Great Lakes Fishery Commission formed a binational Task Group to gather and evaluate the Lake Ontario stocking program[2] (Task Group for Technical Evaluation, 1992).

The Task Group eventually reported that the prey community was being stressed and recommended that New York State Department of Environmental Conservation (NYSDEC) and the Ontario Ministry of Natural Resources (OMNR) reduce the number of fish being stocked. In 1993, the NYSDEC and OMNR reduced stocking of Chinook salmon and lake trout. The "Sustainability of Intensively Managed Populations in Lake Ecosystems" (SIMPLE) model was developed by Canadian and US scientists to look at the relationship between these popular sport fish and the prey they consumed, mostly alewife and smelt. The primary management question focused on how many healthy large sport fish could be sustained by the existing stock of prey and what might happen to the population and condition of the sport fish if the prey population declined. Such declines might occur due to reduced productivity of the lake as a result of further pollution control efforts, extreme weather, excessive predation, or a combination of these factors. The model showed the salmonid fishery was vulnerable to changes in the alewife populations (e.g., over-winter survival of alewives). The model also included information about feeding rates for each species of sport fish, thus making it possible to achieve the same reduction in predation pressure through different mixes of species being stocked.

Following public consultation, the annual stocking of Chinook salmon was reduced from 3.4 million in 1992 to 2.1 million in 1993, to 1.5 million in 1994 and to1.6

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[1] Chinook salmon were infected with bacterial kidney disease (BKD), a sign of the fish population being stressed.

[2] The Task Group was charged with four objectives: (1) Describe the current status and health of the Lake Ontario alewife and rainbow smelt populations, and factors influencing them. (2) Determine if the Lake Ontario alewife and smelt populations can be sustained with existing levels of predations. (3) Project likely changes in the Lake Ontario fish community following fishery management options designed to stabilize a declining alewife population. (4) Summarize pertinent data and conclusions (Task Group for Technical Evaluation, 1992).

million in 1995. Lake trout stocking was reduced from 2 million in 1992 to 1 million per year in 1993-1995 (Personal conversation with Robert O'Gorman, October 2007). The 1992-1993 stocking decision making process was characterized as an open process, encouraging extensive public participation, including anglers, charter boat operators, commercial fishermen, and representatives from small businesses, local governments, and environmental groups, with charter boat captains being the most active group (Report from the Lake Ontario Technical Panel, 1996).

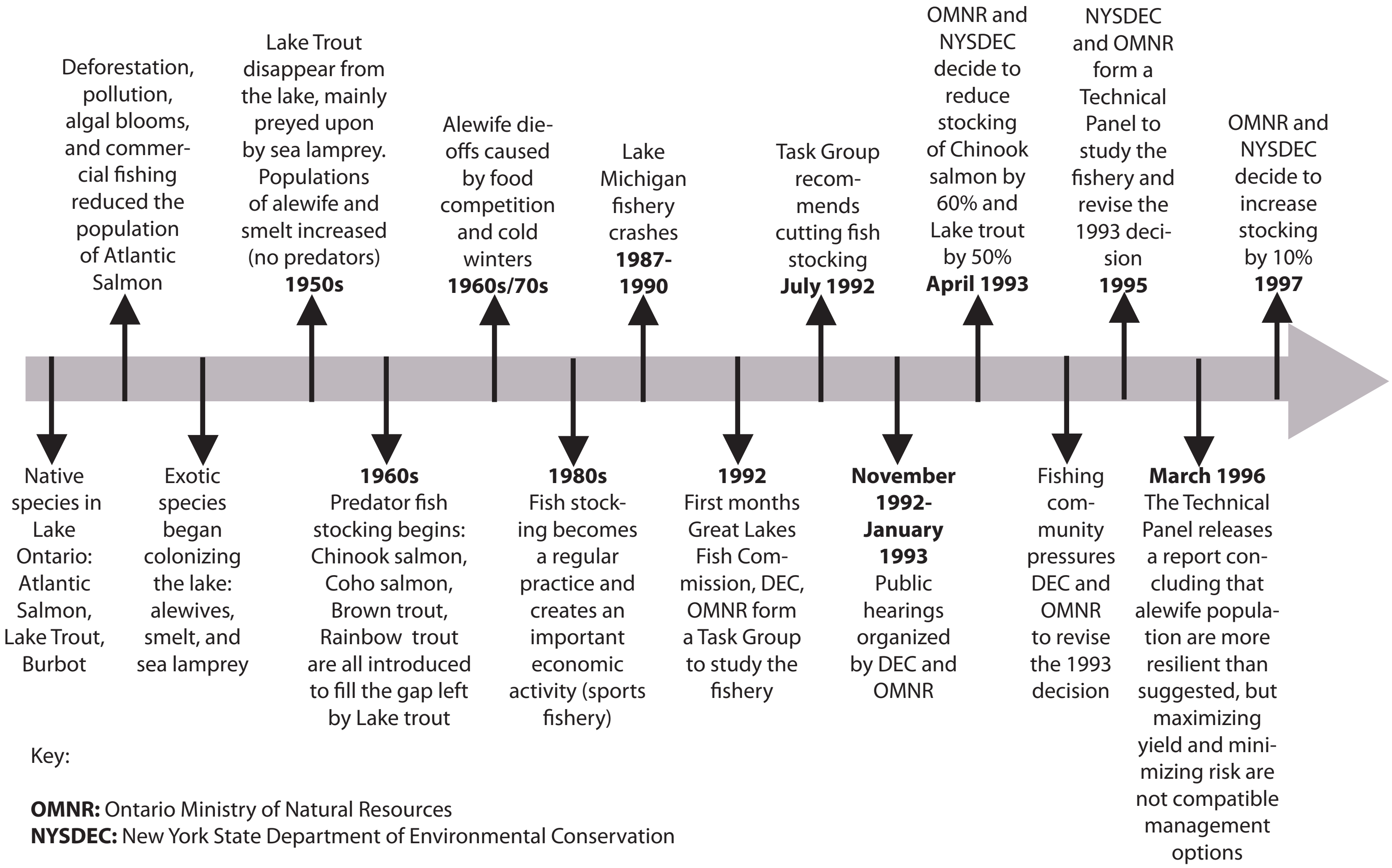
In 1996, the NYSDEC formed a Panel of Experts, including two invited representatives from the charter boat industry, to review the 1993 decision to cut stocking and to evaluate the status of prey populations (figure 5). This panel used two models to evaluate the 1993 decision: a Lake Ontario Ecosystem model (taking into account phosphorus loadings and chlorophyll *a* levels) and "a risk analysis of a food web model centered around alewife population dynamics," called the RISK model (Report from the Lake Ontario Technical Panel, 1996, p. 5).

The models included three more years of data (1993-1995) and stochastic elements meant to represent weather and other "unpredictable" events. Based on these models, the management agencies increased stocking by 10% from the previously reduced levels, relying on a conclusion by the Lake Ontario Technical Panel that "alewife population is more resilient than previously suggested" (Report from the Lake Ontario Technical Panel, 1996, p. 8). This process was not open to all citizens; nevertheless, two representatives from sectors that had interests in stocking regulation were invited to observe.

This case is interesting and informative for the purposes of our analysis for several reasons, including:

- It is an example of the ongoing shift to ecosystem-based management of fisheries, which is highly dependent on modeling of complex ecosystem dynamics.

Figure 5. Historical context and timeline for Lake Ontario fisheries management modeling effort



Key:

OMNR: Ontario Ministry of Natural Resources
NYSDEC: New York State Department of Environmental Conservation

- It represents an attempt to use models both to inform management decisions and to communicate to stakeholders in a public forum.
- It involved an early attempt to achieve shared understanding of problems and solutions by educating stakeholders in the most current science of ecosystem dynamics through the use of model simulations.
- Scientists came out of their labs and classrooms to interact directly and through their models in a form of policy-relevant public education.
- It involved significant shorter-term economic needs and longer-term ecological risks that were at odds with each other, a sustainability conundrum faced in a great many decisions and one that is destined to recur as long-term ecological risks are better represented in models.
- Perhaps most importantly, the process was carried out over nearly a decade, first using the SIMPLE model and then later reevaluated with a more sophisticated model (RISK), with additional data and with a process that was based in part on lessons learned during the first effort.
- It has come to be seen by the participants themselves as a rich resource for lessons to be learned.

Widely regarded as a failure of process (primarily on the U.S. side) and for some a failure of outcome, participants nonetheless talk about the experience as having been a major learning experience. Surprisingly, they mostly agree on what lessons were learned, even though they agreed on little else at the time. One participant, a modeler, sums up their experience thusly:

> *I think the way the SIMPLE thing went was not successful. Part of the problem was communication between stakeholders and the management agencies. It has led to a decade of angst. It was not good. I don't think it was bad science. I think it was a communication problem. The whole way we did it was very naïve. I certainly wouldn't be as naïve going into it. I would lay the ground rules a lot better. And also that first SIMPLE model, the way we went about it was -- and I am not sure if this was our [modeler's] intent but maybe it was the managers' intent -- it appeared to the public that we were saying, 'We want to reduce stocking and this is why and here is the model.' And that is putting the decision before the process. You have to do it the other way around. You have to put the process first. You have to say, 'Here is what we know about the ecosystem. Here is how it is working. Here is what we don't know, and here is where we think it is going. Now, what do you want to do?' And I think that would permit a more open dialogue rather than everybody drawing a line in the sand and saying, 'Okay, we are on this side, and you are on that side' and throwing rocks at each other (TG-2).*

Ecosystem-based management

The concept of ecosystem-based management, like most reforms, emerged as a critique of existing management practice. The critique was that conventional natural resource management had long been directed at maximizing those components of the ecosystem that are most economically valuable rather than being directed at sustaining the underlying relationships that keep an ecosystem healthy and productive. The new emphasis on systems and complex food webs was made possible by advances in computer modeling, which in turn, created an increased demand for evaluating and continually improving fisheries models. By the 1980s, scientists were able to trace and describe in great detail the Lake Ontario food web as well as the specifics of how food energy was allocated between growth, metabolism and activity. This knowledge allowed scientists to begin to aggregate various process models into a systems model that could be used to forecast the future population and condition of prized sport fish. By the mid-1980s, scientists put these pieces together. In addition to the standard algebra of recent years' stocking numbers, reports became available for catch per unit of fishing effort, trawl results, and numbers of fish returning to spawning sites, so that managers were now being asked to add to their management tools detailed ecosystem modeling. This gave managers the opportunity to respond to early warning signs in the ecosystem and to be able to prevent future problems by adjusting management strategies. This was largely viewed as an advance in fishery management capability, about which most managers were enthusiastic.

In the mid-1980s, to many of the fishery scientists and managers, their reading of the ecosystem cues strongly suggested that prudence warranted a significant reduction in stocking levels, particularly the stocking of the most voracious predators, Chinook salmon. The primary food for these Lake Ontario salmonids were alewife, and by 1992, the size and abundance of alewife were in decline. In addition, scientists noted that a prey fish decline in Lake Michigan was related to a recent severe outbreak of a bacterial kidney disease (BKD) linked to nutritional deficiencies.

The SIMPLE model was considered at the time to be state-of-the-art for evaluating predator-prey interactions, and thus an ideal method of investigating the stocking question (Jones et al., 1993). Previous computer models had focused exclusively on either predator demand (Stewart et al., 1981) or on prey population dynamics (O'Gorman et al., 1987), but the SIMPLE model integrated both and also explored multi-species responses (Jones et. al., 1993). The objective of the SIMPLE model was to calculate the relationship between prey abundance and numbers of salmonids in Lake Ontario. Relying in part on the results of the SIMPLE model (driven by rates of consumption of alewife and salmonid survival rates), the Lake Ontario fisheries managers concluded that a dramatic reduction in stocking levels, 50 % or more, would give the fishery its best chance and bring the ecosystem more into balance.

This new confidence in the power to forecast future conditions came at the same time as economic stakes in the Lake Ontario fishery were increasing. A booming recreational fishery drew anglers from near and far, creating new economic opportunities for lakeshore communities. The most heavily invested and therefore the most vulnerable to change were the charter boat captains, who own their boats and work as hosts and guides for recreational fishers. The abundant salmonids, in particular the large and powerful Chinook, drew throngs of anglers that kept the captains busy and the industry growing. If there were to be fewer Chinook available per boat, some in the charter industry predicted that operators would go out of business. The more casual recreational anglers tended to see the charter captains as the professionals with tested experience on the lake, and charter boat captains were seen as representing the interests of recreational anglers as well. The captains for their part were interested in sustaining the booming fishery and were willing to make what they saw as sacrifices to protect their business in the future, but they needed to be convinced that the threat was real. They were not seeing evidence in their own fish catch, and most expected and certainly desired to see the fishing boom continue.

In many ways, here was an ideal case for exploring the value of models as ecosystem education, decision support, and collaboration tools. The two main groups (managers/scientists and charter boat captains) had different sets of experiences and skills and different perspectives and ways of understanding the lake and its fish populations, yet they had a common interest in protecting the fishery. Both groups possessed extensive knowledge of and direct experience with the lake. Each could learn from the other and were mostly motivated to do so. As one modeler described it, the ideal was that a model would become:

> *…an objective statement of how the system will behave. Then they could concentrate on their different points of view, and then we will let the model go forward with the run and see the kinds of uncertainty it generated, [if it was] a big response or a small response. So they were able to ask a lot of questions and gradually the idea was that in the round table process, there will be a consensus that we will begin to build (MF).*

Our interview data suggests that the opportunity existed to advance collaboration between these groups for ecosystem-based decision making, but the opportunity was mostly lost at the time. As one modeler noted:

> *We took the SIMPLE model out to the public and tried to sell a management decision with it, and it just turned out to be a bomb. It blew up in everybody's face (TG-2).*

In the eyes of the managers in particular, what had started out as a progressive experiment in using models to educate the public about trade-offs ended up making the managers more reluctant to experiment with models in decision making again:

> *Managers are certainly reluctant to take models like that out to the public anymore, even though I think they [the models] are better. I know they are a lot better now, but they are also more complex which increases the difficulty of explaining them to the public that is largely ignorant of how these things are put together and the uncertainty around them. It is a difficult thing to explain (TG-2).*

At the same time, the interviews also suggest that many participants, managers, stakeholders, and modelers drew similar lessons from the experience, and therefore, the case can yield many insights for future efforts at using models as ecosystem-based management tools in collaborative, participatory decision processes.

Policy analysis and policy process

What emerges from the case is that while a great deal of attention was placed on using the SIMPLE model to communicate expert opinion, there was little attention paid to developing a process for involving the public in the decision. The major decision, to reduce consumption by predators through reductions in stocking, was made as a result of the scientific deliberations, informed by the modeling. The question before the stakeholders was not whether to reduce stocking, but instead the best, most politically acceptable way to allocate reductions among the several species of popular sport fish, each with its own community of enthusiasts. This confused the fishing community who believed they were going to learn from the scientists but also that they would participate in the decisions about how best to sustain the fishery.

[I wanted to] learn as much as I could. It was about trying to understand the fishery, the ecosystem. I looked at the whole thing as a learning process, and then to be able to play a part in some of the meetings where there was my input in the decision process, that was a blue bird [an exciting opportunity] (FS)

According to one observer, the agency scientists and managers saw themselves as embracing public participation because they were inviting stakeholders in to explain to them the reasons behind their decision:

DEC felt that this whole process of making this decision, the public meetings, all the way and up through when the decision was actually made, was a triumph for them simply because they went through the process of engaging the public. They presented the information and they also made a decision based on the best science available, which was true at that time. And in so doing, they didn't lose any power or credibility in making the decision because my experience has been during any process in which the public is involved in the decision making program, the department is happiest when they have full control over the process. And regardless of what the public says, they are going to do what the managers feel they are going to do (PE).

The managers seemed to fear that the fishing community, or at least that part of the community most likely to become involved in the process, could not be convinced of the need to reduce stocking to prevent a collapse in Chinook salmon population as experienced in Lake Michigan. They saw the models as a way of gaining cooperation from the angling community.

"They [DEC] were certainly worried, you know, if they made a decision they were going to have to have something to back it up in terms of the science because the stakeholders were going to want to continue to stock and never stop" (TG-1).

While the model described predator/prey relationships and clearly warned of significant changes in the forage base, it was not used effectively to help develop a common understanding of the problem. There was never an attempt to draw on the knowledge of the anglers and charter captains to help characterize important aspects of the system dynamics in the process of designing the model. According to a Sea Grant specialist who observed and participated in the process:

Basically at that first stocking decision making process, two options were presented to the public: status quo or stocking reduction. The public had to focus on what might be acceptable to them. The first iteration of the model was put together solely from fisheries management and research input, and as I said, it was kind of tweaked. But the information wasn't really presented like 'Let's get together and talk about this, and we will learn from each other.' It was basically more like an authoritarian approach in which 'Here is what is going on and here is the result of the model. We are looking for your input.' There wasn't a lot of that give and take. There was in the next iteration of the stocking discussions several years later, but during the first one it was more an authoritative thing" (PE).

A member of the fishing community came to the same conclusion:

When they [DEC] said they were going to have meetings [where] they were going to present problems and solutions open to discussions, that was not the impression I took home with me. It was, 'Here is our problem, and here are our solutions. What do you think of them? And by the way we don't really care what you think of them'… We didn't participate so much in this discussion as listen to it. They presented the information to us, but they weren't really concerned about what we said. That they gave us seven choices, don't believe it. That is not true. None of the choices were acceptable to the charter industry or to the stakeholders, none of them, but that is all we had. It was chaotic because everyone had an agenda. I mean, you put seven or eight different areas together and you have seven or eight different ideas of what you should be doing. That is not concurrence; that is chaos, and that is what this was (BC).

At that Fisheries Congress Meeting, the DEC senior official got up very early on and conducted what I think is best called a fish auction. 'How many steelhead would you like?

Would you willing to give up this? If we add this many Chinook, can we take back that?' I think it hurt the rest of the process. It would have been a smoother process if that individual wouldn't have done that. Probably it would have been a more open dialogue, and I don't know if the outcome would be any different, but probably it would have made a better meeting (FS).

Instead of a fish auction, the fishing interests hoped to explore, with the model if possible, options other than an immediate, large reduction in stocking:

Instead of reducing the stocking totally, if you reduced it every other year, if you alternated years, then you will always be in the middle of three year cycles, and you will be able to move more quickly to control a bad situation. I don't know, maybe that is over simplistic. I don't know all the environmental problems (FSC).

Several of our participants expressed that they had wanted to use the process for their own learning, but it was not designed that way. Some pointed to successful experiences in other parts of the Great Lakes where they used what the participants called "Red Flags Scenarios"[3]:

Michigan went through an exercise where they presented Red Flag Scenarios. I think they, the Michigan DEQ, did a good job marketing it with their stakeholder community. So when they went through the '99 or 2000 25% reduction, everybody was pretty well on board with that, and when they went to the last one, which was this spring, everybody was pretty well on board with that because they had a reasonable objective. They set the parameters, and it's like, 'These are the conditions in which we need to reduce stocking' (FS).

From the education stand point of view, the advantage that I see of that [Red Flag Scenarios] is that it tends [to get] the stakeholders to look at the big picture … They are looking at various food web indicators which forces the stakeholders to acknowledge that it's more complicated (PE).

I think it [a Red Flag Scenario] works well because instead of throwing some obscure set of formulas off the wall that I wouldn't have a clue of what you are talking about, you got a set of ten criteria up there that even a dummy like me could understand (FS).

We consistently heard that the fishing community wanted to learn from the science and the models, but there was little opportunity to do that. The so-called Red Flag Scenarios basically asked fishermen what signs they would look for and understand as suggesting that the fishery was in trouble. This kind of group process can be used to help develop a common set of indicators that could conceivably be integrated into the model and could create a sense of ownership and co-responsibility between agencies and the fishing community. Furthermore, it involves managers and the fishing community in a process of joint fact finding to assess the health of the ecosystem.

The Canadian experience appears to have been quite different, according to a Canadian participant whom we interviewed. (We were not able to interview members of the Canadian sport fisheries community.) To this participant, the U.S. process appeared more adversarial.

I found that the public consultation in New York was more adversarial in that there had to be a legal-type system where you have to argue for a certain case. You would present evidence for that case and nothing else. It was up to the other side to present the other side of that case, and they would present evidence for that side of the case, and nothing else. It was more like two legal arguments going back and forth, and it was quite clear that there had to be a winner. Somebody had to be right and somebody had to be wrong. There was even, I would say, a disturbing development at some of these meetings where agency people, meaning New York State agency biologists, who were the most knowledgeable people of the system, were not allowed to offer their opinions or comments while these deliberations were going on. They were basically told, 'These are public discussions and limit your opinions.'

On the Canadian side, it was not perfect either, but there was more of an attempt to arrive at a consensus, and there was more, in my opinion, open discussion. It wasn't clear that there had to be a winner and a loser. It was more that we are all trying to achieve the same thing. We are trying to achieve a sustainable fishery, and we had some decisions to make, and there were some risks associated with those decisions, and some potential benefits associated with those decisions, and we have to sort of come to some agreement, or at least sort ourselves into opinions. We might not be able to come

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[3] The Red Flags Scenario uses ten indicators or "red flags" to assess the status of the ecosystem. These are: 1) Harvest information (harvest levels, effort, catch rates), 2) Index of abundance (open-water survey), 3) Reproduction (historic estimates), 4) Growth (survey, master angler awards), 5) Ratio (historic and open–water survey), 5) Ration (open-water surveys, historic), 6) Forage abundance (bottom trawl, acoustic/midwater), 7) Temperature (surface water index), 8) Fish health (visual signs, percent water, BKD tests), 9) Maturity schedule (open-water survey, creel), and 10) Age composition (Creel, open-water survey) (Great Lakes Fishery Commission, 2005)

> *to an agreement, but we have to recognize that we share the same kind of information and try to come up with our own understanding of what is going on, and ultimately the government has to make a decision. They are responsible for the resource, so they will make the decision. But they want the public to understand what is at risk and what the options are, and they want to hear from the public what their opinions are and what their understanding is. There were some commonalities between the Canada and US experiences, but I felt that there was a cultural difference. The US was more adversarial (SMC).*

It is tempting to speculate why. Canada has much more experience with what are called "roundtable" processes in which a variety of stakeholders are brought together to discuss a policy issue. It would seem that the use of models as a tool for collaborative deliberation would be more advanced in Canada and other parliamentary systems where bureaucrats have considerably more discretionary authority and seldom face the prospect of litigation. In the U.S., individual citizens and corporate actors have more developed rights to challenge decisions in administrative and civil courts. Participants in collaborative, roundtable-like public processes in the U.S. may find that binding decisions rarely result from such processes. They may determine that it is better to pursue one's interests instead in U.S. state and federal legislatures or in the courts which are better able to direct agency actions than are the legislatures and courts in nations like Canada, with parliamentary systems. Further research will be needed to explain what our participant called the "cultural" difference in the U.S. and Canadian experiences.

Another interesting theme that emerged from our interview data was the effect of the three-way relationship between managers, academics, and the fishing community. The emergence of academic fisheries biologists and modelers as active participants in fisheries management is a relatively new phenomenon. It may in part result from the rapid changes in technology that occurred long after most fisheries managers completed their training, the aging of the fisheries managers, and declining numbers of fisheries professionals working in the agencies. By the 1990s, the agencies had come to depend on the academic scientists more and more, and a strong working relationship had developed. However, the stakeholders tended to view the academic scientists with suspicion. Although there is tension between the fishing public and the fisheries agencies, as there always is between regulated industries and their regulators, there was also a long history of working together and understanding each other's roles and responsibilities. The influence of the university-based scientists added a new element that needed to have been planned for:

> *There was a very close tie between the fisheries managers [and] the researchers. They routinely met on an informal basis in other meetings, and the level of cooperation in terms of data sharing was incredibly good. Very cooperative atmosphere. The sport fishing community, the public, the stakeholders were less than supportive of the scientific community, much more so than their feeling toward the fisheries managers. [It] just seemed to be, when the researcher presented this modeling approach, it just really aggravated a lot of dissent between stakeholders and researchers (PE).*

Despite this level of cooperation, there were complications in the relationship between scientists and managers, primarily in terms of who was to control the process and especially, the data and how it is used. As one scientist explained:

> *We are in the era where we don't have enough people in the agencies to develop that, so we have to do this in partnerships. The dance between the academics and the agency people is very delicate. It's not that they [managers] are unwilling to do it, distrust the models per se, but they've got to worry about the process because you have people like me [a modeler] giving away the model to the commercial fishermen and making a mess with them in a court case [referring to a different situation where a model developed by him was misused in court] (MF).*

Nevertheless, the resistance and skepticism of the public to the process united managers and modelers even more. The fishing community attacked the model. Since the model, with its simplifications and uncertainties, had not been vetted with the fishing community, it was an easy target. What appeared to managers and scientists as a real advance in decision-support models came across to the fishing community as flimsy evidence on which to make such important decisions. The choice of acronym, SIMPLE, did nothing to inspire confidence. Elsewhere in the literature on modeling and decision making and in this report, the trade-offs between simplicity and complexity are discussed (EPA-SAB, 2006; Jakeman et al., 2006; Felleman, 1999; Modeling Task Force, 1987; Scavia, 1977). Sometimes simple models can best inform the policy decision and facilitate the policy process. In this case, however, the SIMPLE model may indeed have been too simple, missing some important ecosystem variables and factors of stochasticity:

There was no element of factoring in variability, you know. The estimates of alewife population, it was strictly a deterministic approach to modeling the situation. And also very importantly it did not factor in changes in nutrient levels going into the lake, so it was strictly predator/ prey, not much else… It [the SIMPLE model] was basically, 'Here is the curve trend of the alewife population and here is the number of predators out there to eat. Now if the alewife population continues to decline below a certain point, the fishery will collapse' (PE).

In the first iteration of the process, it appeared that the agencies (NYSDEC and OMNR) were using the model to convince the fishing community of the validity of their arguments. Furthermore, they failed to communicate the uncertainties in the SIMPLE model:

I don't think there were confidence limits or anything like that. I can't recall anything like that. It was just 'based on the input of the model, here is a likely scenario.' I think that model [SIMPLE] was a good effort to try to piece things together, but the model's limitations … weren't presented adequately in the public discussions" (PE).

So the models were helpful in providing a way of vetting the policies. They weren't terribly helpful in deciding what level of cut to do because there was just too much uncertainty (MF).

In the SIMPLE model, we weren't using terms like uncertainty. I think it was more presented like, 'Well this is the model and this is what is going to happen.' That was, looking back, certainly not the way to present it. But we didn't have things like error bounds around it or anything, although we had it set up like a gaming system so people could tweak it and put in different inputs, 'If you do this what might happen?' But back then I don't think the computer technology was set up to deal with something like uncertainty analysis and running various simulations and getting a range…We didn't have that computing power available on our desktops back then (TG-2).

According to the fishing community there seemed to be a sense that admitting and describing uncertainty would be to show weakness and leave the fish managers vulnerable to criticism. The one example of managers attempting to explain the uncertainty led to disappointing results:

Where I did get [the creator of the model] to concede was when I said to him, 'Okay I understand that you had to use these numbers, but you are going to speak to 300 or 400 people in this meeting. Now, would you do me a favor and tell them that the accuracy level of this model is about the accuracy level of a weather model predicting weather in Russia a week in advance?' And he did say that, and I felt really good about it. I understood what that meant and probably five other people in that room that weren't professors understood but we lost a lot of people anyway (BC).

Furthermore, a little display of vulnerability may have helped.

I think that models are great, but because I was in an industry that used models, I know what you can do with them. They are very powerful instruments. I don't think that the DEC had an agenda, but if you don't present the model correctly, you are going to be perceived as trying to get one over on us again. That is the problem with the models. But if you say, 'Hey, we don't know. We don't have an answer here. This is our best guess,' you show vulnerability, [and] it is okay, so by all means let's make some more models (BC).

A modeler noted the importance of presenting the model and sharing its limitations with the stakeholders.

Present the model with all its flaws right up front, and then let the stakeholders make the decision. I mean that is basically it. And you have to have people, communication experts, who can communicate this highly complex scientific jargon to the layman. You have to be able to get your message across, but you cannot have an advertising agency trying to sell the public on making the decision you want. You have to sort of [say] 'This is what we know. This is how the model works. What do you think? And here is our uncertainty.' I think the uncertainty term is a nice one to use with the public because that was a great bone of contention when we presented that model because we only had one output (TG-2).

Years later, a more complex model, known as the RISK, garnered more confidence from the stakeholders and led to reevaluating and increasing stocking levels by 10%. According to one of our informants, one of the reasons that the second process seemed to work better than the first was that the model was *not* used as part of an open and public process. Instead from the beginning, representatives from the fishing community were invited as observers during the Technical Panel's deliberations. The same mistakes were not made twice:

The role of models in the second one was kind of downplayed a bit. In other words, I don't really think there was a lot of exposure to the public. I don't really remember a lot of the public meetings focusing on the role of the model. It was presented, but not as the focal point. Instead it was more, 'We want to hear from you, you stakeholders out there. You *heard from us.' [There] was a lot more effort paid to soliciting public input and trying to balance that in the decision making. So the whole biological model was there, but there was a lot more attention by fisheries managers in that process to engaging the public and incorporating their input into decision making, which was not done during their first go around in' 92,' 93 (PE).*

The concept of a "model" can be very different depending on one's experiences. Before undertaking a participatory effort using models, these notions need to be explored. In this case, some of the participants had engineering experience. One of the managers remembered a particularly illuminating moment when talking to a member of the fishing community:

I remember one meeting in particularly when you can see a light going on in his head and he realized we have nowhere near the information that he does when he is working with engineering. I mean [when] you are building a bridge, you know how much weight your steel can take, down to the third decimal place, what expansion and contraction materials you have, and everything you know. We had no idea. We had this wild estimate of prey fish out there that we ramped up with patrolling surveys with error bars around that. [He must have thought,] 'My God, people are crazy trying to manage the system this way' (TG-2).

Over time, the fishing community realized to a certain extent the difficulties modelers face when dealing with natural systems.

I think the lake is complex,…and I give the guy [the modeler] a lot of credit for trying to model it. I think there are things that you can't model. There is too much going on. You can make attempts, but ecosystem modeling, I don't know who can understand this (BC).

Our data suggests that even though the managers went to the fishing community to invite their participation, they believed that the public participants held simplistic notions of fish ecology. A member of the fishing community reported that:

They [managers] probably were pretty well set on what they wanted to do …which brings up one of the issues: there is a lot of suspicion within the sport fishery community about data…That is one of the problems that we have had over the years. It seems that the sport fishery community had in their mind a direct relationship between fish stock and fish cut, almost one for one. Well maybe, maybe not. How many survive? What are they eating? How big are they going to be? (FS).

But one of the charter captains' leaders told us:

We saw from our own experience that the amount of bait out there was decreasing and that the fish were getting worse. The signs were there we had a problem in the fishery. Did it require a draconian type of situation to solve it? We weren't sure (BC).

There had been no systematic attempt to glean from the fishermen how they understood the system. And there was a great deal of distrust on both sides about what the other considered meaningful data:

There is a lot of suspicion within the sport fishery community about data, forage data for example … 'We are seeing tons of bait fish; you are saying there aren't any'… The first [meeting where the model was presented] I think was in '91, the SIMPLE model. The model was viewed with suspicion. I guess that is the best polite term. They [the fishing community] didn't feel that the forage base numbers were reflected accurately. They didn't feel that the survival rates that were put into the model were accurate. They didn't feel that there were enough factors in the model to describe the lake (FS).

Nobody knows what is going on out there fully. Even the scientists get surprised. They are honest about it. But you know three years ago in the State of the Lake (informational and assessment meeting), they said basically that rainbow trout were extinct in Lake Ontario. That was their conclusion. And last year they said that they bounced back phenomenally, so despite all we do, there is the unknown out there (FSC).

Problems developed with even basic communication. To members of the fishing community, it seemed that the agency was only concerned with the alewives, not with the salmon, because the modeling and much of the discussion focused on alewife population and condition. If the objective of the process had been more clearly communicated as being about saving the fishery, some problems may have been avoided:

The objective of the SIMPLE model was to save the forage base, and that killed them [the fishing industry]. The objective wasn't what they wanted to hear. It is true they [the agency] had to be concerned with the forage base, but our interest in the forage base was as long as it created fish. They [the agency] didn't make that link. So if the objective would have been how do we save the fishery, then it might have been a lot different. And they [the fishing industry] kept throwing at me, 'They only want to save alewives.' [And I said,] 'Well that is what this fish eats, folks. You have to save the alewives.'… When you come up with a model, and you are going to deal with stakeholders, you might want to look *more at the fish part of the fishery as opposed to the forage base. It is how it affects these [charter captains] guys that are making money out there. They see you [DEC] as the enemy taking dollars out of our pockets" (BC).*

Some participants believed that if a broader range of participants, particularly those with a more indirect but significant interest in the fishing industry had been involved, the model might have been used more effectively as an educational tool:

Unfortunately the whole thing was driven by the charter boat industry and a few vocal sportsmen but mostly the charter boat industry, so the majority of the people whose livelihoods depend on the fisheries out here weren't really involved in the decision making process. That was sort of unfortunate. The management agency tried to get other people like those with the recreational tourism industry involved. They went to the Chamber of Commerce or whatever trying to get other people involved, but the majority of the people just said, 'We don't really fish. The fishermen must know a lot about it. We are just going to send them.' So the whole decision making process becomes very heavily driven by just a few vocal people that have their own agenda, which is unfortunate [because] there are other people involved in this. It is hard to get the people who own the motels, the restaurants and the marinas out to these types of meetings and get them heavily involved in this. They just don't see it like they have any expertise or anything to offer, which is unfortunate. They do have something to offer because if you put the model up and run it and explain how you do the model and how you do your survey and all that, it is understandable by the layman. And that is one of the things that the social scientists have to help the natural resources people with: how do you get this broader group of people involved, the broader public who have a stake in the outcome of these management decisions (TG-2).

In the mid-1990s the reduced stocking levels were re-evaluated using the RISK model. The agencies (OMNR and NYSDEC) demonstrated that it had learned several lessons from the earlier process in how they organized the new process.

First, they did not attempt to simply present model results in order to convince a reluctant group of stakeholders. This time, they invited stakeholders to observe the scientific discussions at early stages:

What I really thought was great about what we did [in] our[modelers] work, we did our evaluations and then we came together. This was all organized by Sea Grant, but at that workshop where we were doing the re-evaluation, there were charter boaters. They came and they listened to us debate the science and discuss things (GR).

Second, they selected participants carefully:

But I think we learned from that first SIMPLE model how to present to the public. Once we got burned with doing that with the SIMPLE model, we had these long series of very painful meetings which were quite contentious. They, the managers, in my opinion, they simply opted not to go that road again. They just invited a few people to the meetings who were reasonable. They didn't take it out to the general public (TG-2).

Third, they included a discussion of uncertainty and variability:

There were a couple of people in 1996, a couple of representatives from the sport fishermen that came to the workshop as sort of observers …They had nothing to do with designing the model, only in the sense that from the '92 exercise, some of them complained that there was not an account of variability. So we went back to the drawing board. We got another grant. I guess we said, 'We need a framework that has variability because they are complaining' (MR).

In the end, the entire two-staged process did appear to bring the fishing community and the managers into a closer, better working relationship:

The process was good from my perspective because I think that I was willing to accept what they said, and I think it has proven out. If you look at the results of the crash of Michigan, my understanding there is that up until this year, last year, they hadn't reduced stocking. Now they've reduced stocking, [but] they don't have the size of fish that we have here. We wouldn't have that size of fish if it weren't for the reduction in numbers. And there is not a huge difference between catching 20 fish and 10 fish, there really isn't. It depends in the quality of the fish. Probably people are a whole lot happier with bigger fish. … I don't think there was any downside to that process at all. Even if we thought that the biologist had a preconceived notion about it, at least we understood it better. I think they have been justified based upon the results; I really do (FSC).

Lessons were learned, and in fact there was much more of an active engagement of diverse stakeholder interests in the second go around where it wasn't just open to the public, anybody that wants to come can be there. But the second go around, people were actually invited from diverse interests to make sure that instead of being dominated by just charter boat captains, as was the case of the first go around, the second one would better represent bait and tackle dealers,

> *county fisheries advisory boards, Chambers of Commerce, so on and so forth… The environmental community was there. Atlantic States [Legal] Foundation was invited. [I'm] not sure who else. What actually happened there was the formation of the Fisheries Congress, a task force of diverse stakeholders at a series of meetings to provide input (PE).*

However, others noted that the SIMPLE process soured the atmosphere for models and decision making for a long time to come:

> *Really, [it was] the first exposure that the public had to a scientifically based model used to make decisions. If you start talking models now, even to this day, to the public about decision making, they will just shut you off, and they will say, 'This is all b.s. We've been through this before, and we got raked over the coals' (PE).*

Nevertheless, some modelers/ scientists described the SIMPLE process as successful because the decision was based on the scientific information presented and not on the politics or popular actions that could have led to a crash in the fishery.

> *Our expectation was that, you know, our [modelers'] recommendations will be carried forward in some way, but the reality of it was that the political process took over, and you know, the sciences might not have had any impact. I guess that was the neat thing about this, that the political process didn't take over in this situation which is kind of unusual (TG-1).*

There was a long history in Lake Ontario, as in most managed fisheries, of tensions between managers and the fishing community. Detailed stakeholder analysis to identify not only interests but also worldviews and perceptions could go a long way toward designing effective collaborative processes involving models. Much of the actions of the managers (particularly in the SIMPLE model) were based on their preconceptions about the fishing community and its capacity or willingness to understand either the model or the ecosystem dynamics the model purported to represent.

Indicators

Deliberative effectiveness

During the first process (SIMPLE model, 1992-1993), a great deal of attention was placed on using the model to communicate expert opinion, but there was little attention was paid to developing a process for involving the public in the decision. The model appeared to be used not as a tool to improve public participation and discussion, but as something the managers were using to justify their decision to the public. It had the effect of drawing attention to the model rather than facilitating a discussion about solving a problem.

In the second process (RISK model, 1996-1997), the model was not directly a part of the discussion. Scientists and the fishing community were discussing the results rather than the uncertainty or validity of the model and its assumptions; this time there was not much discussion of the model itself but rather discussion of the modeling output. The management agencies understood that in this second process, the fishing community should be included from the start.

Therefore, they decided to include representatives from the 1992 process in a Technical Panel formed to study the fishery and to revise the 1993 decision. Furthermore, managers gave instructions to the modelers to include elements in the modeling process that were points of controversy in the SIMPLE model, such as stochasticity variables and nutrient levels.

Explanatory effectiveness

While the SIMPLE model described predator/prey relationships and clearly warned of significant changes in the forage base, it was not used effectively to develop a common understanding of the problem or to promote a better understanding of the ecosystem dynamics. Several of our study participants said they had hoped to use the process for their own learning, but it was not designed that way. The focus was on the model rather than on the system. The modeling exercise, how the model was built and its variables and assumptions became an issue rather than a tool to clarify the issue.

Managers and modelers might consider certain points so that the model doesn't become the focal point of the process but is used instead to illuminate problems and solutions. One of the things that we learned from this first process is the importance of having clear goals and explicit expectations, keeping in mind a vision of both what the process intends to do (ends) and the means to achieve that vision. In the SIMPLE case, modelers and managers presented the issue to the fishing community in a way that polarized the community so that the model itself was put on trial. The issue was presented as a negotiation between managers and the fishing community over which species to cut, rather than a joint effort to preserve the fishery of Lake Ontario and to create a common vision of a healthy and sustainable fishery.

Policy Relevance

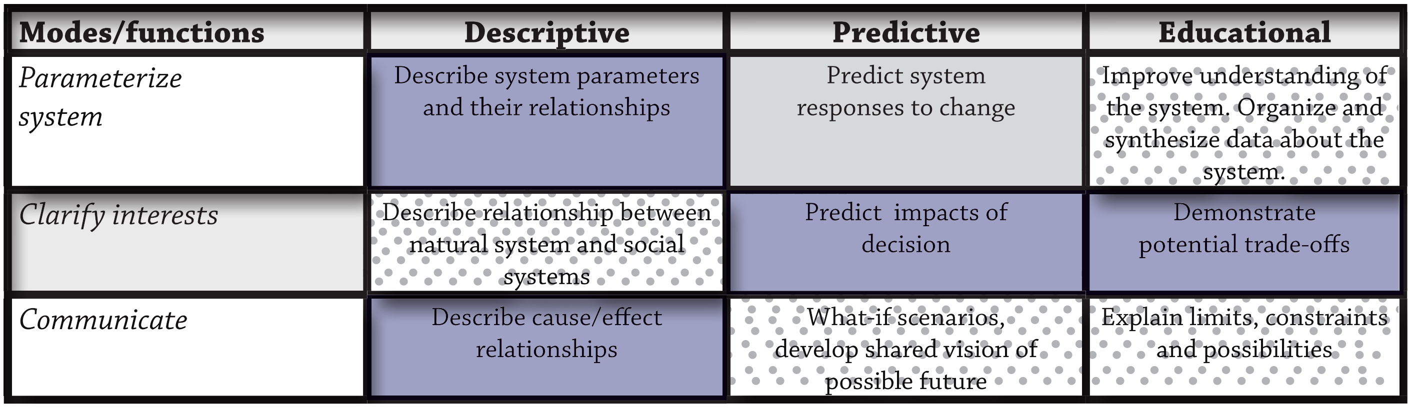
In the 1992-1993 effort, the model helped to define the problem, and it was offered as a means to making a decision. However, the modeling results, although they were relevant and based on science, created controversy in the fishing community which felt it had been left out of the process. The model determined that the fishery was in danger, that the predation demand on prey fish had to be reduced, and that fish stocking should be cut. NYSDEC and OMNR decided that a 50% cut in stocking would prevent Lake Ontario's fishery from crashing and went forward with that decision, despite discontent within the fishing community.

The second time around, the model was used in a way that was relevant to the policy decision. This time, members of the fishing community were invited to participate and the process was not as controversial as the first. Lessons learned from the SIMPLE modeling process were applied in the RISK model process. The RISK model was never run in an open public meeting but instead used by the Technical Panel whose work was observed by stakeholder representatives who could then explain the recommendations to their constituents. The RISK model determined that the system was more resilient than previously thought, and OMNR and NYSDEC decided to increase stocking by 10%.

Modes vs. Functions Matrix

The following matrix of three functions (descriptive, predictive and educational) and three modes (system parameterization, interest clarification and participant education) represent a summary of the most relevant uses and functions of modeling ventures for this synthesis paper. In this section we compare the performance of Lake Ontario's fish stocking modeling (SIMPLE and RISK models) against the matrix of functions and modes.

Figure 6: 1992-1993 Process—SIMPLE model

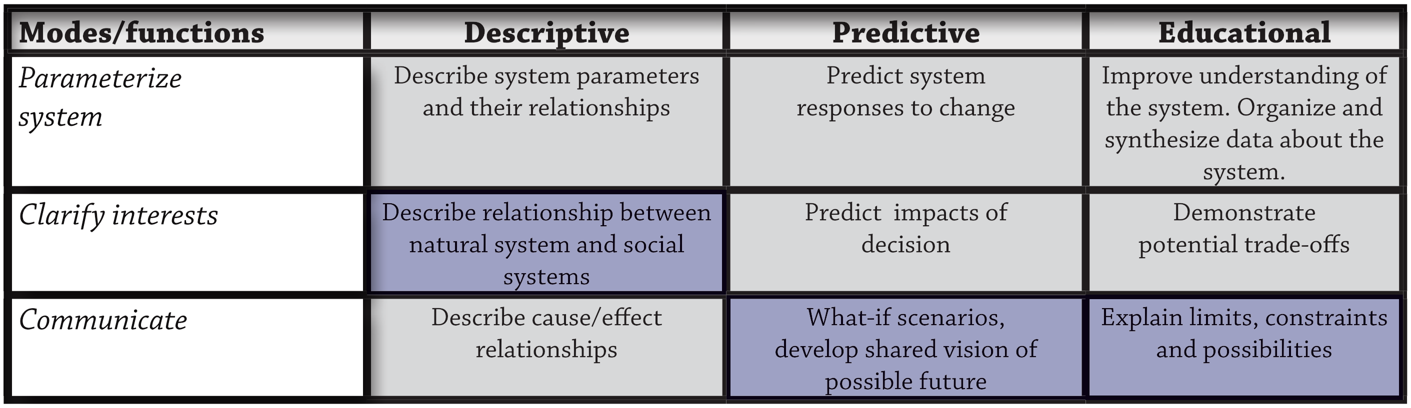


Modes/functions	Descriptive	Predictive	Educational
Parameterize system	Describe system parameters and their relationships	Predict system responses to change	Improve understanding of the system. Organize and synthesize data about the system.
Clarify interests	Describe relationship between natural system and social systems	Predict impacts of decision	Demonstrate potential trade-offs
Communicate	Describe cause/effect relationships	What-if scenarios, develop shared vision of possible future	Explain limits, constraints and possibilities

The sections in blue represent areas where the modeling effort could have been improved. The sections with dotted backgrounds are areas that were missing in the modeling exercise and that generated controversy. The model could have included elements of stochasticity; the fishing community claimed that the model was deterministic and that stochasticity was missing in its conception. Although the fishing community was presented with alternatives, they claimed that those options were not appealing but were canned scenarios that modelers and managers felt comfortable with.

The model failed to create a common vision and bring understanding of the system; instead, it fed animosity among participants so that discussions centered on the flaws of the model, rather than the system the model described.

Figure 7: 1996-1997 Process—RISK model



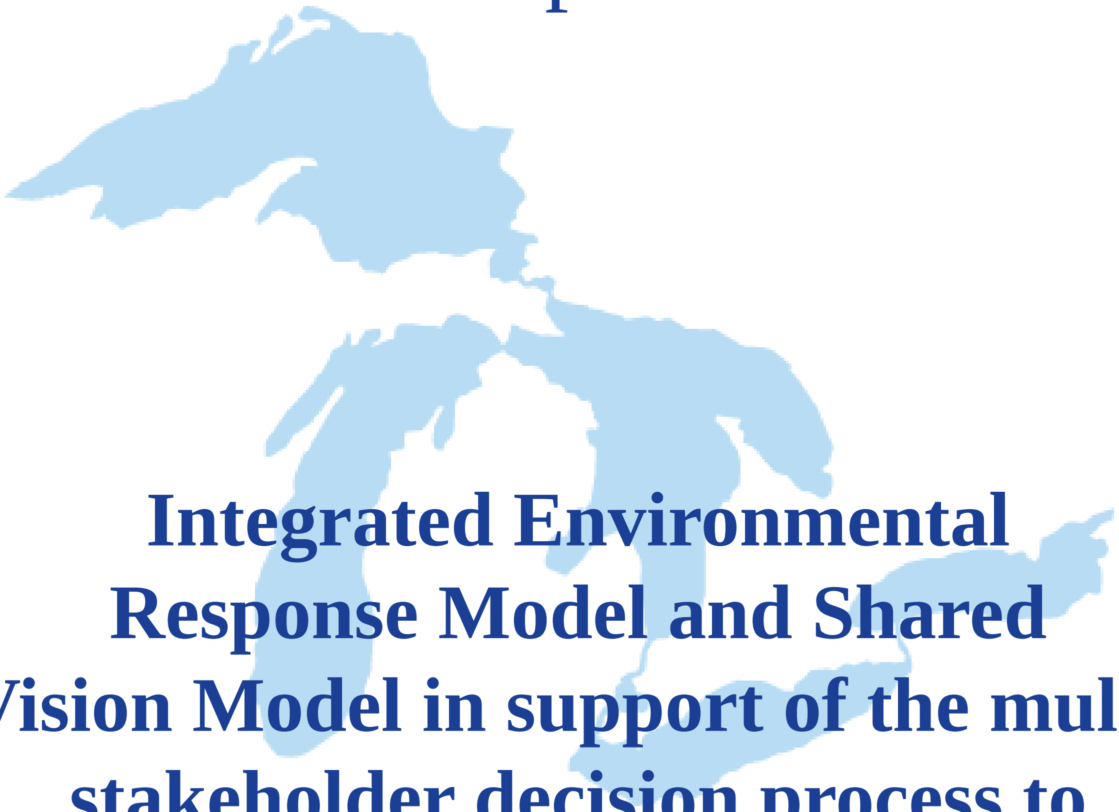
Modes/functions	Descriptive	Predictive	Educational
Parameterize system	Describe system parameters and their relationships	Predict system responses to change	Improve understanding of the system. Organize and synthesize data about the system.
Clarify interests	Describe relationship between natural system and social systems	Predict impacts of decision	Demonstrate potential trade-offs
Communicate	Describe cause/effect relationships	What-if scenarios, develop shared vision of possible future	Explain limits, constraints and possibilities

Variables and elements left out of the SIMPLE model were included in the RISK model, as were several "what-if" scenarios, making the model more complete. However, in this process, managers and modelers did not completely open the modeling process to the public; instead, they chose to invite a select group from the fishing community to observe the Technical Panel. This approach did not acknowledge the value of input from the fishing community, but rather constituted a way to avoid disagreement and controversy. The modelers and managers did not want to open the process to the public, as they were "burned out" from the 1992-1993 process.

Recommendations

Inviting the fishing community to participate from the start of the modeling process increased their later acceptance of the results since their questions and suggestions could be addressed and implemented in the modeling process. Moreover, an organized approach with carefully selected representatives of diverse stakeholder groups, such as a "Fisheries Congress," seems more likely to succeed than an open meeting that can be dominated by a single interest.

The level of model complexity should be decided by participants, based on the modeling goals and on the comfort level and desired outcomes articulated by participants. The interview data showed that the fishing community wanted the SIMPLE model to be more complex in order to better represent the system. The absence of more variables and elements of stochasticity created discontent and distrust in the process.



Chapter 5

Integrated Environmental Response Model and Shared Vision Model in support of the multi-stakeholder decision process to recommend changes in the outflow regulation plan, Moses-Saunders Power Project, St. Lawrence River.

2000-2005

The Moses-Saunders Dam was completed in 1958. It harnessed the International Rapids of the Saint Lawrence River for electrical power and opened a major new shipping route from the Atlantic to the Great Lakes. The dam transformed Lake Ontario and the St. Lawrence River into a water system whose flows and levels could now be partially controlled. Since the river formed part of the boundary between Canada and the U.S., any dam required approval by the International Joint Commission (IJC) created by the Boundary Waters Treaty of 1909. This treaty prevented any construction of flow obstructions or diversions on one side of the border that might harm the interests of the other[1] . It gave decision making authority to the IJC to approve water management structures in boundary waters and to operate these structures cooperatively for the benefit of both countries. The Treaty described these benefits as transportation, power production, municipal water supply and sanitation.

Once the two countries agreed to build the dam and powerhouse, the IJC was required to establish the rules for how they would be operated, first and foremost how decisions would be made about the amount of water allowed to flow through the dam's control structures. Holding water back or releasing water at the gates would raise and lower levels upstream in Lake Ontario, drown or parch the vast wetlands and dunes of the eastern lakeshore and upper St. Lawrence River, and create the reverse conditions downstream in the biologically productive shallow wide-waters of Quebec. Changes in water level would also dramatically affect operations in the newly expanding Port of Montreal. Every decision about how much water to release downstream or store in the upstream reservoir has consequences, some potentially severe, for the wellbeing and economic prosperity of millions of people.

Deciding how much water to release is the task given the St. Lawrence River Board of Control. The Control Board is required to make its decisions based on rules that set maximum and minimum water levels in the lake and in the river up and downstream of the dam at different times of the year. These decisions are based on criteria meant to balance to some extent competing water needs for hydropower production, commercial shipping, and drinking water supply. Each has a somewhat different optimum level and flow depending on the season. The greater the flow, the more electrical power, but with too much flow, currents could endanger the shipping lanes. Too little flow can expose the water intakes of downstream communities, but too much flow can flood sewage systems downstream.

The Moses-Saunders Dam: Photo Courtesy of Dalton Foster

While trying to balance these needs, the Control Board has no control over how much water comes its way from the upstream Great Lakes watershed. The large surface area of Lake Ontario, in relation to that of the St. Lawrence River, means that flow adjustments at the release gates at Moses-Saunders has a delayed effect upstream on Lake Ontario even while the effects downstream are felt suddenly and powerfully. Mistakes can have dramatic impacts and take a long time to correct. Guiding these decisions are the rules and criteria that make up what is called the Regulation Plan, approved by the IJC in its Orders of Approval in 1956, allowing the dam to operate. After a period of several adjustments, the Regulation Plan known as "1958D with deviations," otherwise known as 1958DD, was adopted and has guided the water release decisions of the Control Board since 1963. The "with deviations" means

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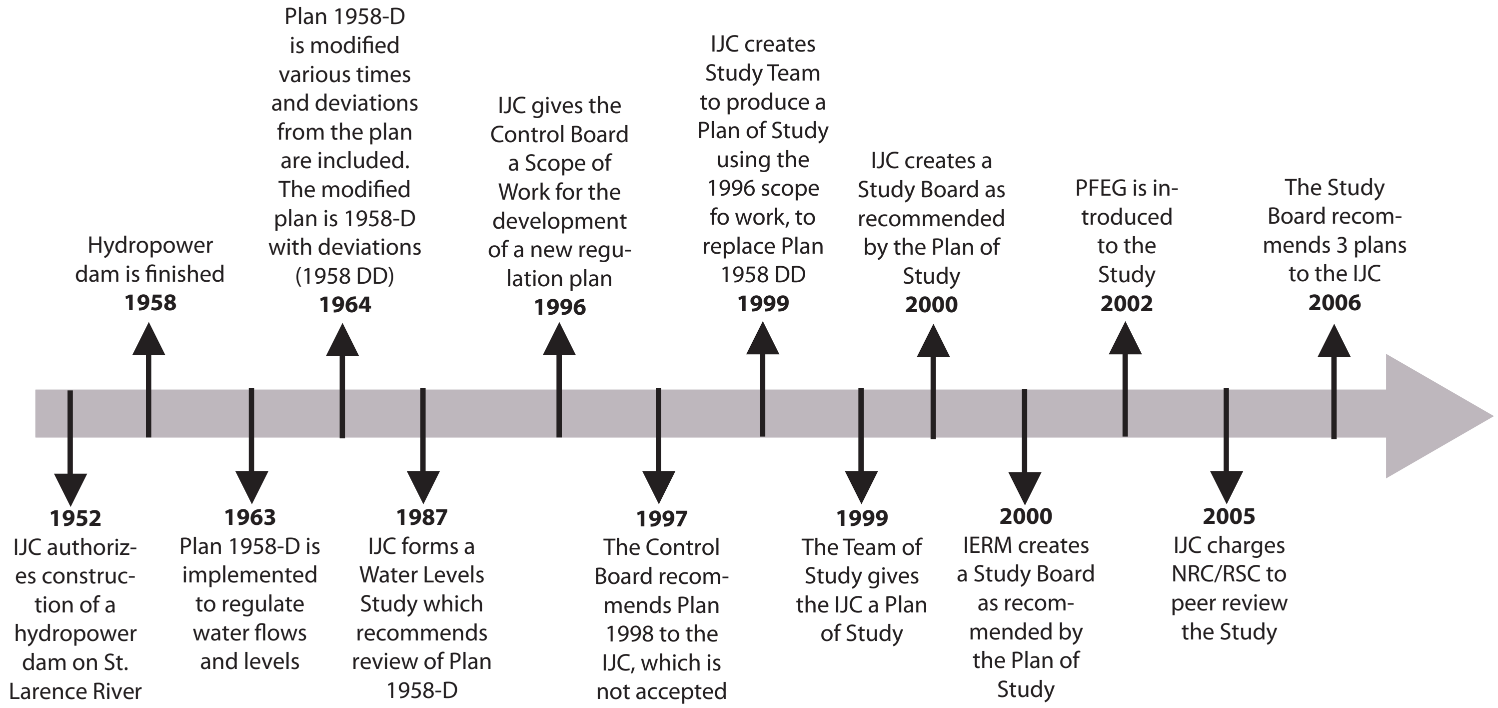
1. At this time no consideration was given to the sovereign rights of the Mohawk people who resided on either side of the border and the islands, who depended on the river for their sustenance and livelihood and who saw themselves in a relationship of interdependence and mutual responsibility with the river.

Figure 8. Historical context and timeline of the Lake Ontario-St. Lawrence River Study



Key:

PFEG: Plan Formulation and Evaluation Group
IERM: Intergrated Ecological Response Model
ETWG: Environmental Technical Working Group
IJC: International Joint Commission
RCS: Royal Society of Canada
NRC: National Research Council

that the Control Board has the authority to deviate from what the rules and criteria written into the Plan might say in order to respond to additional concerns. In recent years the Board has deviated from the Plan flow in approximately half of its decisions, often in response to concerns about shoreline erosion or recreational boating access and safety, two issues that were not effectively addressed in the Plan 1958D.

Many things have changed along the shore since the dam was constructed in the 1950s. Some changes were wrought by water management, some by the availability of inexpensive hydropower and water transport with its accompanying industrial boom, and some by growing population and wealth. In addition, new water-related activities have gained popularity, especially recreational fishing and boating. New understandings have emerged about the environmental impacts of water level regulation, in particular the dampening of extremes of high and low water resulting from the Control Board's efforts to manipulate flows to maintain optimum conditions for hydropower and navigation while preventing riparian flooding.

During a period of historic high water levels when shore erosion and property damage occurred in some areas in the mid and late 1980s, the US and Canadian governments asked the IJC to undertake a comprehensive review of water level variability and control throughout the Great Lakes Basin. Among the outcomes of this Water Levels Study was a recommendation that regulation in Lake Ontario and the St. Lawrence River be reviewed and possibly revised.

In response, the Control Board undertook a limited review of several alternative approaches to water flow regulation and eventually recommended a new plan to the IJC, dubbed Plan 1998, that would have made small adjustments to the existing plan. But the IJC rejected the new plan because, among other reasons, the Control Board had not considered the environmental impacts of regulation and because a scientific basis was lacking for accepting or rejecting any revised plan. The IJC rejection and the continued reliance on a plan more than four decades old highlighted the need for a more thorough assessment of existing flow regulation practices and a wider range of alternatives.

In 2000, the U.S. and Canadian governments provided funding and the IJC established a Lake Ontario-Saint Lawrence River (LOSLR) Study Board (University of Ottawa, 2002). The LOSLR Study Board was responsible for overseeing research, modeling, and preparing recommendations, including optional regulation plans for the IJC. The Study Board was charged with overseeing a process that would:

(1) Be based on a sound scientific foundation
(2) Provide opportunities for public participation
(3) Consider environmental impacts
(4) Be transparent
(5) Consider changing climate conditions

The study participants included representatives from several government agencies, academia, and non-governmental organizations, and it relied on the work of hundreds of people. The Study Team included the Study Board, six Technical Working Groups[2] (TWGs), an Information Management Group, a Plan Formulation and Evaluation Group, and a Public Interest Advisory Group, each with members from both Canada and the U.S. and each led by U.S. and Canadian co-chairs (Final Report of the LOSLR Study Board, 2006a).

For the purposes of our analysis of the use of computer simulation models in environmental decision making, we focused on the Environmental Technical Working Group (ETWG) and its use of multiple models. These models simulated the response of key environmental variables to different patterns of water levels and flow expected to result from different regulation plans. We also focused on the integration and synthesis of these models into the IERM (Integrated Environmental Response Model) and the ETWG's interactions through the IERM with the Study Board's information management tool, the so-called Shared Vision Model (SVM). This case is interesting and informative for the purposes of this synthesis for several reasons, including:

- It was a complex, large-scale, multi-million dollar decision making process involving the use of several types of models, raising monumental data management and communication issues.
- Despite five years of study and another two years of review and evaluation of the resulting recommendations, the IJC has still not made a final decision. [On September 10, 2007, the IJC extended the period of consultation and has not set a date for announcing a final decision, according to information found in the webpage: www.ijc.org (as in 24 Oct. 07)].
- The process was eventually structured around a management model, the Shared Vision Model, to consolidate, organize and report the results of several process models in order to actively facilitate decision making.
- It was one of the first times that the Corps of Engineers' Shared Vision Planning process and its associated management model (the SVM) was tried in a project this large and complex.
- It is the most recent Great Lakes policy initiative to rely on simulation models and other computerized decision support tools to help make policy, and it gives us the opportunity to see how the relationship between models and decision making in the Great Lakes has evolved and whether or not lessons from earlier processes have been learned.
- The process and the models in particular received an ex-post scientific review which was available for our analysis.

In the first two years of the study, the Study Board was faced with the daunting task of managing the rapidly proliferating data from the technical groups and trans-

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[2] The six TWGs were Environment, Recreational Boating and Tourism, Coastal Processes, Commercial Navigation, Hydropower, Municipal and Industrial Water Use, and Hydrology and Hydraulics

lating it into a form that would compare alternative approaches to regulation and how they perform under a nearly infinite range of possible water supplies. Ultimately, it was the Study Board's task to make recommendations to the IJC. A Study Board member, a senior planner at the Army Corps of Engineers who had extensive experience with a decision support method known as Shared Vision Planning, convinced the Board to adopt this framework. The Shared Vision Model and the Shared Vision methodology became central to the LOSLR Study and structured how the results of the scientific research and modeling would be reported. According to the Study Board's Final Report (2006b), the SVM is "a decision making tool used to develop a collective representation (image or view) of the future a group aspires to create" (p. 260). The "group" in this case included participants from each of the TWGs as well as the Public Interest Advisory Group and the Study Board.

The Shared Vision Model was a computerized representation of the Corps' longstanding decision making practices based on identifying the relevant interests, predicting the monetary costs and benefits that would accrue to each interest under alternative options, and finding the option that resulted in "the greatest benefits for as many interests as possible while minimizing losses to any one sector" (Final Report of the LOSLR Study Board 2006a, p. 23). The final LOSL Shared Vision Model consisted of a 'pyramid' of four models: a water level impacts model[3] , the Flood and Erosion and Prediction System (FEPS)[4] , the St. Lawrence River Model (SRM), and the Integrated Ecological Response Model (IERM) (Final Report of the LOSLR Study Board, 2006a).

The data gathered for this project and earlier work by Manno (2003) demonstrate how much the decision to adopt a shared vision planning approach affected how the case unfolded, particularly with regard to the environmental component. By conflating the Technical Working Groups with "Interests," the TWGs were subtly transformed. No longer co-producers of data and co-analyzers of key relationships who would help inform decision makers, each Work Group was required to become an advocate that needed to present data in such a way that its interests would be advanced over the interests of others.

The Corps' planning methodology also created a template for how environmental science should be reported, always in terms of how a given ecosystem component, for example, muskrats or pike, would respond to selected and random supply sequences over a multi-year period. This left the scientists in the ETWG with the messy if not impossible task of expressing long term ecosystem effects through indicators like the population and recruitment success of an individual species. In response, the ETWG eventually turned to the development of the Integrated Ecosystem Response Model which made it possible to report effects at the scale of ecosystems, as most ETWG scientists believed it should be. But this left the ETWG's results with much less specificity than its "competitor interests" who could report dollar-denominated relationships between regulation plans and electricity produced, cargo carried, property damaged, or angler days spent in boats. In the end, the environmental scientists, by being included as an "interest" in the Shared Vision Model, were left with neither scientific legitimacy (see the critique of the environmental component in the NRC/RSC peer review) nor much standing to assert their claims against the other interests.

There were those, including the former director of the NYS DEC region that included the St. Lawrence River, who had been very active in convincing Congress to appropriate the funding for the study, who believed that the purpose of the study was to revise water level regulation to end and possibly reverse the environmental degradation attributable to water level management under the existing plan. One of the TWG members reported that the regional director had:

> *told me that the wetlands and the ecology had suffered for many years from the lake level management and the whole idea of the Study was to look to see if there was a better way to control lake levels to improve the environment…[He] was really set that people had taken advantage of the management of lake level for years, and it was time that the wetlands and some of the ecology began to reap some of the benefits from lake level management. So I had a broad introduction from [him] to the Study … [that] the whole idea of the Study*

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3. The Recreational Boating and Tourism and the Municipal, Industrial and Domestic Water Uses Technical Work Groups fed their results for water level-impact into a model built using STELLA modeling software.

4. The Coastal Processes Technical Work Group adapted and updated the FEPS computer model, developed by Baird and Associates in 1997 for the Army Corps of Engineers for the Lake Michigan Potential Damage Study.

was to look to see if there was a better way to control lake level to improve the environment (SB-1).

Other members of the Environmental Technical Working Group (ETWG) thought that their task was to use their expertise to describe in as much detail as possible the environmental impacts of the regulation plan over the last half a century. One claimed that:

> *We have been operating under water level regulation guidelines that are harming the environment, and I thought that the charge was to develop a plan that will not continue to harm the environment without significantly impacting the other interests…It turns out that the goals really were to determine and assess alternative plans relative to all the interests. In other words to try to balance everything" (GR).*

On the other hand, a Study Board member believed the intention of the study was to identify trade-offs and find an optimal, most economically efficient regulation plan that would improve the situation for as many interests as possible, without causing any single interest to lose. In order to achieve a Pareto optimization he introduced the use of the Corps' planning principles.

Thus, this was a case of people who were required to work together on a very complicated project who did not necessarily share the same idea of the purpose of the undertaking. This Study Board member was certain that part of the problem was the environmental scientists' lack of experience with multi-objective planning. As he described it in our interview:

> *So when you are dealing with specialists who have no experience in planning and [who don't know] that planning means developing alternatives, making tradeoffs, doing benefit-cost analysis, looking at the economics of a problem, that it is not just a technical scientific problem. Which is what most of the people wanted to look at. [They wanted to] look at the Lake Ontario problem and simply say, 'Let's establish a new water level. Let's establish new flows.' They looked at it mainly as a physical problem, just developing physical criteria in terms of flows and lake levels and not looking at the consequences of those, [not looking at] 'If we make those changes in the physical criteria, how would that affect people? What are the social impacts? What are the ecological impacts and what are the economic impacts?' So that was the thing that I brought to the Study was the overall planning process, in particular the Shared Vision Planning Process and the Shared Vision model [which] is a major component of the Shared Vision Planning process. It was where all this information would be put into a modeling framework so that anyone in the public, anyone in the Study Group could look at the impacts and the feedback loops and do the analysis, do the sensitivity analysis, and examine all the consequences much in the same manner that any technical specialist could (SB-2).*

The ETWG and the Study Board had different mindsets; the expectations of the leadership of the process were very different from the expectations of people who were participating in the Technical Working Groups. These different definitions and conceptualizations of the issue were fed from the beginning of the process by unclear objectives and miscommunication among participants. Several participants commented that when the process began, they were floundering without clear direction. The SVM, despite its inherent difficulties for the Environmental TWG, at least gave clear direction to the Study but only after much valuable time had been lost. A member of the Public Interest Advisory Group noted:

> *The Study Board didn't really formalize the objectives of the Study until about the third year…There were no prescribed goals for it. I mean the way it was run, all I can say is that it was in typical government fashion: 'This is a job that we have for five years and then we need to look up what we were going to do for the five years after that,' and it wasn't as if, 'We need a better plan, and we are the guys responsible for that, so we need to get the best information that was out there because that is why we did the Study.' Once we recognized that, there was no way we could come up with a better plan without some better base line information (BP).*

Nevertheless, many understood that part of the purpose of the Study was to include two concerns (environment and recreational boating) not included in Plan 1958 D. Scientists with environmental concerns were pushing to include the environment and get increased variability in water levels to mitigate some of the habitat loss caused by the current regulation plan:

> *The regulation plan of Lake Ontario is structured to give preference and priority to hydroelectric power, navigation, water supply, and then secondarily to the riparian interest, that is, the shoreline owners on Lake Ontario, but they didn't include recreational boating or the environment. So the basic question was: can you create a new set of regulation plans, operating rules that would do better for the recreational boater, address their issues along with the environ-*

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5. An explicit step-by-step procedure for producing a solution to a given problem. Specifically, a mathematical equation typically executed using a computer program (or set of programs) that is designed to systematically solve a certain kind of problem (www.racteam.com/LANLRisk/Glossary.htm)

ment, while not harming the other sectors that are already built into the Order of Approval (SB-2)?

Furthermore, the initial charge from the IJC was to conduct required "studies or activities" that would take into account environmental and recreational boating criteria. These were to include climate change, topographic and bathymetric data, environmental impacts, shoreline impacts, possible demographic changes, and public input. The ultimate goal was to develop "system flow modeling using compiled historical flow records" and to implement a "decision-support algorithm[5]" for choosing among the alternative approaches being modeled (Plan of Study, 1999, Annex4-13). The Initial Plan of Study transformed these required activities into six interest groups, assigning each group an interest to be investigated. Initially these groups were called Study Teams though later on they came to be known as Technical Working Groups. In addition, the Plan of Study specified an Interest Advisory Group (later called the Public Interest Advisory Group) to involve the public and a Study Board to collect and analyze information and suggest alternative regulation plans.

A long history of distrust and dissatisfaction existed within many of the interest groups, especially shoreline property owners, recreational boaters, and environmental advocates. Each regularly found fault with the way the Control Board managed water levels. The Shared Vision Planning and subsequently the Shared Vision Modeling framework were attractive to the Study Board because it promised a mechanism to bring these groups together in a process that could lead to improved understanding of each other's perspectives.

[A Study Board member] was my boss at the Corps ... and of course knew about the work I had done on what we called Shared Vision Planning [SVP], generically collaborative modeling to help in decision support. He suggested that I audition it before the Study Board which was looking for ways to formulate and evaluate new regulation plans but had just a broad direction in the Plan of Study. So I looked at existing models, and I built what I called a mock regulation model and basically made a presentation to the Study Board, arguing that it will be very difficult for them to affect a new regulation plan, in other words to get the Commission to endorse a new regulation plan, unless they had broad support from stakeholders in the basin. And that support probably would not happen unless the stakeholders were involved in a process like SVP in making the decisions (MA).

Shared Vision Planning intends to build a common vision among the participants, increasing the understanding of the system and considering consequences before making decisions (Werick & Whipple, 1994, Palmer, 1998). In its report, the NRC and RSC review team defined this Shared Vision Planning as a "collaborative process of water resources inquiry, systems modeling, and stakeholder participation that strives to converge on water regulation plans worthy of consideration by the IJC" (Committee to Review the Lake Ontario-St. Lawrence River Studies, 2005, p. iv). As part of this approach, the Study Board decided to include a Shared Vision Model in the Study:

The Study probably had been underway at least for several months, so they were casting about. By that time, they had already committed a fair amount of the Study's budget to data acquisition and economic evaluations, but they had not yet decided how they were going to weave them all together so the research would support the decision. The Study Board listened [to an audition of the model] and decided that that was the way they wanted to conduct the Study. Then I came on board, and basically because of that, the Study Board decided to form a new Technical Working Group called the Plan Formulation and Evaluation Group (PFEG). Working with colleagues on both sides of the border, a small group of us pursued SVP for the LOSLR Study (MA).

The ideal expressed by the designers and promoters of the Shared Vision planning process was one of openness and collaboration. Once the major relationships between the interests and the resource being managed was clearly expressed by the interests themselves and entered as mathematical relationships in the spreadsheet, results of alternative actions could be visualized and various scenarios examined with all the interests involved.

A major component of the Shared Vision Planning processes was that all this information would be put into a map modeling framework so that anyone in the public, anyone in the Study group can look at the impacts and the feedback loops and do the analysis, and do the sensitivity analysis, and examine all the consequences much in the manner that any technical specialist could (SB-2).

One of the goals of the Shared Vision modelers was to have their system open to the public so at the public hearings people could say, 'Hey, what if you were to try this or that, or remove that interest.' Well that was a good idea, but it never really happened that way. The end result was very arduous to the general public (CLC).

The way the Shared Vision Model was actually used was quite different. For people who interacted with the model, it was overly complex and failed to bring understanding of the system:

The SVM again is all in the name, lovely name, the Shared Vision Model. We all sit around the table, and we build together something that is going to take us further. The intent of the original model, the way it was conceived, was just that: to let stakeholders participate in the elaboration of the plan that would suit them all…But to me, it was a very large black box (CLC).

We didn't play around [with the Shared Vision Model]. It was too complicated for us, so we didn't actually go in, but we looked at the results and we went through the reports (CLP).

Participants have different perceptions about the introduction of the Shared Vision Model into the Study. Some Board members perceived it as a necessary component for integrating and analyzing data, and argued that it was chosen from several alternative models. For example:

We discussed many different options and among the various options was, 'Let's just use the conventional hydrological models that are there…Let's just use those entirely without even looking at economics.' So there were many discussions in the first year. It took me about a year to convince people that we needed an integrated ecological response model (SB-2).

We had the SVM, and we had one other model [an interest user model] …We dropped out the interest user model …It was too publicly driven and not scientifically driven. Even though the SVM didn't do much else, it wasn't publicly driven. At least the data was fed into it, so the Board went with the SVM (SB-1).

Members of the ETWG felt that the SVM was being imposed upon them by the Study Board, and although the SVM had never been used on a large scale study like this, no alternative approaches were seriously considered:

It seemed like a done deal, in spite of the fact that, I think, the SVM had been primarily used in the past with very small groups … I think it had proved its worth in the small scale, but I don't think it had on a much larger scale (CLC).

The SVM was thought of as the very next best thing after sliced bread. It was presented to us as, 'This is the solution to all of our problems.' I don't think there was much debate or much question. If there were questions, we did not go very far into that as to why we had to select that type of model (CLC).

Some members of the ETWG wanted to introduce to the decision process The Nature Conservancy's approach, using the TNC's Index of Hydrological Alteration (IHA) to reveal the potential environmental impacts of water flow regulation (Richter et al., 2003; Richter et al., 2005). The TNC used the IHA, a statistical tool, to analyze the hydrograph (patterns of variable water supply, levels and flows) by comparing existing daily or even hourly variability under regulation with the hydrograph as it would have appeared if the flow was unimpeded or "natural." By detailing the regulation-induced alterations, reasonable hypotheses could be generated about the environmental impacts. More detailed scientific assessments of these impacts could lead to specific recommendations for changes in dam operations.

Changes in levels and flows affect life in the river in numerous ways. They determine whether nesting and spawning sites are on dry land or underwater. They significantly affect the temperature and velocity of the water which often serve as signals for the best time and place to feed or spawn. They determine the shape of the shoreline and the location of sand bars and riverbeds with just the right grain-sizes of pebbles. They make food more or less available for filter feeders and dive feeders, and so on. Thus being able to compare the timing of dam operations with the timing of life cycle events can provide direction for both the study of the ecological effects of water management and for taking steps to reduce ecological disruptions.

The logic of the TNC's approach to reviewing and revising water regulation stood in sharp contrast with the Corps SVM approach. In TNC's approach all the stakeholders, or interests, had a responsibility to manage their activities in ways that recognized the patterns of the finely tuned relationship between hydrology and biology in which the life in the river and lake had evolved. From this perspective the environmental purpose of the whole Study would be to negotiate changes among users (interests) in the direction of reducing impacts as much as possible. Those who gained economic benefit had a responsibility to avoid unnecessary harm. In the SVM approach, in contrast, each of the 'interests,' including the environment, were asked to prepare a reasonable argument in favor of a flow regime that would maximize their benefits. The job of the decision-maker was to balance these rights in the direction of maximizing net benefits without unreasonably reducing benefits or increasing costs for any particular interest.

These differences in perspective, while almost never clearly articulated, surfaced frequently in the decision process in the conflicting understandings of the Study's primary objective and in the very different conceptions of the purpose for the models' being developed. There were also different understandings of how data should be collected and interpreted and how results should be reported and their implications expressed to the decision makers, the IJC commissioners.

From the perspective of the Corps' planners, the individuals who expressed concern about the environmental impacts of dam regulation were not calling on decision makers to behave responsibly. From the perspective of some on the Study Board, the Environmental "advocates," which because of the design of the SVM process became conflated with Environmental "scientists," were making unreasonable demands on the process, forwarding the idea that the other interests should make economic sacrifices to benefit their "interest." There was also frustration over the Environmental group's unwillingness to express their interest and the results of their research in dollar terms. Furthermore, the critics of the ESWM approach argued, the strategy of comparing the existing regulated hydrograph to an imaginary unregulated hydrograph revealed the TNC's unscientific assumption that an unregulated river was a "better" environment. It was pointed out that the dam and the construction of the Seaway had permanently changed the ecology of the St. Lawrence River especially, and to a lesser extent Lake Ontario, and there was no going back to some hypothetical natural state.

In the end, the Planning group appeased the "environmentalists" by including as one of the Plan options a Plan B+, an option that represented managing the dam for levels and flows that would mimic the historic pre-dam, pre-regulation hydrograph. This was, of course, very different from what the TNC and others were proposing, which was to modify regulation specifically at the most vulnerable times, a process which would be informed by the results of the environmental studies.

Some members of the Study Board and PFEG criticized the TNC approach in this way:

The [TNC model] made an assumption that if you restored the natural hydrology, that the natural environment would follow. What we didn't know was if this was true. Secondly, we didn't know what the impacts are on all of the other sectors like the economics of navigation, hydroelectric power, recreational boating, flood damage, etc. So yeah, we took a part of their thinking and we expanded it to look at 'Okay, you need to look at the consequences. You can't simply assume that just because you recreate the natural flow regime that everything will be perfect.' In fact, we found that the natural flow regime created the most economic damages of all of the alternatives (SB-2).

[According to the TNC model] the first assumption should be that the environment that we see was built on natural water levels and that natural periodicity and fluctuation is best for the environment … [A TNC modeler] developed metrics, an Index for Hydrologic Variability, something like that, that would allow people like the Lake Ontario Study Board to have numbers to judge whether the regulation of, for instance, a reservoir is good for the environment or not. This was an overarching hydrological-based number [that was] separate from whatever biological studies you might pursue. It [TNC model] didn't apply too well on the LOSLR Study. Part of that was because we were really looking at weekly regulation. A lot of the variability that they found important was hard to track down. That view of theirs became transformed, I would say…into support for the team that was working on the natural regulation plan that eventually became Plan B+. The idea there was to go with unregulated releases except when doing so will cause a lot of damage (MA).

When the original environmental Plan of Study was prepared, it emphasized the effects of water level regulation on wetlands. The condition of the wetlands throughout the river and lake were seen as evidence for environmental decline which was hypothesized as being a result of regulation. The Plan of Study, written together by a U.S. and Canadian biologist, focused on documenting and detailing these changes, relating them to hydrological alterations, and suggesting changes to management practice to minimize the impacts (St. Lawrence River-Lake Ontario Plan of Study Team, 1999). However, the introduction of the logic of the SVM into the LOSLR Study changed the emphasis of this environmental research. Study Board members argued that wetlands should be but one of many indicators and that the ecosystem should also be represented by other environmental indicators. The environment now needed to be expressed as an interest that could be quantified and related in some hypothetical way to levels and flows. To most biologists this was impossible. The ETWG members were prepared to study processes and develop testable hypothesis between water regulation and specific environmental conditions. It was not their task to assert a particular benefit from any particular environmental condition. Thus, the ETWG research itself broke down into units of competing interests. Each researcher was required to fit their studies into the framework of Performance Indicators (PI). Performance Indicators were considered anything that could reasonably be shown to have a relationship with hydrological conditions that could then theoretically be calculated for different levels and flows and programmed into the computer. In other words, one sequence of levels and flows would mean this much income for hydropower and shipping, this much shoreline erosion and property loss, this much breeding success for dabbling ducks, and so on.

Understandably, the environmental scientists were reluctant to engage in this exercise. The relationship between water levels and flows and hydroelectric production and cargo capacity were relatively simple to quantify. Recreational boaters' access to docking and safe conditions were somewhat more complicated and geographically variable, and shoreline erosion was more complicated still. But from an ecological point of view, what was "good" for any particular species was not necessarily "good" for the ecosystem as a whole if it was subjected to that particular pattern of variability over a long period of time. Wetlands, on the other hand, could well serve as a surrogate for ecosystem conditions as a whole, particularly trends in wetland conditions over time. They had the added benefit of being essential habitat in the life cycle of many aquatic species.

Within the ETWG, there was considerable debate on how best to integrate a variety of indicators so that the environment could be represented as one interest in the SVM.

The question… was how do you integrate the environment? So there are people when you talk about the environment, they see the environment as something bigger than wetlands even though wetlands, because of being hydrologically connected, are probably the most critical habitats affected. We had people that wanted to study the zooplankton and phytoplankton, you name it… because it was the environment that we were adding…If the question had been posed differently, maybe the product would have been different. It would have been a more focused product (SB-1).

The ETWG came up with several Performance Indicators but had no protocol for integrating them into the SVM. With the support of a Study Board member, the leaders of the ETWG engaged a modeling firm[6] who proposed developing what they called an Integrated Ecological Response Model (IERM) as a way to integrate these indicators and analyze the data:

We came up with 40-plus performance indicators. At that point, I would have said … 'Boy, we have to be able to come up with some way to put this together, and be able to see them in some rational way.' You don't want to look at pages and pages of output. You have to squeeze the result of the 400 performance indicators into something that you can assemble into your head at [a] quick glance (CE).

They [ETWG] weren't very organized and didn't synthesize, didn't have a plan to put it all together. [They] all were doing individual studies on wetland plants, on birds, frogs, fish, etc. About one year into the project, some of the people on the Study Board thought that it would be really good to develop an integrated model that would allow you to assess the environmental response or the ecosystem response as a whole, and that is where we came in. Our role was to develop what we called an Integrated Ecological Response Model to assess all these various components and put them all into a synthesis or an integrated framework that would allow you to see whether a given plan for regulation was good or bad for the environment, how good was it, or what components were impacted by the plan, and what components benefit from the plan (GR).

Towards the end of the LOSLR Study, the most relevant environmental PI turned out to be the one representing wetlands. Though the Study funding and other resources were distributed among several PIs, the PI for wetlands emerged as the one best able to represent the environment. Thus, the Study ended up where it began, placing emphasis in wetlands.

The IERM, like the Shared Vision Model, created controversy among members of the ETWG. Although the Plan of Study recommended the use of models, the ETWG resisted the introduction of the IERM for three primary reasons, which at their core highlight the very different ways participants conceptualized both the system and the decision process.

The first reason was the fear that conforming to a modeling framework would oversimplify system processes and result in a single number that would poorly represent the value of the environment and could be improperly used to compare the environment with other interests measured in dollar values (e.g., hydropower).

The SVM originally wanted to put everything in economic terms. The environmental work group really fought that all the way because we felt that there was no way that the environment could be put into economic terms and evaluated in those terms. So our model did not estimate economic costs or benefits of given plans. We just said, 'These components of the environment benefit this.' We also, at the Study Board's request, computed some overall environmental indices that weighed the various Performance Indicators. At least some people at the Study Board wanted that because they wanted to see one number. That was another sticking point. They [ETWG] didn't really like doing that because it was very subjective and it wasn't a really good indicator of necessarily overall ecosystem integrity. I mean we just didn't have the data to ...really model the integrity of the ecosystem (GR).

The other technical working groups basically had set out fairly straightforward [relationships]. It was not that clear at the beginning what kind of relationship we [ETWG] would get for the environmental components. I mean, we knew we had to relate hydrological conditions to surface area or number, or habitat, reproductive success, or whatever but not in such a formal way (CLC).

I always felt like we [the ETWG main modeling team] were trying to serve two masters. We would try to do things the way ETWG would like them done. But on the other hand, we were getting pressure from the Study Board to do things the way they wanted them done. There was always that balancing game to try to satisfy two masters' sometimes conflicting ideas on how things should be done, how the modeling results should be evaluated. An example was that the Study Board wanted to come up with this single, weighted index… The ETWG didn't like that at all. We did it and put all sort of caveats on it, and we did it because the Study Board commanded us to do it, but then that was counter to the desires of the ETWG. So those kinds of things happened a lot. But with big studies like that, it is always going to be that way (GR).

The second reason that the ETWG was resistant to relying on models was the adversarial way the modeling framework was presented to the ETWG within an already hostile environment:

He [a Study Board member] wanted the ETWG to be more quantitative, and he wanted there to be a model. [The] ETWG resisted it. One of the reasons was personality, the fact that he was imposing this upon them. It wasn't generated by the group (CE).

We were told, 'Well, you are going to make a simplified integrated index so that all the environmental PIs are collapsed into one magic number which is 4.2, 3.5 [or something like that] and then you add 10% margin of error of variation on all that.' Which is completely arbitrary. And that was unilaterally decided by the Board and by the PFEG against all the comments of ETWG (CLC).

On the other hand, a Study Board member was surprised to encounter resistance in trying to implement a holistic and comprehensive plan that included more variables.

I insisted on having an Integrated Ecological Response Model which included ultimately 500 indicator species. I wanted to know what was happening around the lake, not just to the wetlands but to all the species that were somehow linked to those wetlands and marshes. So it is mainly my doing that we went far beyond the scope of work on the ecological part, and I met a lot of resistance. I was amazed … that ecologists themselves were telling me, 'No, we don't need to do this. This is impossible to link species behavior and performance indicators' (SB- 2).

The third reason for ETWG's hesitancy was related to the competition over the resources that the group had been allocated. The ETWG felt that the modeling exercise was going to require resources that might otherwise go to the individual scientists to fund research projects; this fear increased with the continuing lack of clarity and rules on how the money would be allocated within the ETWG:

I still remember the first meeting I had with the ETWG when we were brought on board to do the modeling. It was really a pretty cold environment. I think they felt that the resources that were going to us to do the modeling were therefore not going to them for more field work (GR).

At the end of the modeling exercise, and in spite of the initial animosity, members of the ETWG felt satisfied with the IERM. The modelers had spent a significant amount of time and effort discussing the environmental components and finding ways to incorporate models made by members of the ETWG into an overall framework that allowed the group to look at the big picture

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6. One of the co-authors of this report, Joseph DePinto, was the developer of the IERM.

and place each Performance Indicator within an integrated framework As part of this process, the ETWG identified what they called “key performance indicators,” which they felt best represented the overall state of the economy.:

I think what was really key, there was a very strong back and forth flow of information, so when the preliminary version of the IERM was developed, everybody had an input into fixing it or making sure that it was really saying what they thought it should say (CE).

Whenever possible, we actually used the models that the individual researchers were developing on their own, like [a scientist within the ETWG, who] was developing a wetlands plan diversity model. We spent a lot of time working with him to incorporate his algorithm into the IERM. We did the same thing with the fish group that was working on fish spawning in response to water levels, and they had certain ideas about useable areas for fish, useable habitat and how that got impacted. We incorporated their ideas and algorithms into the model. So that helped them to buy into the overall concept because they could see that their work was benefiting from our help in integrating all of this. So over time, continually interacting and working with them helped (GR).

By the time the SVM and IERM were introduced into the Study, two to three years of data had been collected. The research had been done without clear goals to guide the hypotheses or the methods. Therefore, the SVM and IERM had mainly to use the available data rather than directing its collection and analysis.

We [IERM modeling team] sort of formed the model to the available data, instead of forming the data collection to the model, so there were things we couldn’t do with the model because we didn’t have the data because it was not part of the design. And that was kind of hard for the Study Board to understand (GR).

Although there was no integrative conceptual framework to guide data collection during the first phase of the study, the introduction of the SVM and IERM did guide subsequent research. Once the modeling framework was introduced, modelers engaged in a debate about communication between the Shared Vision Model and sub-models and among sub-models. The Plan Formulation and Evaluation Group (the group responsible for preparing alternative regulatory plans and evaluating their impacts on the various “interests”) preferred Stella, the user-friendly modeling software package that was used to build the SVM. Nevertheless, the ETWG modelers decided to use Fortran and Visual Basic for the IERM, arguing that it allowed them to make the model more robust and flexible.

Originally they [PFEG] wanted us to do the model in Stella which is the way [the SVM modeler] wanted to do the SVM. After we developed our conceptual model and figured out how we would be doing the various components, it took a little while, but we finally convinced [the modeler] that we couldn’t do the IERM in Stella. We did it in Fortran and Visual Basic because of the database that we had to develop within the model…Ultimately we just wrote the model and he incorporated it into the SVM (GR).

The final report of the Study Board notes that the output of one sub-model constituted the input for another and that code developed by individual researchers was included in the final sub-models (Study Board Final Report 2006a, p. 22). However, participants noted that the sub-models were being forced to fit the framework of the SVM and that there was no communication between the SVM and the sub-models:

They [PFEG] were requesting that the outputs from those [sub]models be outputs that could be funneled into the SVM … All the [sub]models fit awkwardly into the SVM … We had invested millions of dollars on the FEPS [Flood and Erosion Prediction System] model, the coastal management model, and that wasn’t communicating with the IERM model. There weren’t feedback loops that should have happened in many of these models that due to time and money just didn’t get funded or didn’t get done. So everything [was] fed awkwardly into the SVM. The PIs got funneled down during that time …By the time we got the SVM up and running, we were in our fourth year of study. Literally, the Board was crunched to look at all this data and figure out what the plans were that we were going to [present as options to the IJC]. We should [have] been looking at data long before we looked at it, in my book (SB-1).

Furthermore, the Plan of Study did not provide clear guidelines for integrating the information being collected or for developing alternative regulation plans. The Study Board played an important role introducing the Shared Vision Planning approach and defining how the collected data would be integrated and alternative regulation plans developed. However, the Study Board defined this course of action in an undemocratic way:

The Board members and especially the chairman of the Board on the U.S. side had a mind of his own as to how things were to be done. He more or less pushed everybody towards the system that he was comfortable with. And so *this very dominant person managed to push and shove and harass and do whatever he could in order to make sure that things were done his way even though I think a lot of the Board members did not necessarily agree with him (CLC).*

The ETWG felt that they did not have a voice and were not listened to by the Study Board:

We had two or three individuals that took us [ETWG] hostages and did whatever they wanted. No matter how much we protested, how much we disagreed, how much we wanted to propose something else, it just never worked (CLC).

An interviewee not directly related to the Study perceived that the leadership of the Study failed to build a common vision or drive participants to a shared goal or desired outcome:

You needed somebody in the St. Lawrence system to capture the collective imagination, and that never happened. You have just a bunch of modeling put together with vested interests demonstrating why their interest was the most important interest (GU).

The technical working group design adopted by the Study Board placed participants into competing interest groups. The Study Board did not build a vision of how a regulation plan should perform other than the Pareto optimization paradigm. Part of the reason is that the Study board never came to a consensus on what the vision was—which should have been the first step in the process.

The absence of a common vision and clear guidelines provided fertile ground for disagreement and group polarization. Participants could not agree among themselves on the modeling approach to take. The participants in the ETWG divided themselves in two groups; one advocated modeling, while the other questioned the legitimacy and the credibility of quantitative models in the process. The latter group felt that expert knowledge should have played a more important role in decision making and that the time scales and range of uncertainty were too large to provide useful predictions of the impacts of water level regulation on a particular resource:

There started to be a very strong polarization within the [ETWG] group. On one side you had the modelers, people who were working with theoretical models [and] very little data, all kinds of fancy 2-D hydrodynamics models and so on and so forth. [On the other side you had] the ones that were empiricists working with field data, long-term data- series people with lots of very pointed expertise for the environmental species' requirements. [These people] came to realize that 'Well, the window of time scales that we have to work with may not be appropriate for the life history point that we are trying to highlight here.' I mean if we are stuck with operational constraints at quarter monthly values, intervals of a week more or less, and if there is peaking and ponding and the eggs go dry for only an hour, even if the weekly average tells you that all is fine, all is not fine. So the mentality of those two groups and the attitude towards the models and the data and the performance indicators was extremely different (CLC).

On the other hand, quantitative model advocates argued that the development of the model highlighted the scientific community's poor understanding of the natural system:

These people [scientists and ecologists] don't know as much as they think they do, and that was borne out by the modeling. There are many myths that were developed by many people around the lakes, and what the modeling showed was that they really didn't understand how the lake actually worked, what the responses were and how the ecosystem worked. (SB-2).

Study Board members also felt that the inclusion of modeling was an important component of the Study and therefore they created the Plan Formulation and Evaluation Group (PFEG) to review the input from each group and then propose policy alternatives However, this most likely further divided the participants and reduced direct communication between the Study Board and the Technical Working Groups:

It [PFEG] was initially a technical advisory group to the Board, but it ended up being an insert between us [the Study Board] and the technical researchers. Right at the point the data had stopped being collected and they were starting to enter [data] into … all the sub models, the PFEG formed and stepped in, and we got isolated from those sub-models (SB-1).

When introduced into the study, PFEG was conceived of as a cross-cutting group across the TWGs, rather than as an intermediary between the Study Board and the TWGs, which ended up being the case:

The Plan Formulation and Evaluation Group [PFEG] was not part of the [1999] plan. It was not at all part of the initial plan of the Study. It was formed later on during the Study and it took a part of very large importance. It became not a

> *technical group among others. It became more or less an intermediate level between the working groups and the Board, a separate and independent entity (CLC).*
>
> *The modeling group should have been on the side such that the Board could have more interactions with the modelers... I don't think we got a chance to interact with the scientists and the sub-models at all. We [did not] get the ability to question the models or the functionality of the models (SB-1).*

The control and power that the PFEG and some members of the Study Board had in crucial matters, such as the measurement of uncertainty, was criticized by both ETWG members and by other Study Board members. Members from the ETWG argued that the 10% uncertainty measurement was arbitrarily chosen by the Study Board and PFEG and that it did not represent the contribution and impacts on individual Performance Indicators equally or accurately:

> *He [Study Board member] said, 'Well it is not important [error consideration]. Let's do plus or minus 10% around the environment,' and I said, 'What is the basis for the 10%?' [And he said], 'Well we don't need the basis. We just know there is a bunch of error, but we've got the experts working on it, so we shouldn't have to worry about it.' And I said, 'Okay, so are we going to do plus or minus 10% around the economic numbers?' And that never got dealt with. So the economic models and the economic numbers all had error with them, but none of the error ever got [dealt with]. I mean the further up you go, the more error you get. So when you look at the plan, I don't care which plan you choose, …there are differences in PI's. Are those significant? I asked that question, and nobody seemed to [answer]. 'Of course it is significant, the number says.' That is [his] response. I said '… you are not listening, is it significant?' and no one can answer because no one knows (SB-1).*

The joint NRC/RSC report and some of the interviewees shared their concerns about the options being considered. Both sources argue that the magnitude of uncertainty within each plan is comparable to or greater than the magnitude between the effects predicted in plans A+, B+, and D+. The NRC/RSC report notes, "Without formal analysis and discussion, it is not possible to assess the types or magnitudes of error and uncertainty for particular water regulation plans, or to know whether differences between plans are significant" (National Research Council/Royal Society of Canada, 2005, p. 5). The report recommends that the Study Board "inform decision makers of the types of quality assurance measures that were and were not undertaken and discuss their potential implications for decision making" (NRC & RSC, 2005, p. 5).

On the other hand, the Study Board's formal response to the NRC/RSC report dismisses these comments by stating that "our primary conclusion is that the NRC/RSC perspective and approach to the review was highly theoretical and did not fully recognize the practical nature of this large Study" (Study Board Director's Response, 2006, p 1). A Study Board member reinforced this need for practicality as part of public decision making:

> *I think what the NRC confuses is the very technical, analytical way of doing risk and uncertainty which would require another order of magnitude and detail, which is okay for academicians, but it isn't practical for us in a public decision setting. Remember, this is public decision making. This is not writing an academic paper (SB-2).*

In addition, the Study Board member argues that the measures of uncertainty used in the study were discussed among Study Board members and Technical Working Groups and that these groups decided to use 10% as a reasonable description of the range of uncertainty:

> *We developed qualitative metrics or measures of this data. If for example, an environmental indicator . . . referenced to the existing plan was 1.1 or 0.9, we felt that that 10% difference was about the range of acceptable uncertainty and that there was hardly any difference between the number that said 0.9 vs. 1.1, but anything beyond that range was a significant number. And so, we came to these decisions and conclusions based on a lot of risk and uncertainty analysis that went into the modeling beforehand, but it …wasn't discussed explicitly (SB-2).*

Indicators

Deliberative effectiveness

The Shared Vision Model, its use and misuse, has been emphasized in this chapter because the SVM played such an important role in determining how simulation models were used in the decision process.. All the models developed as part of the Study were required to produce results that fit the Corps' management planning approaches, including how the problem was conceptualized and which options would be put forth for solving the problem. Alternative approaches to understanding the problem and alternative solutions were neglected because they failed to fit into the SVM approach. The environmental working group, in particular, was severely constrained by the need to recast their role from that of scientific advisors to one of advocates for their particular "interest." This proved to greatly limit the possibility of a fundamental deliberation about how the environmental information would be utilized and how it might be used to revise regulation.

In addition, by organizing the deliberations through the SVM, the Study Board concentrated the entire process on comparing alternative proposed water regulation plans, which thereby limited the Board's ability to address other potentially environmentally significant aspects of water management. The Board never reviewed, for example, the decision processes used by the Control Board when deviating from the regulation plan, the information it relies on to make deviations, and how open or environmentally informed those decisions are. Other issues include daily fluctuations of levels resulting from the practice of pumping, storing and releasing water on a daily basis to coincide with peak periods of electrical usage, the time scale of the management actions, and other important topics virtually ignored by the Study Board study.

Although the Shared Vision Model was designed specifically to improve the effectiveness of deliberation, it became very complex and overwhelming for the majority of the participants. Initially, the Study Board introduced the Shared Vision Model using the argument that the individual interest groups would be able to manipulate the data and look at the results to create scenarios. Unfortunately, the way the Shared Vision Model handled data and the enormous amount of data that needed processing and analyzing meant these interactions did not occur as planned. Instead, an interface, called the Board Room, was developed *post hoc* to provide some of these capabilities.

It is important to note, however, that the Board Room was not part of the Shared Vision Model itself; it was a set of Excel spreadsheets created by the PFEG to facilitate deliberation and negotiation among interest groups. The outputs of the SVM and its sub-models were displayed on spreadsheets, and users could select from among a limited number of scenarios to evaluate regulation options. Nevertheless, participants considered it a positive example of how the Board Room helped with visualizing the models' results.

Explanatory effectiveness

The SVM was very effective in explaining the system as a set of claims, rights, and interests competing for water management practices that best served each group's interests. To the extent that that is a true representation of the system, the explanations were effective. The evidence in this case suggests that defining the environment as an interest rather than a shared responsibility created significant confusion for how the ETWG carried out its work. Nonetheless, the ETWG's models of the various relationships between hydrological variability and the life histories of a number of plants and animals in the lake and river enhanced the collective understanding of the linked system, especially how it responds to water level management. In addition, the Integrated Ecological Response Model synthesized the information produced by these individual models. The IERM assisted the ETWG in pulling together the various Performance Indicators into a form that allowed comparison between PIs and promoted increased understanding of the various PIs.

The idea behind the SVM was to promote a shared vision and understanding, but as a model of how the system works, it was already constrained by a set of assumptions in the Corps' planning model, assumptions which proved to be less than conducive to the stated goal: building a shared vision. Thus the SVM approach created a situation in which people felt forced to defend their "territory" and led participants to understand the objective as an agreement on tradeoffs between system components. In such a way, the SVM model made cooperation more difficult for participants.

Policy Relevance

The Shared Vision Model formally defined the approach of the Study as an "optimization challenge." The modeling also proposed and defined the alternative regulation plans as possible policy options to be decided upon by the International Joint Commission. The IJC has not yet come to a decision, and it is still not clear how the IJC will consider the alternative regulation plans proposed by the Shared Vision Model. Thus, the relevance of the SVM to the policy has yet to be seen. Certainly the judgment of the NRC/RSC review was that many of the results did not provide an adequate scientific basis for making the decision the IJC is entrusted with. That is a damning conclusion for a process whose purpose was exactly that, to inform the IJC in its decision making.

Modes vs. Functions Matrix

The following matrix of three functions (descriptive, predictive and educational) and three modes (system parameterization, interest clarification and participant education) represents a summary of the most relevant uses and functions of modeling ventures for this synthesis paper. In this section, we compare the performance of two models of the Lake Ontario-St. Lawrence Study (the Shared Vision Model and the Integrated Ecological Response Model) against the matrix of functions and modes.

Figure 9: Shared Vision Model (SVM)

Modes/functions	Descriptive	Predictive	Educational
Parameterize system	Describe system parameters and their relationships	Predict system responses to change	Improve understanding of the system. Organize and synthesize data about the system.
Clarify interests	Describe relationship between natural system and social systems	Predict impacts of decision	Demonstrate potential trade-offs
Communicate	Describe cause/effect relationships	What-if scenarios, develop shared vision of possible future	Explain limits, constraints and possibilities

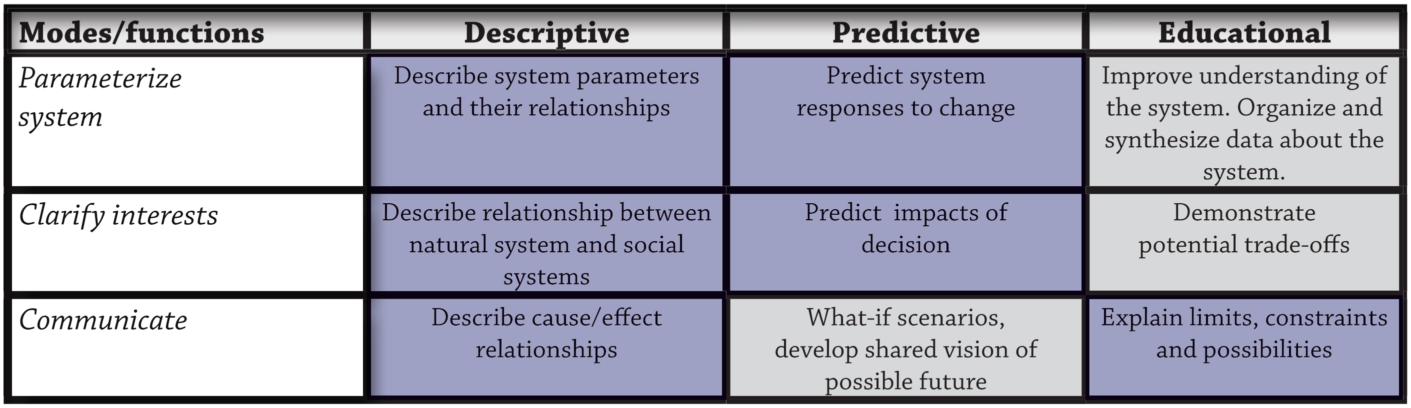
Sections in blue represent the areas where the Shared Vision Model could have been improved. The SVM improved the understanding of tradeoffs among interests to a certain degree; however, the Study's uncertainty measurements were questioned by its participants. Both the NRC/RSC review and Study participants questioned the validity and significant differences among plans.

At one point, the Study Board had difficulty interpreting and comparing the environmental section of the Shared Vision Model to the economic sections. Thus, the Study Board requested that the ETWG modelers produce an ecological index value. However, the ETWG resisted creating a single number to compare the environment with other interests, as they did not want to represent tradeoffs between environmental performance indicators. Due to the Study Board's increasing frustration, the ETWG was forced to create an index value to represent the environment.

The participants had two different conceptualizations of the issue which the modeling effort failed to bridge. One group saw the Study as an effort to include the environmental and recreational boating criteria as interests in a new water level regulation plan where six interests would be weighted equally against each other. The other group thought they were participating in the Study to include an environmental constraint which was long ignored by the current regulation plan. This group saw the study as an effort to measure the impacts of water level regulation on the environment, provide for mitigation, and agree on a new regulation plan that performed better for the environment without affecting the other interests (including recreational boating). The Shared Vision Model served only to increase this polarization and failed to create a common vision.

The SVM ended up having layer after layer of models, much like an onion. Each layer further separated participants from control and ownership of the data, from the results of the model, and from the process itself. The debate over Performance Indicators and the technology deflected attention away from the human interactions and relationships that are so crucial to achieving a shared vision. The debate centered on modeling and interests rather than on achieving a common goal.

Figure 10: Integrated Ecological Response Model (IERM)



Modes/functions	**Descriptive**	**Predictive**	**Educational**
Parameterize system	Describe system parameters and their relationships	Predict system responses to change	Improve understanding of the system. Organize and synthesize data about the system.
Clarify interests	Describe relationship between natural system and social systems	Predict impacts of decision	Demonstrate potential trade-offs
Communicate	Describe cause/effect relationships	What-if scenarios, develop shared vision of possible future	Explain limits, constraints and possibilities

Areas in gray represent the functions and modes where we conclude that models performed well, while those in blue represent the functions and modes where this modeling effort could have been improved. The IERM could have portrayed relationships among ecosystem variables as opposed to simply gathering and presenting first order environmental impacts. It is our understanding that these strong relationships were not drawn because the IERM as well as the SVM, to a certain extent, had to adapt and use data previously collected. The communication and measurement of uncertainty also could have been improved; the IERM did not provide an uncertainty analysis. The IERM also could have improved on integration of the environment with the social systems. Finally, even though the model expressed cause and effect relationships, these were limited to environmental variables. Nevertheless, the IERM aided participants in integrating the Performance Indicators and by serving as a bridging mechanism between models previously developed by individual scientists and the SVM.

Conclusions

The ambiguity at the beginning of the process, followed by the delay in formalizing objectives for the Study until the third year of the process, could explain some of the miscommunications and misunderstandings highlighted by participants. PFEG filled the gap left by the Plan of Study to formulate and compare the plans. PFEG became the de facto leading group in the Study, as they had significant influence in several of the decisions that the Study Board made, including the distribution of funding among Technical Working Groups. PFEG became the driving force in trying to bring the six competing interest groups together by promoting the use of common criteria that would fit into the SVM. However, the approach taken by PFEG also isolated the TWGs from the Study Board, and may have led to increased friction among these groups.

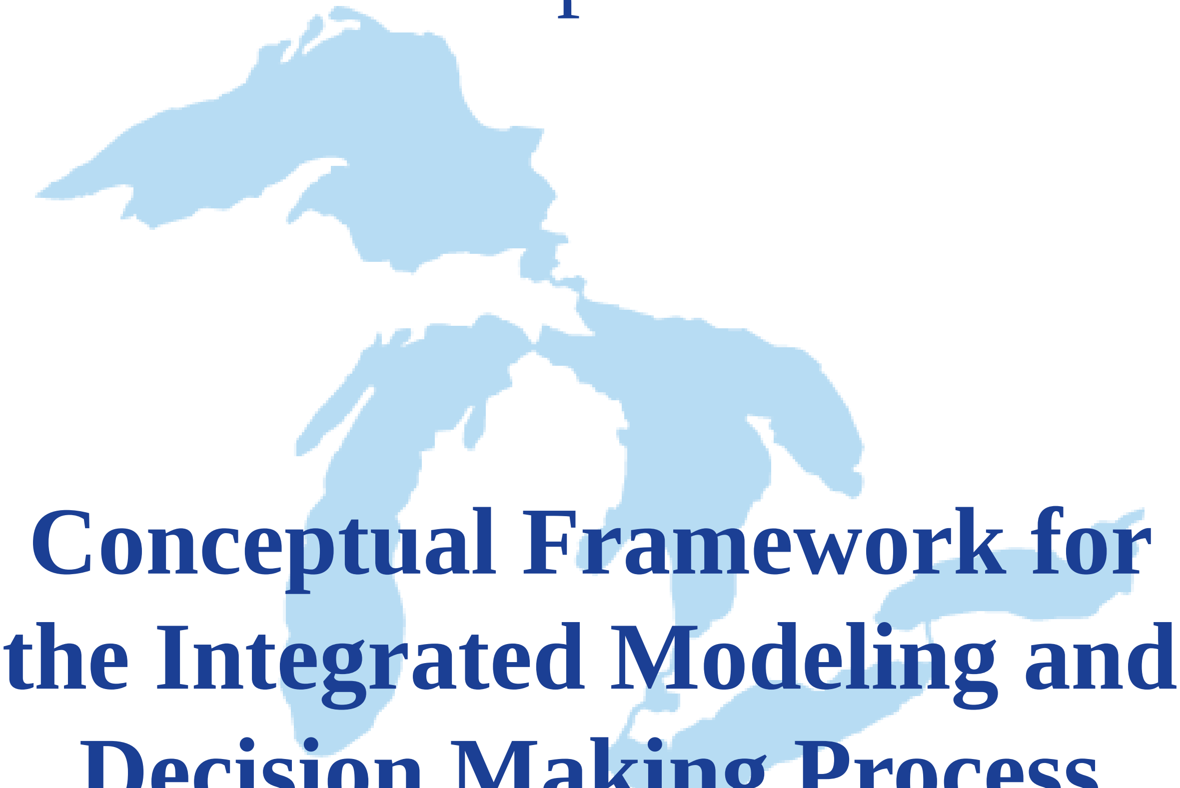
Lessons Learned

The Study was not reviewed by NRC & RSC until the end of the process. However, both interviewees and the literature (SAB, 2006; Jackins, 2006; Modeling Task Force, 1987) recommend concurrent peer review. The value of parallel review is two fold: first, the reviewers have direct knowledge of and opportunity to observe the decisions that are made throughout the process and therefore, to better understand the decisions made (such as leaving certain variables out of the model). Second, ongoing review provides the study organizers and modelers with an opportunity to fix mistakes and include recommendations in their processes before the final decision is made.

For the first three years of the study, data were being collected without any integrating modeling framework. The SVM and the IERM had to accommodate data that had already been collected. By the time the IERM was introduced into the Environmental Technical Working Group, most of the data had already been collected to support the use of Performance Indicators. Modeling should be considered early enough to inform data gathering, allowing discussions between modelers and data providers about the objectives of the modeling exercise and its data needs. Furthermore, decisions about funding allocation and data collection and analysis protocols should be considered and discussed in light of the modeling framework to be used.

From the beginning of the process, objectives must be discussed among and communicated to the participants in such a way that they are able to achieve a common understanding. This way, modelers would be able to know what questions are of greatest interest. Ideally, research and modeling frameworks would be derived from the objectives, rather than trying to fit together objectives, research practices, and modeling efforts each conceived with a different vision.

Chapter 6



Conceptual Framework for the Integrated Modeling and Decision Making Process

From the lessons learned in our case studies and our review of descriptive and prescriptive writing on modeling and decision making, we present a conceptual framework of two overlapping process cycles: the modeling cycle (as experienced primarily by modelers) and the environmental decision making cycle (as experienced by decision makers). This conceptual framework encompasses the entire process from problem conception to decision implementation and beyond (figure 11). While it is unlikely that a specific modeling and decision making process will proceed exactly along the paths specified here, this conceptual framework offers a prototype for designing future processes.

We have defined five distinct stages of the modeling/decision making process and six ongoing management considerations. The use of computer models to support decisions can be conceptualized as a spiral, with problems and modeling applications proceeding from previous turns of the cycle while new problems and applications feed into the next turn. “Short circuiting” occurs in the cycle when one stage triggers a relapse to an earlier stage. The five stages in the integrated modeling and decision making process are:

(1) Problem(s) Definition and Process Planning
(2) Refining the Approach
(3) Building the Model
(4) Application and Decision Making
(5) Adaptive Management

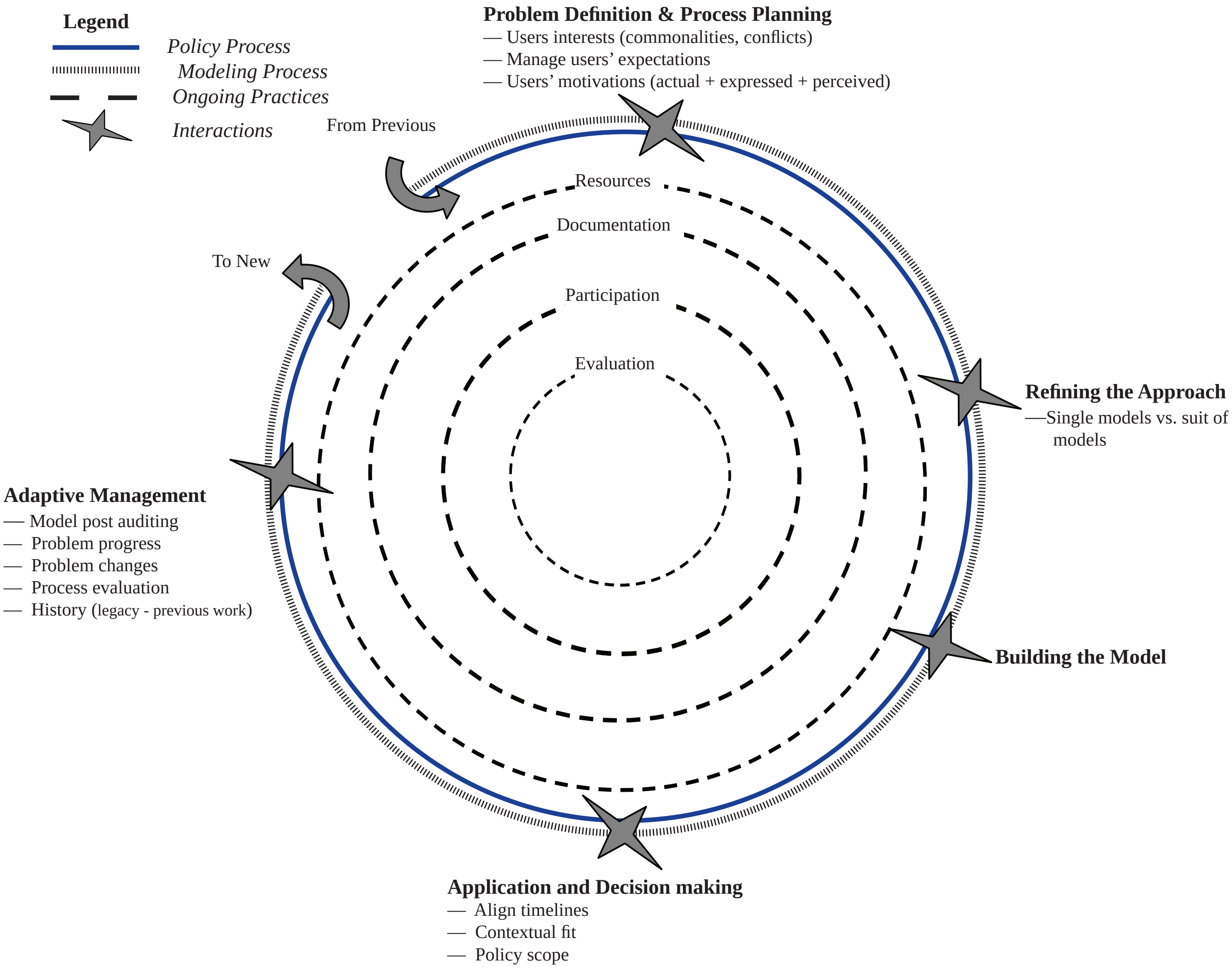


Figure 11. Interactions between the modeling process and the policy process

In addition, we found that there are several aspects of managing the process stages that should be considered throughout the cycle. The six overarching management concerns revolve around:

- Communication
- Participation
- Complexity and Uncertainty
- Evaluation
- Documentation
- Assuring Continuity of Resources

Lastly we discuss four categories of primary actors in the modeling and decision making process.

- Decision makers – those who have the legal authority and the administrative capacity to act, either by allocating resources to address specific environmental problems or by making policy with the explicit intent of affecting environmental change. These can include administrators in environmental agencies (i.e., upper level EPA administrators, fisheries managers), individuals or groups with politically recognized authority over certain aspects of environmental management (i.e., IJC Commissioners, US Army Corps of Engineers), and individuals empowered to resolve disputes and conflicts (i.e., judges). These participants often await recommendations to emerge from the modeling and decision making process and may or may not be involved with managing the advisory process. Decision makers may or may not include non-governmental and/or non-professional participants, depending on how the decision process is structured.

- Process Managers – those with the task of overseeing the process by which knowledge about the problem and its solution is generated and analyzed and how recommendations are delivered to the decision makers. Sometimes the decision makers and managers are one and the same. Some processes, like the Lake Ontario-St. Lawrence River Water Levels Study, are managed by a group such as a Study Board which may include non-governmental participants and stakeholder representatives.

- Modelers – those who are actively involved in the development and programming of environmental and decision-support models. At times, one or more of the other participants may be involved in some aspect of the modeling in different capacities.

- Public Participants and Stakeholders – those who are engaged in the process, either by invitation or self-selection, with the understanding that they represent interests, including both private and public interests. Stakeholders and public participants may promote values of both social and economic well-being and possibly the interests and well-being of other, non-human beings and future generations.

In the section below, we describe three overarching management concerns: 1) communication among modelers, data providers, process managers, decision makers and stakeholders; 2) degree of complexity and uncertainty of the model; and 3) problem framing. In reviewing these management concerns, we hope to explain how process designers and others involved in modeling and decision making can better plan for open, accessible, and hopefully successful experiences using computer models as environmental decision-support tools in the Great Lakes and elsewhere.

Overarching Management Concerns

1) Communication

It is apparent that accurate, timely and thoughtful communication throughout the process is essential if models developed for decision-support are to be used effectively (Peterson et al., 2004; Jakeman et al., 2006; Glaser & Bridges, 2007; EPA-SAB, 2006). This includes especially the communication between the modelers and the environmental managers who, in effect, commission the models, but also the communication among models and modelers since data from one model provides input to another. It also includes communication between the modelers and the scientists and technicians who provide data, and between the modelers and stakeholders who are participating in making decisions (Robinson, 1992). What appears to be essential is that there should be clear and well documented communication from:

- Decision makers to the environmental managers and all the participants about the problem to be solved, the scale at which the problem will be tackled, and the decision that needs to be made (Koontz et al., 2004; Smith & Koontz, 2003).

- Managers to the modelers and participants about the nature of the questions and the value of the model's output in answering these questions. Questions should be carefully formulated to elicit responses that will be of value in solving the problem(s) as defined by all decision makers, including stakeholders (Glazer & Bridges, 2007).

- Managers to the modelers about the type of output required, the level of precision and detail expected of the model, and the budget and other resources available (Modeling Task Force, 1987; Heidtke, 1986)

- Modelers to the managers about the limitations and assumptions of the model, about how the model will work, about the type and amount of data needed, about how data will be fed into the model and how the model will transform data into outputs (Felleman, 1999; EPA-Science Advisory Board, 2006).

2) Complexity and Uncertainty

There is an obvious but not necessarily simple relationship between model complexity and confidence in the model's output or level of "certainty." In general, the more variables and relationships "captured" or expressed mathematically in the model, the more confident one can be in the results. However, it is also true that the more data that is fed into the model, the greater the opportunity for error (Kendal, 2001; Scavia, 1977). One relationship is clear: the more complex the model, the more expensive and time consuming its development and maintenance. When deciding how complex the model should be, the most important factors to take into account are: 1) the questions the model is expected to help answer and 2) the amount of time and other resources available for the modeling effort (Wainwright & Mulligan, 2004).

The evidence from our research clearly suggests that decisions made in the beginning processes -- about problem definition, issue identification, and decision making -- will largely determine the future of the entire problem solving exercise. It is at this point when communication between the managers and the modelers is most important. Although managers seem reluctant to invite participation until this part of the process is concluded, our research suggests that this is a mistake. The lasting effects of these initial deliberations make participation by the professionals and public participants essential (Krantzberg, 2003). Early in the process, participants should reach a shared understanding of the issues being addressed, of the resources available for modeling, and of the model's management requirements (Robinson, 1992). These factors will determine how complex or how simple the model should be (Modeling Task Force, 1987; EPA Science Advisory Board, 2006).

In the fisheries management case study, for example, the SIMPLE model was criticized for being overly simplistic and deterministic, not expressing stochastic elements or communicating the level of uncertainty. In the subsequent revision of its earlier decisions, a new model, the RISK model, addressed these concerns. In the Lake Ontario-St. Lawrence River case, the clear need for a model to integrate the numerous environmental indicators that vary with water regulation was not recognized until very late in the process. Researchers and modelers never had the opportunity to work together to design the Integrated Environmental Response Model, and researchers were not given direction so their data and monitoring efforts would meet the model's needs. In the PCB mass balance modeling case, the model's value as a tool to advance knowledge of the fate and transport of persistent toxic chemicals (a research goal that pushed the modeling to ever greater levels of complexity) sometimes competed with its value as a decision support tool. Managers needed an estimate of the time needed under alternative management scenarios to achieve water quality goals. These management needs could have been met by a relatively broad-brush prediction confidently reached by even a simple model: that under every scenario it would take a very long time to achieve the standards for PCB levels set under the Great Lakes Water Quality Agreement.

3) Issue Framing and Problem Definition

Great Lakes ecosystem conditions are determined by chemical, physical, and biological processes at spatial scales from the microscopic to the planetary and temporally from nanoseconds to eons. The great intellectual challenge of modeling ecosystem state and behavior is deciding which processes and what scales are most significant. This requires a solid understanding of the system's components and dynamics, the skills to model them accurately, and the data with which to test the model's assumptions. Equally important for success, however, is an understanding of why the problem matters and to whom.

Scholars of environmental communication often stress the distinction between an environmental *problem* and environmental *issue*. Environmental conditions become *problems* only when so identified by people. In the case of Lake Ontario water levels, the *problem* for some only exists when levels are “too high;” for others, the *problem* exists when water levels drop “too low.” Water levels may be “too variable” for some while for others, they are not variable enough. In each case the *problem* exists when something one values is threatened. In the water levels case, the *issue* for everyone is water level fluctuations and the management of outflows at the Moses-Saunders Dam. In our fish management case, the *problem* from the standpoint of the fisheries scientists was the threat to the highly managed recreational fishery from a predator/prey imbalance. From the standpoint of the charter captains, it was the threat of a stocking reduction leading to fewer fish and fewer customers for fish charters. The *issue* for both was fisheries management. *Problem definition* always implies a standpoint while *issues* are categories of human activities that intersect with the environment and are relatively, though not completely, independent of standpoint.

Case	Issue	Problem(s)
Phosphorus modeling	Eutrophication	Fouled beaches, turbid water, fish decline, etc.
PCB mass balance	Toxic chemicals in the environment	Contaminated fish, contaminated sediments, health effects
Lake Ontario fish management	Fisheries management	Prey fish availability, predator/prey dynamics, fish catch, species preferences, ecosystem health
LOSLR water levels	Water level regulation	Power production efficiency, boating access and safety, wetland conditions, biodiversity, erosion, property damage

Our cases and literature review suggest that *problem identification* should be undertaken early in the process (Robinson, 1992; Kendall, 2001; Nelson, 1977; Cockerill et al., 2007). The EPA Science Advisory Board (2006) suggests dividing the *problem definition* stage into four distinct steps:

(1) Discuss the question to be answered. The questions a model needs to answer should be given as objectives in the initial statement of work or in other forms of communication from the decision makers to the modelers and process managers. The quality of measurement should be determined on the basis of these objectives

(2) Decide the type of model and the decision alternatives to be tested. Provide alternatives and compare different types of models, such as deterministic vs. stochastic, simulation vs. optimization

(3) Specify the domain of the model, the variables to be included, and the boundaries, time, and scales to be used

(4) Discuss the factors that could constrain the modeling process such as funding, availability of data, time, knowledge about the system, and expertise (see implementing the modeling)

Another aspect recognized throughout our case studies and highlighted in our conceptual framework is the importance of budgeting so that resources are available throughout the modeling and decision making process. This allows models to be post-audited and extended to other problems, if appropriate. For example, an important aspect of the eutrophication modeling effort was the continuous monitoring and data collection over several years after the models were built and implemented, which confirmed the validity of the models and made them useful as the seed for the later toxic chemical mass balance modeling ventures.

The stages in the conceptual framework are:

(1) Problem(s) Definition and Process Planning

(2) Refining the Approach

(3) Building the Model

(4) Application and Decision Making

(5) Adaptive Management

In addition we also described ongoing practices that should take place throughout: participation, documentation, evaluation and on-going support.

Implementing the Modeling and Decision Making Process

Problem Definition and Process Planning

While our case studies suggest that this ideal is not always achieved, environmental decision processes should always begin with a clear and transparent problem statement and a plan for the process that will lead to the decision. The more open and transparent this step, the easier communication will be later. This is especially true with regard to the communication between decision makers, process managers and modelers. It is important to start the modeling process with a particular policy problem in mind (Lee, 1973). The problem should be defined in terms of current conditions, desired outcomes, scale and boundaries of the problem, and indicators of policy success. This generally requires a systems approach (Van Dyne, 1966; Odum, 1993) since social, political and economic processes are likely to affect the outcomes even if the boundaries of the decision process are restricted to environmental indicators and policy levers. One of the most difficult and complex problems associated with problem definition is deciding where to draw the boundaries of the system (Hall & Day, 1977). They can represent both interest boundaries and geographical boundaries, and where they are set determines both the problem and who can participate in the subsequent modeling and decision making process (Wengert, 1976).

Early public involvement and publicity about the upcoming processes can facilitate more flexible and socially-responsive research (Krantzberg, 2003; 2006; Sclove, 2000). [See the section "Participation" for further discussion of selecting participants.] At this initial stage in the process, communication between modelers, decision makers, and other stakeholders can have a considerable impact on the outputs and outcomes of the process with relatively little expenditure of time, money, or effort. Discussions centered on the context of the problem, the technical capabilities of the modeling team, the sources of funding for tackling the problem, and the political motivations for addressing the problem help to set the boundaries of the problem. These discussions eventually assist in reaching agreement on a suitable definition of the problem and the scope of the subsequent problem solving approach.

This is also the stage where the objectives of the modeling process are set. Including potential users of the model is very important at this step, since defining the objectives is essential for selecting a modeling approach that is responsive to the needs of stakeholders and decision makers (van den Belt, 2000; Peterson et al., 2004; Peterson & Durfee, 2005). These discussions are also important in understanding the expectations of various stakeholder groups and determining what their expected outcomes might be.

Box 1. Problem definition and process planning: Examples in each case study

Eutrophication: + Participants agreed on a definition. The problem and the process were clearly defined and planned for at early stages.
Fisheries Management/ LOSLR Study: — Participants had different interpretations of the issues which caused animosity among participants throughout the process. *PCB Mass Balance* — Scientific ends and decision making ends were not always in alignment.

(+) denotes a positive aspect of the case study (-) denotes a negative aspect of the case study

Refining the Approach

Once the problem has been defined and the boundaries of the system set, it is possible to begin constructing a general model of the system. Previous models of the same system or of a similar system may be useful, as are discussions with stakeholders who have knowledge of the system (Jakeman et al., 2006). These discussions will help in transforming conceptual models into concrete hypotheses about the system, and eventually into the equations needed to create a simulation model. Hypotheses may serve as the main drivers for the model and are a way of defining assumptions (Glazer & Bridge, 2007). Discussions should include both what the hypotheses are and acceptable levels of uncertainty in model results (EPA-SAB, 2006; Robinson, 1992). These discussions can also help various stakeholders further articulate their ideas about the system and how it works. Questions at this stage of model development might also include the types of desired outputs (e.g., graphical, numeric, representations of uncertainty, etc.) and how users will access the model structure, management scenarios, and model outputs (Felleman, 1999).

Discussions should also focus on how to balance the various needs of the model users with the practicalities of the modeling and decision making process. For example, simple models are easy to understand but are also more likely to oversimplify the system, while models that are more complex reduce specification errors but magnify measurement errors (Wachs, 1982; Scavia, 1977). Therefore it is important to involve stakeholders in striking a balance between ease of understanding and complexity (Cockerill et al., 2007; Lund & Palmer, 1997; Modeling Task Force, 1987).

There are several ways to approach the development and choice of a specific model. The process could follow that of *collaborative* model development, where participants come together and arrive at a common understanding of the major system components and drivers (Peterson et al., 2004; Peterson & Durfee; 2005; van den Belt 2000; 2004; Cockerill et al., 2007). Another approach is *pluralistic* model development: several stakeholder or research groups develop their own model or use a common model framework as the basis for creating a new model (Lund & Palmer 1997; Palmer 1998; Palmer et al., 2002; Werick & Wippel, 1994). The models are then compared and contrasted during the decision making process. Both approaches have numerous benefits and disadvantages, thus the decision should be made after discussions with participants.

Finally, it may be necessary to conduct one or a few pilot studies using various modeling techniques to test particular approaches. For example, in the mass balance case study, the IJC organized a workshop in 1987, commonly called “the battle of the models” where three modeling teams were invited to represent the behavior of PCBs in the lakes using different assumptions and approaches. This exercise built more confidence in the use of models as tools to make decisions (Report to the Great Lakes Water Quality Board by the Task Force on Chemical Loadings of the Toxic Substances Committee, 1988)

Model Development

Creating the specific model or models requires multiple steps that could be generalized as: formalizing the knowledge of the system, defining variables and boundaries, conceptualizing the system in a diagram (drawing relations between variables), transforming the relations into equations, converting these equations into computer code, conducting trial runs of the model to work out “bugs,” and finalizing the model (Hall & Day, 1977; Jackeman et al., 2006). Modeling is both science and art, and modelers must balance theory, objectivity, and intuition in selecting the final parameters and processes (Lee, 1973; Wainwright & Mulligan, 2004). Models that maintain this balance are likely to be successfully applied.

Modeling is an iterative process that requires several rounds of verification, validation, and calibration prior to application (Glazer & Bridges, 2007). These steps can be very important tools for educating stakeholders about how the model works, for building model credibility, for confirming and refining expectations about the accuracy, precision, and uncertainty associated with the model outputs, and for discussing the role of these outputs in the larger decision making process. In spite of the importance of these steps, often they are dismissed, as they were in the Lake Ontario-St. Lawrence River Study and in the SIMPLE model of the fisheries management case study.

Application and Decision Making

Perhaps the most important question about models is not whether they are valid, but whether they are actually used in decision making (Ford, 1999; Robinson, 1992). Successful use requires that they are well-aligned with the timelines of the decisions, that they satisfy the requirements of both the institutions and individual stakeholders, and that they are accessible to the users.

The language of mathematics and computer code is different from the everyday, political, and legal language familiar to policy makers and citizens. Thus when they are used, models may contribute to confusion about certain aspects of the decision making process (Haan et al., 1990; Robinson, 1992). Therefore, it is important to ensure that stakeholders and decision makers understand how the models work, what the outputs mean, and how models are being used in the decision making process. The general public should have access to models - so called open modeling, hence they can participate in debating the alternative futures suggested by the models (Felleman, 1999; Walsh, 1993; Simonovic, 1996).

Box 2: Influence of modeling in decision making:
Examples from the case studies

Eutrophication:
- The results of the modeling applied mainly to open waters and thus the decisions did not take into account the differences between open water and near shore conditions.
+ Realization that non-point sources were the biggest concern

PCB Mass Balance:
+ Applied to remediation plans.
+ Realization that non-point sources were the biggest concern.

(+) denotes a positive aspect of the case study
(-) denotes a negative aspect of the case study

Distributing a “reduced form” model to users and training them in model operation is one way to facilitate the application of modeling to decision making and to ensure its credibility (Felleman 1999). Modelers may wish to conduct workshops that teach users how to use modeling software (Wyatt, 1999; Chen et al., 2004). Web-based data and models improve both the portability and accessibility of models (Beres et al., 2001). Other web-based modules may allow users to post comments about or vote on different management scenarios (Chen et al., 2004). These user interfaces are the primary means that most stakeholders and decision makers will rely on during the modeling and decision making process (Grimm & Railsback, 2000).

Continous Learning

After the initial application of the model and its incorporation into decision making processes, it is necessary to periodically return to the real world problem and make sure that the model continues to be relevant and accurate (Beres et al., 2001). Model results can only be supported with observations and data from the field, so “confirmation” of the model is only possible so long as monitoring continues (Oreskes et al., 1994). Repeatedly testing the appropriateness of recommended actions (“post-auditing”), includes updating model parameters and data inputs and correcting previous errors in model calculations or applications. This ensures that the models will continue to be accepted and used (Denning, 1990). The model may also require revision to account for shifts in the state of the ecosystem (e.g., introduction of a new species or extirpation of an existing species). Once a model has proven useful in one management application or geographic setting, it may be appropriate to use as a prototype for applications in similar ecosystems or for new and expanded management problems. The decision about how to apply models in new situations should be based on what users are doing with existing models and how these models might be redesigned to better meet the needs of these applications (Nix, 1990).

Box 3: Learning and building from previous experiences: Examples from our case studies

Eutrophication: + Continuous post-audit until the early 1990s. + Increased modeling techniques and skills that then were applied to toxic chemical mass balance models.
PCB Mass Balance + Built on the knowledge and models of the Eutrophication efforts. + The costs of the effort in Lake Ontario were reduced due to previous experiences in Lake Michigan and Green Bay - Could have been expanded extensively to other chemical pollutants. Due to lack of funding, it was only applied to a reduced number of other pollutants .
Fisheries Management/ LOSLR Study: + The RISK model took into account the recommendations and lessons learned from the SIMPLE model + Subsequently, participants were more satisfied with the second model.

(+) denotes a positive aspect of the case study (-) denotes a negative aspect of the case study

Participation

Models are often very useful tools for facilitating discussion and agreement on the quantity, quality, and kinds of information needed to improve our understanding about the health of ecosystems (Garrett et al., 1990; van den Belt, 2000; Cockerill et al., 2007). Ideally, modelers will include intended users in the early stages of the modeling process – problem definition and process planning (Kranztberg, 2003; EPA-SAB, 2006). The model development process must include both users (who bring knowledge of the problem and potential solutions) and analysts (who bring knowledge of the technical abilities of software and modeling practices) (Loucks, 1995; Robinson, 1992). Active and ongoing communication between stakeholders, decision makers, and researchers creates a feedback loop between research (in this case, modeling) and informed decision making (Firth, 1996).

While the value of public participation in decisions that affect the public may seem obvious, it is still a rather recent phenomenon. Natural resource and environmental decisions in the past have largely been made by agency bureaucrats with input from scientific and policy experts. It still may be necessary for a manager to argue the case for the benefits of public participation and the need to identify stakeholders' goals. Process designers should consider citizens' rights to environmental quality, amenity, and legal standing on environmental matters (Sewell & O'Riordan, 1976). Motivations for including participation in the process include: fulfillment of legal requirements, as a strategy to achieve certain objectives, as a means of conflict resolution, empowering disadvantaged or previously ignored groups, and developing literacy in a particular area of natural resource management (Wengert, 1976; Schneider, 2000; van den Belt, 2000). A further motivation might be how the invitation to participate may be perceived by potential participants and by others outside of the process.

It may also be helpful to clarify the historical and institutional context in which the decision process is taking place (Beierle & Cayford, 2002). Creating diagrams of the relationships among all the actors may be useful (Felleman, 1997). Such elucidation can be used in subsequent steps such as identifying potential participants and later in evaluating the participation process. Process managers should next identify potential participants by considering the roles of the various actors. These participants may be drawn from a wide range of expertise, ranging from technical experts and interest groups to the media to policy makers and citizens (Koontz et al., 2004). Further examination of the problem will likely yield additional potential participants, and more participants may be identified throughout the modeling and decision making process. Process designers should consider the roles of various actors in the process as they think about who should participate and how they should enter the process.

It is also important to devise an appropriate participation process for the decision making situation. There are myriad ways to incorporate participation into the process, including communication designed to get information *to* the public (e.g., briefings, exhibits, newsletters, and advertisements) and communication techniques designed to get information *from* the public (e.g., task forces, focus groups, interviews, hearings, and conferences) (USEPA, 2002; Creighton, 1992). Participation may take different forms for different actors, even within the same modeling and decision making process, so the most successful method may combine several techniques to get the broadest range of participants available. Designers should be aware that stakeholders may require some sort of incentives to participate (Belsten, 1996). Certain barriers to participation may exist (e.g., limited time to participate or economic constraints on both citizens and governments) (Kleinman, 2000), and it may be necessary to offer incentives to overcome these barriers so that stakeholders do not purposefully or inadvertently hold up the process (Lund & Palmer, 1997).

Finally, the process itself should be evaluated, not just the model and the decision outcome. Evaluation throughout the process will assist in modifying the ongoing participation methods to better serve the interests of the stakeholders and the goals of the process (Beierle & Cayford, 2002). This evaluation should ask if the participation method(s) chosen were appropriate to the context of the problem, if the outputs of the decision making process were useful, what types of relationships were formed during the participation, and how the participation built capacity within the various stakeholder groups (Beierle & Cayford, 2002).

Evaluation

Systematic evaluation is critical to improving environmental decision making, but consistent and ongoing evaluation prior to implementation is often overlooked (McAllister, 1995). Robinson (1992) suggests three types of qualities that are important to models:

(1) *Analytical quality* (the calculations are correct, the equations and models are valid);

(2) *Methodological quality* (the assumptions and approaches are appropriate); and

(3) *Political quality* (the analysis is timely and addresses important policy issues, the outputs from the model are usable).

Different groups of participants are concerned with each of these types of qualities and should be involved in their assessment.

Peer review is an important aspect of model evaluation for analytical and methodological quality (Garrett et al., 1990). Depending on the structure of the modeling and decision making process, peer review of the model structure and outputs could be done by other participants in the modeling process (Lund & Palmer, 1997), disciplinary experts not involved in the modeling process (e.g., state or national academies of science), or by "critical public interest scientists" who do not have commitments to powerful political or scientific interests (Robinson, 1992). In any of these cases, peer review should be incorporated throughout the process, rather than only as review of the final products (Study Board response to NRC review, 2006).

The political quality of the process and decisions is often determined by the citizens and policy makers. Important considerations include both legitimacy and saliency of the process and its results (National Research Council, 2007). Legitimacy refers to the fairness and impartiality of the process: did the participants have access to information, were their ideas and emotions considered (civic standing), and did they have influence in the process (the opportunity to discuss and decide on objectives and alternatives) (Lucas, 1976; Burke, 1979; Senecah, 2004). Saliency refers to whether the process provided results that were relevant to the initial objectives that users defined.

Documentation

The underlying technical assumptions, data series, and forecasts associated with models are usually not well understood by most of the non-experts involved in the modeling and decision making process, especially those who have not been intimately involved throughout the process (Wachs, 1982). Therefore, it is important that the choices and assumptions made during the modeling and decision making process be documented and this information be made available for all participants and public that might be interested (Jakeman et al., 2006). Even at very early stages in the decision making process, addressing questions about how the process and choices will be documented are important. Questions that process designers should consider while determining the need for documentation include statutory rights for access, philosophical grounds for access (e.g., education), and future needs for information about the model and model results (Sewell & O'Riordan, 1976; EPA Science Advisory Board, 2006).

Transparency is one of the most important attribute of any model (Lee, 1973). However, the documentation accompanying models is often incomplete or confusing (Beres et al., 2001), lacks mechanisms for reporting on uncertainty (MacKay & Robinson, 2000), does not follow a consistent format (Beres et al., 2001, Grimm & Railsback, 2005), and often does not record the process. Because of these problems, modelers should develop a standardized protocol for reporting. All documentation should strive for uniform language, transparent explanations, and placement of models in the landscape of possibility (Beres et al., 2001; EPA Science Advisory Board, 2006). In addition, model documentation should include sections related to each of the steps in the modeling process (Beres et al., 2001; Grimm & Railsback, 2005). Uncertainty should be represented through a range of estimated outcomes. Sources of uncertainty should be discussed, whether contributed by the model structure or caused by the quality of the data (Graham et al., 1988).

It is up to both the technical experts (modelers and scientists) and the non-expert users (stakeholders and decision makers) to make sure that there is sufficient and accessible information about the models and the process surrounding their development and use. The experts must "tell the truth" about the models by answering the following questions (Haan et al., 1990):

(1) Are the underlying data used in the model correct? Where did the data come from?

(2) Are the underlying theories correct?

(3) Does the model properly implement the underlying theory?

(4) Were the processes within the model completed accurately? What were the safeguards against error?

Likewise, citizens should ask the experts questions about the model and its interpretation (Schneider, 2000):

(1) What is the range of possible outcomes?

(2) What are the probabilities associated with model outputs? What do these probabilities mean?

(3) What are the underlying assumptions about the problem?

If these questions are asked and answered frequently, throughout the modeling and decision making process, and the answers made available for participants at all stages, the process will be much more transparent and accessible, and participants may have more chances to influence the modeling and the decision making process.

Resource Continuity

Financial, technical, temporal, and human resources must be sustained both during the process and into the subsequent stages of monitoring and evaluation (Koontz et al., 2004). Financial resources refer to the available and anticipated funding. In most cases, these resources will determine the degree of complexity of the modeling effort and the incentives offered to individual and organizational participants for joining (Belsten, 1996; EPA-SAB, 2006). Technical resources are directly related to the technology available for building models and model products (e.g., computers, software). Technical resources also include the scientific and technical understanding and knowledge of the system in question (including available data and analysis products). Time is an important (perhaps the most important) non-renewable resource, and it places constraints on nearly every step in the modeling and decision making process. Human resources refer to the personnel participating in the process and the skills, abilities, and experiences they have. The availability and personality of leaders are also important human resources that must be considered (Koontz et al., 2004).

We hope this conceptual framework for integrated modeling and decision making processes proves useful for others as they go about developing such models. We would also encourage model developers, decision makers and managers to share their "lessons learned" so they might contribute to the literature on evaluative research that documents model process development, success, and effectiveness.

Chapter 7

Lessons Learned/ Recommendations

In preparing this synthesis paper, we brought together the thoughts and experiences of participants in four major case studies, and we reviewed the scholarly literature on the modeling process and the use of models in decision making. If there is one overarching conclusion that we can draw, it is that as the tools of modeling become more powerful and more widely available, the greater their potential to contribute toward improving environmental decision making. As modeling becomes increasingly significant, the more important it becomes to plan and manage the *process* of using models to support decision making. This final chapter summarizes our findings regarding this process.

Problem Definition and Process Planning

We cannot overemphasize the importance of clear, accurate communication between the modelers and the managers. They need to arrive at a shared understanding, in writing, of the questions the model will be expected to inform, at what spatial and temporal scales it will operate, and what degree of confidence it will provide. Models perform many helpful roles in decision making. They can conceptualize a problem and its potential solutions. They can present competing alternatives, balance interests, and forecast outcomes of alternative actions. Given such a range of important functions, managers need to communicate clearly and openly their expectations, and modelers need to communicate their limitations. There may be significant obstacles. Managers are usually agency personnel supervising a process or project whose purposes have been determined by decision makers either at higher levels in their organization or by legislators, judges or executives. Often these mandates may be vaguely expressed in terms such as “undertake scientific assessment” or “provide opportunities for public participation,” or “prepare recommended alternatives.” It may be necessary for managers to persist in getting a well defined mandate before engaging the help of modelers[1]. Modelers on their part must be careful not to promise more than can be delivered. Like most professionals, modelers must promote their expertise and simultaneously acknowledge their limitations; the line between confidence and hype can be narrow.

Ambiguity at the beginning of a process can undermine chances for success. In the Lake Ontario-St. Lawrence River Water Level Study, participants reported miscommunications and misunderstandings which could be blamed on ambiguity at the beginning, followed by delay in formalizing objectives for the Study until the third year. In the phosphorus study, models were only able to simulate whole lake processes; near-shore dynamics were too complex to model. While the case is clearly regarded as a success and our research largely confirms this, we have no evidence that modelers adequately communicated this important constraint. Had this been adequately communicated, perhaps the monitoring would have continued over the years and produced the data to prevent algal blooms and other signs of eutrophication in many Great Lakes shore zones.

Once modelers and managers have agreed on the issues and the role of modeling, there remains the daunting task of communicating to the public, especially those expected to participate in the decision process. The fishery management case provides a good example of how communication was mishandled. The case involved extensive cooperation between fisheries managers and university-based fish biologists and ecologists to an extent that set new precedents in the Great Lakes. The communication and mutual education that occurred was a highpoint for most of the professionals involved. But when it came time to communicate with the sport fishing community, significant errors were made. The scientists understood that the condition of alewives was a measure of the future conditions of large predator fish. Alewives were the primary prey fish for the large salmonids that made Lake Ontario a popular fishing destination. When the scientists’ concerns about alewife populations were communicated to the public, however, many were left with the impression that the agencies (DEC and OMNR) were only concerned with the alewives, not with the salmon. If the objective of the process had been more clearly communicated, some misunderstanding may have been avoided.

While it is quite likely that prior to any active public involvement, discussions about the modeling and decision making process will occur among professionals, it need not be that way. As our cases demonstrate, the

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[1] This assumes that modelers enter at this stage of the process. In many if not most cases, models have been part of framing the issue that began long before the processes that have been the focus of this study.

decisions that may arise from these early discussions greatly affect the outcome of the entire process. Discussions involving problem definition and issue framing may be significantly enhanced by public and/or stakeholder input, and such public involvement may improve communication later in the process. Furthermore, as the number of participants and the complexity of the issues increases, it becomes increasingly important to pay attention to group dynamics. Teams, whether of participating environmental professionals or wider groups of participants, should have frequent meetings to avoid communication impasses; if face-to-face meetings are difficult, meetings could be web-based. A trained facilitator could detect miscommunication issues and clarify them for a smoother process (Cockerill et al., 2007).

Communicating about model complexity

Managers and decision makers often see models as a means to simplify complex environmental issues and make them conceptually manageable. Yet any simplification of complex and fundamentally unpredictable (chaotic) systems comes at the cost of uncertainty. To validate the model and its uncertainty bounds, the system being modeled should be continually monitored (Kendall, 2001). There is also a strong correlation between complexity and cost. Modelers and managers need to engage in negotiations that are very clear about these relationships between costs (in terms of both time and money), complexity, and uncertainty.

During the problem specification stage, managers and modelers should negotiate the appropriate degree of model complexity for the problem being addressed and the resources available. This type of back and forth communication between managers, decision makers, and modelers helps control expectations and avoids misunderstandings. In general, the academic and professional literature suggests that models should be kept as simple as possible to effectively inform the policy decision and facilitate the policy process (Scavia, 1977; Modeling Task Force, 1987; Felleman, 1999; EPA-SAB, 2006; Jakeman et al., 2006). However, in our fishery management case, the model with the telling acronym, “SIMPLE,” may indeed have been too simple, missing important ecosystem components and factors. The appearance that the agency had already made its important decisions prior to the public outreach process led to considerable distrust, especially when those decisions appeared to have come from an overly simple model of a system that anglers and charter boat captains knew in complex detail.

Models as pedagogical opportunities

Models can create opportunities for mutual education. While the SIMPLE model described predator/prey relationships and clearly warned of significant changes in the forage base, this information was not used effectively to develop a common understanding of the problem. Furthermore, in the process of designing the model, there was never an attempt to draw on the knowledge of the anglers and charter captains to characterize important aspects of the system dynamics. Interviewees consistently reported that the fishing community wanted to learn from the science and the models, but there was little opportunity to do that.

Understanding Different Ways of Conceptualizing and Defining Environmental Problems

Even when modelers and managers come to a common understanding of the problem the model will address, other participants may well have different points of view. People with many different perspectives should be included early in the problem definition stage, and managers should prepare a detailed analysis of not only stakeholders’ interests, as is typical, but their perspectives as well. Many of the communication and trust problems described in the fishery and water level management cases might have been avoided if such an analysis had occurred.

If the problem is clearly defined, broadly agreed upon, and represented in official public documents (e.g., terms of reference, charge to the parties, appointment letters, etc.), the chance of successful collaboration increases. Our findings concur with the U.S. EPA’s Science Advisory Board report on modeling (2006) which suggests that the problem definition should be broken down into four components: (1) Discuss the questions to be answered. They should be given as objectives in the initial charges. Data collection and measurement decisions should be made on the basis of these objectives; (2) Decide the type of model or models to be used. Provide alternatives and compare different types of models, such as deterministic vs. stochastic, simulation vs. optimization; (3) Specify the domain of the model, the variables to be included, and the boundaries, time, and scales to be used; and (4) Discuss the factors that could constrain the modeling process such as funding, data, time, knowledge about the system, and expertise.

Advantage of Multiple Models of the Same System

In the phosphorus modeling case, the scientists and managers involved took the opportunity to not only address the problem of phosphorus management through the models but to advance the practice of water quality modeling. The managers engaged several teams of modelers who produced a range of models from the strictly empirical (without a theoretical examination of causal relations) to complex process-oriented models. Later, in the PCB modeling case, this approach was organized into a "battle of the models" that was helpful in highlighting which processes and relationships led to PCB concentrations in water and in fish. The extensive deliberation among modelers, scientists, and managers meant that by the time results were presented and used to inform policy, confidence in their predictions was high. Kendall (2001) also encourages the use of multiple models and competing approaches, arguing that over time one approach or another will accurately predict outcomes.

Adaptive Management

Models are an essential component of what some call "adaptive management," the commitment to monitoring the effects of management action and the willingness to reevaluate policies and actions in light of monitoring results. Too often after a decision has been made, an impression is left that the problem has been solved. But in the complex world of ecosystems management, choices must be understood as reasonable hypotheses. Oftentimes, this "reasonableness" arises from the data assembled by modeling. The job is not done until the hypothesis has been confirmed: when changes in the ecosystem are consistent with those the model predicted. Monitoring of the system should be planned in close association with the post-auditing of the model. Through this process, models are refined.

In the Great Lakes, there is a clear need for regular evaluation and refinement of the large numbers of models that have been developed and used. Our case studies demonstrate the costs of not having this institutional commitment to continuous improvements in Great Lakes modeling. For example, despite the success of the phosphorus reduction efforts facilitated in part by the models described in the eutrophication case study, the monitoring needed to improve the models virtually stopped in 1991 due to the lack of financial and technical support. This case highlighted the need for a mechanism for continued evaluation and modification of the models. The Great Lakes are dynamic, and ecosystems change, at times dramatically. For instance, the introduction of zebra and Quagga Mussels significantly altered nutrient and light conditions in ways that models could not have predicted were they built prior to the population explosion of exotic mussels. The filtering activities of these creatures have brought about changes that strongly affect the fate and transport of lipophillic compounds such as PCBs.

Mechanisms need to be in place to regularly evaluate and upgrade the models on which managers rely. Currently, for example, there is no obvious way to maintain and update the many models developed as part of the Lake Ontario-St. Lawrence study and to use them to assess the decisions the IJC makes to revise water level management. Such institutional mechanisms could also facilitate advances in the skills and tools of modeling, helping to show that increases in computing power can lead to advances in understanding ecosystem processes.

Building institutional capacity for modeling and adaptive management would also make it possible to take a "building block" approach that could lead to substantial savings of money and time as in the Lake Ontario PCB mass balance effort. It was possible to take this approach in the Lake Ontario mass balance project because of the knowledge gained in the earlier, more costly efforts in Green Bay and Lake Michigan. Similarly, in the fish stocking case, the later more complete RISK model was used to revise decisions made earlier with the help of the SIMPLE model. The RISK model had more capacity to include input from stakeholder representatives at earlier stages.

Documentation and Evaluation

Our case studies highlight the need to fully document not only the technical aspects of the model but also how it has been used in the decision process. Plans for continuous development and improvement should also be documented. Our work further substantiates the standards for modeling documentation offered by Jakeman et al. (2006):

(1) Clear statement of the clients' and modeler's objectives for the modeling exercise

(2) Documentation of data used in the model (source, quantity and quality)

(3) Explanation of the reasons for choosing the type of model

(4) Justification of the methods and criteria used for calibration

(5) On-going peer review

(6) A statement of model utility, limitations, accuracy and room for improvement.

It is especially important that peer review be planned for and included throughout the process, including early in model development. This is more likely to occur if the project is seen as not only a decision-support effort but also as an opportunity to advance the science and technology of modeling. In the PCB mass balance modeling case, there was a strong emphasis on advancing the practice of modeling of toxic substances in aquatic systems, and there was an emphasis on peer review and quality assurance throughout. In contrast, in the Lake Ontario-St. Lawrence case there was very little planning for how models would be evaluated. Peer review took place after most work had been completed, and there were no resources or time to take advantage of the results. Institutional commitment to ongoing advancement of Great Lakes modeling could create both the expectation and the means to carry out early and ongoing peer review.

Lastly, we believe that the kind of evaluation we did for this synthesis paper, including the qualitative methods used to document people's actual experiences, should also be a part of evaluating all large-scale efforts to use models in support of environmental decisions. We have looked at three types of effectiveness in preparing this synthesis.

- Deliberative effectiveness: Is the modeling used in ways that improve the effectiveness of the deliberations among the participants.
- Explanatory effectiveness: Is the modeling used in ways that improve participants' understanding of the environmental and policy systems and enhance their ability to participate in an informed way.
- Policy relevance: Is the modeling used in ways that are relevant to the actual policy decision being made.

These three measures of effectiveness should be part of all assessments of modeling and decision making processes.

Conclusion

While decisions about models (e.g. how they will be designed and used, who will use them, the level of detail needed, etc.) are often seen as technical matters, they are also matters of public policy and need to be considered by those responsible for managing the decision-making process. When objectives of the decision process are clearly communicated, understood and accepted by the managers, modelers and all the stakeholders in the process, the experience of most of the participants in the cases we studied is that the models have been enormously useful. When objectives are unclear, poorly communicated and/or highly contested, participants' experience has been that the models have largely added to the confusion and led to greater levels of polarization among participants (Jakeman et al. 2006, EPA-SAB 2006). The growing literature on modeling and decision-making is consistent with our findings; all models need explicit statements of the modelers' assumptions and all models need explicit statements regarding the estimated precision (uncertainty) of their predictions.

Models will continue to play increasingly important and diverse roles in environmental management because complex decisions require not only detailed scientific understanding of ecosystem components (indicators) such as chemical concentrations, fish populations, wetland extent, biodiversity etc, but even more so, they require interpretations of these multiple indicators in the context of the complex objectives that give coherence to the relationships among indicators from multiple frameworks.

The four cases we selected together illustrate the increasing demands placed on models, modelers and managers over time by trends in environmental protection and natural resource management toward:

(1) ecosystem-based management and ecological forecasting

(2) increased meaningful public participation and collaborative decision-making

(3) adaptive management, where decisions are made, results monitored and policy regularly reevaluated

(4) sustainability, the inclusion of environmental values and ecological understanding in decision processes previously dominated by economic values.

These four trends guarantee that models will continue to play increasingly important and diverse roles in environmental management because these sorts of decisions require not only detailed scientific understanding of ecosystem components (indicators) such as chemical concentrations, fish populations, wetland extent, biodiversity etc, but even more so, they require interpretations of these multiple indicators in the context of the complex policies that give coherence to the relationships among indicators from multiple frameworks. The demands on environmental modelers and decision-makers are bound to grow.

We hope this conceptual framework for integrated modeling and decision making processes proves useful for others as they go about developing such models. We would also encourage model developers, decision makers and managers to share their 'lessons learned' so they might contribute to the literature on evaluative research that documents model process development, success, and effectiveness.

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