The Formulation and Evaluation of Lake Superior Regulation Plans for the International Upper Great Lakes Levels Study

A Strategy Document for IPR Review

Revised October 29, 2009
to address Independent Peer Review Comments Received on the April 20, 2009 Version.
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Plan Formulation and Evaluation

Strategy and Methods

Summary for Peer Review

This document and the associated appendices present the overall strategy and methods that will be used by the International Upper Great Lakes Study (IUGLS) to formulate, evaluate and recommend a new set of rules for regulating the release of water from Lake Superior. The first draft of this document provided a summary for peer reviewers to begin their task of assessing whether the strategy and methods are suitable for the task. The first peer review of this strategy took place on April 20, 2009 at the Canadian Centre for Inland Waters, Burlington, ON. This version of the strategy includes revisions stemming from that review. Bill Werick and Wendy Leger, the U.S. and Canadian leads for the Plan Evaluation Group (PEG), the IUGLS sub-committee responsible for designing and executing the evaluations, wrote this paper, with input from David Fay, the former Canadian Superior Regulation Task Team leader and now co-leader with Bill Werick of the newly formed Plan Formulation and Evaluation Group. Study leaders responsible for each sector reviewed the evaluation appendix, and are ready to provide any additional information. This revision also includes an updated adaptive management plan and references to two subsequent peer review documents that addressed some of the concerns of the PFEG peer reviewers:


An index showing where the responses to reviewers’ comments were included in this draft can be seen in Table 1, page 2.
## Table 1 Index to changes in response to peer review comments

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The IJC issued a directive to the Upper Great Lakes Study Board under the signatures of its U.S. and Canadian secretaries, approved in principle December 13, 2005 and signed February 7, 2007. It is available at http://www.iugls.org/en/mandate/Mandate_directive.htm. The first two of fifteen sections of that text deals with the substance of what the IJC asks the Board to do and is copied below, with selective emboldening added to the sections most relevant to this paper.

1. “Pursuant to the Boundary Waters Treaty of 1909 (Treaty), the International Joint Commission has an ongoing responsibility for assuring that projects it has approved continue to operate in a manner that is consistent with the provisions of the Treaty as interpreted by the Commission and the governments of Canada and the United States (governments). In carrying out this responsibility, the Commission has prepared and submitted to the governments The Upper Lakes Plan of Study for the Review of the Regulation of Outflows from Lake Superior (Plan of Study), dated October, 2005. The Plan of Study describes the work for the Upper Great Lakes system from Lake Superior downstream through Lake Erie required to: examine physical processes and possible ongoing St. Clair River changes and its impacts on levels of Lake Michigan and Huron; review the operation of structures controlling Lake Superior outflow in relation to impacts of such operations on water levels and flows, and consequently affected interests; assess the need for changes in the Orders or regulation plan to meet the contemporary and emerging needs, interests, and preferences for managing the system in a sustainable manner, including under climate change scenarios; and evaluate any options identified to improve the operating rules and criteria governing Lake Superior Outflow regulation. Additionally, depending on the nature and extent of St. Clair River changes and impacts, recommend and evaluate potential remedial options. In reviewing the Order and Regulation plan, and in assessing their impacts on affected interests, the Commission will be seeking to benefit these interests and the system as a whole, consistent with the requirements of the Treaty.”

2. “This directive establishes the International Upper Great Lakes Study Board (Study Board). The mandate of the Study Board is to undertake the studies required to provide the Commission with the information it needs to evaluate options for regulating levels and flows in the Upper Great Lakes system in order to benefit affected interests and the system as a whole in a manner that conforms to the requirements of the Treaty, and the Board shall be guided by this mandate in pursuing its studies. These studies include:

   a. examine physical processes and possible ongoing St. Clair River changes and its impacts on levels of Lake Michigan and Huron. Additionally, depending on the nature and extent of St. Clair River changes and impacts, recommend and evaluate potential remedial options;

   b. review the operation of structures controlling Lake Superior outflow in relation to impacts of such operations on water levels and flows, and consequently affected interests;
c. **assess whether changes to the Order or regulation plan are warranted to meet contemporary and emerging needs, interests and preferences for managing the system in a sustainable manner; and**

d. **evaluate any options identified to improve the operating rules and criteria governing the system.**

*The Study Board shall provide options and recommendations for the Commission’s consideration. In carrying out this mandate, the Study Board is encouraged to integrate as many relevant considerations and perspectives into its work as possible, including those that have not been incorporated to date in assessments of The Upper Great Lakes System regulation, to assure that all significant issues are adequately addressed."

As suggested by peer reviewers, the Board will conduct a legal review of how the treaty supports or inhibits regulation, especially for the environment, which is not a purpose explicitly protected by the treaty.

**Overview**

The International Joint Commission (IJC), a Canadian-US organization created by the Boundary Waters Treaty of 1909, approved the construction and regulates the operation of structures that control the flow of water from Lake Superior into the St. Marys River and the remaining Great Lakes and St. Lawrence River (IJC, 1914). There is an analogous structure on the St. Lawrence River used to regulate releases from Lake Ontario; the IJC completed the Lake Ontario St. Lawrence River (LOSL) Study in 2006 (LOSL Study Board, 2006). The IJC established the IUGLS for two reasons; to update the Superior regulation rules and to investigate the cause of lower Lake Michigan/Huron levels (IJC, 2007). This strategy paper **deals with the formulation and evaluation of rules for regulating Lake Superior releases.**

The overall approach used on IUGLS is **‘shared vision planning’,** as it was on the LOSL study, but compared to the LOSL Study, the IUGLS has less money to deal with an extra issue, it covers more geography, and the effects of regulation will be much less, both in terms of changes in water levels and changes in the associated impacts (see "4. The central evaluation challenge: the small impact of regulation, page 25). At the same time, the potential of exogenous drivers (e.g. the economic state of Great Lakes industries and climate change) to affect water levels and those associated impacts are anticipated to be an order of magnitude or two greater than the effects of regulation. It is also clear that the impacts of climate change and the regional economy will have an almost inestimable uncertainty and timing – no one can put credible probabilities on the success of the Michigan automobile industry two years from now, or the timing and manifestations of climate change on the Great Lakes.

**In sum,** the strategy is to undertake a slightly less ambitious economic and environmental analysis than was done on the Lake Ontario study, with a greater emphasis on climate change impacts and the ability of alternative plans to ameliorate those impacts, transformed as specific evaluation criteria to deal with those future impacts, along with a complementary ‘adaptive management’ plan as a way of dealing with the large uncertainties inherent in trying to devise plans that address the unforeseen consequences of climate change 50 years into the future. The last two issues are linked; the IUGLS team will focus less on
developing a regulation plan so robust it will suit any coming climate, and focus more on developing an adaptive management strategy that will facilitate and guide plan changes to accommodate climate change.

This summary of the IUGLS plan formulation and evaluation methods covers:

1. The overall approach – ‘shared vision planning’

2. Assessing the physical, economic, environmental, and social dimensions and impacts of current and alternative regulation plans on the affected water-using and water-dependent sectors

3. Determining public needs and preferences through a robust public involvement program

4. Plan Formulation: Creating regulation plans that address public needs, and minimize adverse impacts of changing environmental conditions.

5. Evaluation: Defining performance indicators, Board decision criteria for Plan Ranking and Decision Making,

6. Adaptive Management: a complementary plan that incrementally adjusts to the uncertainty associated with climate change and emerging trends in other social and economic factors that are associated with the use and management of Great Lakes resources, as they become evident.

Planning, Plan Formulation and Evaluation in the Great Lakes

The Study Directive is fairly clear about the processes and procedures that underlie the development and selection of a new (preferred) Lake Superior Regulation Plan. The need for a new Plan emerged shortly after the old plan – Plan 77A – was implemented in 1990, after many years of negotiation and development of several plans, and their variants, formulated in 1977. Soon after its ‘inaugural’ run, the Great Lakes were hit by a very high series of lake levels, and Plan 77-A didn’t seem to deal with the record high levels very well, despite the fact that this plan attempted to avoid the deficiencies of numerous other preceding plans that sequentially adapted to new record lows and highs since the early 1900’s. The constant reformulation of plans was a de facto form of adaptive management, - each step preceded by a comprehensive study of all the physical, social and economic factors affecting the management of the Great Lakes.

The “Great Lakes – St. Lawrence Basin Levels Reference Study” (1993) was one of the major studies that influenced the scope of the current IUGLS Study, and recommended the following actions (among 43 recommendations) specifically related to Lake Superior regulation:

4.2.11. Recommendations:

- The Board recommends that the regulation plans of Lakes Superior and Ontario be modified to achieve water levels and flows similar to those described in Measure 1.21.
- The Board recommends that the Orders of Approval for the Regulation of Lake Superior be reviewed to determine if the current criteria are consistent with the current uses and needs of the users and interests of the system.
The Board recommends that the International Lake Superior Board of Control be authorized to use its discretion in regulating the outflows from Lake Superior subject to conditions similar to those which authorize discretionary action by the International St. Lawrence River Board of Control.

Measure 1.21 is among the early plans formulated by the PFG, based on the recommendations of the “Lake Levels Reference” Study (the plan description is on page 22). The second recommendation is also being addressed in the IUGLS Study, since the original Orders of Approval only specify four principal users of the system: hydropower, commercial navigation and municipal and industrial water supply. The IUGLS Study mandate asks that other users be included as beneficiaries of any regulation options that would be developed, to include: recreational boating and tourism, environment/ecosystems and riparian landowners. Finally, the third recommendation addresses the need for dealing with exigencies and emergency situations. As it stands, the current regulation rules are fixed—with no discretion provided to deal with unique situations. The IUGLS will be developing management options not only for new regulation plans and criteria, but also how to deal with extreme high and low flow conditions, as well as appropriate institutional arrangements for exercising these discretionary choices.

Public Preferences, Emerging Needs and Interests are the Foundations of Planning

Any proper planning effort attempts to meld the technical/scientific/physical aspects of resources management (ecology, hydrology, climatology), which define the availability of resources, extremes and constraints of the natural system and its processes, with the human uses and future demands on those resources. This is the core of planning—balancing projected needs with available resources that are managed in a sustainable manner. Climate change is likely to affect the availability of water, but in a highly uncertain manner. Both the POS and the Study Directive make it clear that the Study is to focus on “...affected interests; assess the need for changes in the Orders or regulation plan to meet the contemporary and emerging needs, interests, and preferences for managing the system in a sustainable manner,”

This means that not only do the new regulation plans have to demonstrate improved performance for the historic and contemporary hydroclimatic record for the four mandated uses of the Great Lakes (hydropower, commercial navigation, municipal and industrial water supply, and irrigation), but also for emerging uses and affected interests, such as ecosystem needs, recreational boating and tourism and riparian homeowners concerned with erosion and flooding. Over the past 100 years, Lake Superior regulation plans have been routinely adjusted to ever-changing conditions in hydroclimatology and emerging needs. It has been the equivalent to an ad hoc, but continuous form of ‘adaptive management’, overseen by the International Joint Commission.

With all these uncertainties and unknowns about the future of the natural environment and of human uses, on what basis, then, are plans formulated and evaluated? This is the crux of planning, and of the process used in the IUGLS, ‘shared vision planning’. Who determines what these regulation plans should do and how is the ‘best’ plan decided? How does one derive criteria for evaluation from qualitatively stated ‘public preferences’? How are qualitative factors such as ‘fairness’ or equity in the distribution of beneficial impacts and adverse impacts determined in plan evaluation? How does the public influence...
the planning and evaluation process? This strategic document lays out the processes and procedures for addressing these fundamental planning questions.

The sources for plans, needs, evaluation criteria, performance indicators, values, preferences and planning objectives reside in four major interlocking components of the IUGLS Study, something of a Venn diagram:

- The **IUGLS Board** will develop evaluation principles that will guide tradeoffs among various sectors, needs and geographic areas, and will recommend several feasible alternative plans for consideration by the IJC, all of which, presumably, will be better than the existing Plan 77-A;
- The **Public Interest Advisory Group (PIAG)**, which represents diverse interest groups and users of the Great lakes Basin;
- The **IUGLS Technical Working Groups** who formulate the plans on the basis of expressed public needs and will translate the qualitative preferences, values and criteria of the public into a coherent set of evaluation factors and performance indicators that will serve as the principal basis;
- The **public**, acting through various public interest groups and non-governmental organizations (NGOs) that attend IUGLS public meetings; have access to the IUGLS website, and are interested in the Study.

The ‘Shared Vision Planning’ (SVP) process is the mechanism for eliciting those values; formulating plans that address the expressed needs of the public and interest groups, and integrating the results in an open and transparent manner as part of an iterative formulation and evaluation process. The goal of this SVP process is to develop a set of publicly acceptable and technically feasible plans, all of which improve the management performance of the present system, albeit to different degrees.

Numerous plans will be formulated to represent a wide variety of conditions and address various combinations of needs and interests. Performance indicators and impact criteria will be quantified to enable comparison of each plan on a common footing – economic benefits and costs; ecological criteria; physical changes (erosion rates, lake levels, and flows). The technical impact information for each regulation option simply first order screening criteria – to compare plans, and separate/eliminate the ones that are clearly inferior – i.e. there are other comparable plans that are superior for each criterion. At some point though, the technical screening can only take one so far – there is a need for a higher order set of guidelines that the ‘decision makers’ – i.e. the Study Board – will need to guide their tradeoffs among competing objectives within a feasible plan.

One of the key steps in the process is to establish a set of evaluation ‘**principles and guidelines**’ that the IUGLS Board would use to assist its deliberations and formal evaluation of the various alternative plans that will be developed during the course of the study. Many plans will be formulated to address only a subset of the full range of planning objectives that reflect different public interests. Tradeoffs will have to be made among the various competing management objectives within each formulated plan. The deliberations of the Board should be transparent – hence the ‘**principles and guidelines**’ for evaluation need to be developed in parallel with the SVP. A good example of such ‘principles and guidelines’, developed by the Lake Ontario – St. Lawrence Study Board can serve as a starting point for the IUGLS Board, in particular since they do substantively reflect what are considered as appropriate guidelines for sustainable development. The **Guidelines** were structured to guide the choices, tradeoffs and ultimate decisions of the Board. Ideally, each candidate plan (preferred plan selected for consideration by the Board and IJC) should:
• Contribute to **Ecological Integrity**
• **Maximize economic and ecological net benefits**
• Result in no **disproportionate losses** for any sector or geographic area
• Be flexible in recognition of and **adaptation to unusual or unexpected** conditions
• Be adaptable to **climate change** and **climate variability**.
• Reflect decision-making that is be **transparent and representative**
• **Adaptable** to future advances in knowledge, science and technology.

**Climate Change Scenarios**

Aside from the conventional planning approaches required to formulate and evaluate plans, dealing with highly uncertain climate change impacts will present a uniquely difficult problem for both formulation and evaluation, given the very large uncertainties associated with this aspect of the study. Climate change and variability, along with flexibility in recognizing and adapting to unusual events were key guidelines for the previous LOSL Study Board, which was confronted with very similar issues to those of the IUGLS Board. The IJC Directive and POS make it clear that developing responses to climate change is a major aspect of the study. The 1993 Lake Levels Reference Study recommended this as an important emerging issue to be dealt with explicitly:

> “There remains a considerable amount of uncertainty in the scientific community over the potential magnitude of specific hydrologic impacts of climate change; however, there is a general consensus that climate change is taking place and that the potential impacts of global warming should be considered in decisions relating to the Great Lakes-St. Lawrence River System. Thus, the possibility of extremely low water supplies to the Great Lakes and St. Lawrence River should be considered in future regulation plan design and policy development. Existing regulation plans should be reviewed and modified as necessary to ensure their responsiveness to low water supply conditions.”

The IUGLS Plan of Study (2005) to improve Lake Superior outflow regulation includes:

- Review of how Lake Superior outflow regulation and the operation of the control structures affect water levels and flows in the upper Great Lakes system
- Identification of potential updates and improvements to the criteria, requirements, operating rules and outflow limits as well as incorporating operating experience into the regulation plan
- Reviewing current institutional arrangements governing Lake Superior outflow regulation
- Testing of regulation plan performance under climate variability and climate change scenarios.
However, simply testing the performance of alternative regulation plans under various climate change scenarios, in addition to performance under the historical sequence of flows is not the only aspect of formulation and evaluation. The POS explicitly deals with formulating and evaluating potential structural modifications that may be required in conjunction with Lake Superior regulation plan modifications, should remediation plans for the St. Clair River be required.

No structural modifications to the St. Marys River would be considered when investigating potential improvements to Lake Superior outflow regulation. The evaluation of existing and potential Lake Superior regulation plans may need to consider scenarios of potential structural modifications to the St. Clair River, should physical remediation works in that river be warranted. The testing of alternative Lake Superior outflow regulation plans will take into consideration climate variability and climate change as well. (pg 16, POS, 2005)

“Should remediation measures of a dynamic nature be considered, a regulation plan and operating rules for such measures would need to be developed in concert with Lake Superior outflow regulation. Any plan would also need to be able to respond to unusual hydrological conditions, including the potential for changes in water supply as a result of climate change and variability affecting the upper Great Lakes system.” (pg 36, POS, 2005)

Hence, there are three distinct levels of climate-related (contemporary variability and climate change) formulation, evaluation and impact analysis related to L. Superior Regulation Plans:

- Developing plans that perform well under historical (contemporary) climate variability, particularly under extreme conditions, using historical record to evaluate performance;
- Testing performance of those same plans under various climate scenarios and conventional stochastic analysis, based on statistical extension of historic record;
- If the formulated plans for L. Superior regulation cannot effectively deal with the potentially extreme changes associated with climate change scenarios, then there may be a “...need to consider scenarios of potential structural modifications to the St. Clair R....”

The language of “...scenarios of structural modifications...” suggests only that the IUGLS need not engage in detailed feasibility studies of structural measures to deal with climate change. Rather, it suggests a more notional exploratory analysis of what type of structures may be considered, and what physical effects they might have on mitigating the adverse impacts of climate change on long-term lake levels, based on data derived from General Circulation Models (GCMs).

1. Overall approach

Shared vision planning will be used to support the Study Board’s responsibility, which is to provide options and recommendations for the Commission’s consideration of a new Lake Superior regulation plan and/or changes to the Orders to the Lake Superior Board of Control. Shared vision planning has been in use for nearly 20 years, and was used for the Lake Ontario –St. Lawrence Study. Shared vision planning knits together systems based planning and decision making, modern involvement techniques and the use of an easy to use computer model of the system under study.
1.1 Definition of shared vision planning

Shared vision planning is a well defined approach groups can use to consider the consequences of water management decisions before they are made. This method was first developed for drought management during the Corps of Engineers’ National Drought Study, and is explained step by step in one of the main reports from that study (U.S. Army Corps of Engineers, 1994). The process was next applied to basinwide studies that included the full range of hydrologic possibilities, including water allocation in the Apalachicola-Chattahoochee-Flint, Alabama-Coosa-Tallapoosa (ACT-ACF) basins (U.S. Army Corps of Engineers, 1998) and flooding in Devils Lake, ND (Werick et. al., 1999).

Shared vision planning has three distinguishing characteristics:

- **Planning procedures** based on the systems approach of the Harvard Water Program and the U.S. Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (the P&G).

- **Public participation** structured for effective, fair representation of the various public interests.

- **Shared vision modeling**

1.1.1 Planning procedures

Shared vision planning is a modern extension of water resources planning traditions that extend back to the beginning of the twentieth century. Research and practical experience helped develop an arsenal of planning tools in areas such as economic and environmental analysis and statistical hydrology during the 20th century. Shared vision planning is built on that tradition but is reshaped for use in the types of water decisions that are more common in the 21st century, when it is more likely there will be multiple decision makers with shared responsibility for a basin, and the decision possibilities more often include changes in behavior as well as investment in a new construction.

Shared vision planning proceeds iteratively, tracing and retracing these steps:

- Build a team and identify problems
- Develop objectives and metrics for evaluation
- Describe the baseline condition
- Formulate alternatives to the baseline
- Evaluate alternatives
- Select and implement the preferred plan
• Use, exercise, and update the plan (adaptive management)

In this case, the Study Board members are the first decision makers; they will decide which options to send to the International Joint Commission (IJC) for consideration.

1.1.2 Public participation

Shared vision planning builds on larger trends in public involvement methods. The trend towards greater public access to water decisions long predates shared vision planning. Hanna Cortner identified four overlapping eras of public participation in water resources decisions; closed participation in the early twentieth century, maximum feasible participation (driven by post World War II legal requirements for agencies to publicize decisions), environmentalism (NEPA-style public involvement starting in the 1970s), and collaborative decision making (the most interactive and most recent) (Cortner, 1993). But critics such as Cary Coglianese have shown that access can translate into disproportionate influence of special interests over use of the public resource (Coglianese, 2002).

Shared vision planning is designed to simultaneously expand public access and avoid disproportionate influence. Public participation is pursued using existing public groups wherever possible rather than creating new ones associated only with the study. Interested members of the public can participate in model building and see every detail of the study for themselves, but the problems and planning objectives are systematically developed to address broad public interests for which there may not be an advocacy, such as environmental quality, and economic efficiency in the production of widespread benefits such as lower transportation and energy costs. To reach out to interested public groups, the PEG, in coordination with the Public Interest Advisory Group (PIAG), will be hosting a series of Circles of Influence Workshops to meet with small groups of people whose interest and knowledge on these issues has won the trust of others. Participants in these workshops are suggested by the PIAG and others. The goal of these workshops is to begin to earn the trust and establish a line of communication with interest groups that will radiate out to the people who look to participants for leadership on water level related issues (thus the notion of circles). These are small workshops (no more than 10 people) in which PEG provides some background on the study and then asks participants to describe problems and opportunities from their point of view. A discussion takes place around the expectations for the study and suggestion for things the Study Board should consider in making their recommendations to the IJC.

1.1.2.1 Public Education

Stakeholders who do not understand how limited the impact of Lake Superior regulation is on Great Lakes levels are likely to be critical of any proposed regulation plan its performance will fall short of their expectations. It is fairly common for the general public to be misinformed about water level management, and that has been documented on the Great Lakes; many complaints about levels on the Lake Ontario Public Interest Advisory Group questionnaire blamed the Corps of Engineers, for example, even though the Corps does not regulate Great Lakes levels. These misconceptions persist despite the various outreach efforts of the IJC and others.

This lack of understanding is hard to eliminate completely because so many homeowners are never or rarely connected to the study or any outreach attempt, but the Board is aggressively addressing the issue with general information (website and newsletter), public meetings, and Circles of Influence. The study team developed the so-called fencepost regulation plans, each designed to optimize levels for a
single interest or stakeholder group. The fencepost plan designed to address the concerns of property owners along the coasts of Lake Michigan-Huron above all others shows clearly that regulation of Lake Superior cannot eliminate all flooding or low water impacts on Lake Michigan-Huron, even if Lake Superior is used solely as a reservoir, with no regard to the environment or stakeholders around Lake Superior.

Circles of Influence workshops are designed to allow small groups of knowledgeable stakeholders and IUGLS planners to discuss sophisticated study issues in an open and informal way. The principle behind these Circles workshops is that the study will learn more and stakeholders will be more likely to trust the study if stakeholder experts have the opportunity to provide insights and aggressively challenge IUGLS planners in small group discussions. Although primarily designed to help identify stakeholder preferences, using the “best possible” scenario approach with these experts will help create a credible definition of the limits of regulation to satisfy stakeholder interests. Because these stakeholder experts are already trusted by larger stakeholder groups, and because they often interact on a more continuous basis with stakeholders through interest based organizations, doing this should improve the general understanding of the limits of regulation.

1.1.3 The Shared Vision Model

The central notion of shared vision planning is that experts, decision makers and stakeholders all work together to build a unified computer model of the lake or river system – a shared vision model. This type of model was conceived at the University of Washington by Professor Richard N. Palmer (Werick et al., 1999). Shared vision models are built with user-friendly, graphical simulation software. They bridge the gap between specialized computer analysis tools and the way people conceptualize problems and make decisions (Werick et al., 1999). This helps minimize disagreements about facts and shift the debate to how to balance conflicting objectives. Because the baseline condition is also modeled, participants know what the outcome will be if they fail to negotiate a new decision.

All water management studies of the last several decades have used computer models to generate or support their conclusions, but they typically do so in a fragmented way. In a traditional study, a small number of alternative decisions are identified, and then provided to specialists for evaluation in their several independent models. Planners collect the results from these various models in tables and post them in a planning report. Decision makers study the report to determine which alternative is the best. There are several problems with this approach:

- The experts tend to build models shaped by their research and professional habits, not the decision, so their models may not be very helpful to decision makers;
- Expert modelers tend to work in isolation using software that only experts understand, so others see the models as black boxes whose results cannot be trusted;
- Models like these tend to undetected errors because they are difficult to review;
- Evaluation of alternatives is a lengthy and costly process. Contracts with the team of experts necessarily limit the number of iterations allowed, so experimentation is severely restricted.

In sum, these specialized models tend not to be trusted and may not be useful or even accurate. Shared vision planning requires the collaborative construction of a single model of the entire system under
study, with explicit mathematic links between the experts’ research and the decision makers’ decision criteria. The collaboration helps assure the model will be trusted and well reviewed. The explicit connections improve the chances that the research will address decision makers’ real needs.

Shared vision planning is a form of system dynamics used in publicly accessible decision making. An American electrical engineer, Jay Forrester developed system dynamics and wrote about it in a 1961 book called Industrial Dynamics (Forrester, 1961). System dynamics is related to systems engineering, which was first used by Bell Laboratories during World War II and systems analysis, developed at the U.S. Air Force’s Rand Corporation in the 1950s and first taught at the Massachusetts Institute of Technology (MIT) (RAND, 1996).

The commonality among systems engineering, dynamics and analysis is the conceptualization of problems and solutions in a systems context focused on goals. Forrester took ideas used by Bell to assure that every element in a system of engineering, design and construction would be harnessed to produce the desired product and expanded them so they could be used for social and environmental systems. This approach is most controversial when applied to complex systems in making predictions long into the future; the dangerous conceits are that we understand how complex systems work, that we can model them, and that the future will behave like the present. The most famous of the controversial uses of systems thinking was the Club of Rome’s use of systems thinking to demonstrate the limits on global population growth (Meadows, et al, 1972). The same concerns (do we understand how systems work, can we model it, and will the future be like the present?) apply to the Upper Lakes regulation study, but they are mitigated greatly because the decision at hand is a small modification to practices with a fairly long and well documented history, and because the decision can be revised relatively easily. Adaptive management can formalize the revision process and link it directly to those aspects of the system where we are least sure we understand or can model correctly.

1.1.4 What do you see in a shared vision?

The vision that is shared in shared vision planning may not be the vision about what to do, although that is the goal. William Lord (Lord, et al. (1979) organized water conflicts by three root causes:

1. **Cognitive** conflicts, which result from different determinations of the underlying facts and concepts, creating different visions of the outcomes of a decision.
2. **Value** conflicts occur when two parties disagree about the desirability of the same outcome. These can occur without cognitive disagreement (two people agree that 1,000 acres of wetlands will be lost, but one cares and the other does not).
3. **Interest** conflicts can occur when the parties in the dispute benefit differently from the decision (two people agree the flood will happen, both agree that it will cause $10,000 damage, but one lives in the house that will flood and will lose $10,000, while the other will lose nothing).

These conflicts can be compounded; an artificial cognitive conflict may be created if there is evidence that supports a decision that would create a personal loss or a negative impact to what some parties value highly.

Shared vision planning is well designed to minimize cognitive conflict but the best hope for resolving conflicts arising from differences in values and self interest is to find solutions that can make as many parties as possible better off without making anyone worse off. In one of the first applications of shared
vision planning, the method was applied to drought management of the Kanawha River in West Virginia one year after a drought management study had been done using traditional means. The shared vision planning effort was very successful because the interactive shared vision model facilitated the formulation of better plans than had been produced by the previous study, and because the involvement of stakeholders in the planning process made it easier to design a plan that would have broad acceptance. But in the Kanawha study, the expert analysts were able to devise a plan that was better for most parties and at least as good for others. Cognitive conflicts had existed and were resolved by the shared vision planning process, but it was the solution that addressed value and interest conflicts because it required no tradeoffs. The new plan was put in place quickly.

Shared vision planning can ameliorate value conflicts. The interplay of stakeholders can produce empathy and better understanding of different perspectives. But when the best solutions produced by a shared vision planning create net overall benefits but require tradeoffs that are significant in the eyes of stakeholders or decision makers, then it is likely that “losing” stakeholders will not share the vision about what should be done. In those cases, the best that shared vision planning can do is to serve as a basis for mitigation or adaptation that can, in effect, reimburse the small losses in one sector from the large benefits overall.

2. Plan Formulation and Evaluation

Planning is the consideration of consequences prior to decision making, with the intent of making the best decision. But how sure are we that we have not left the best plans undiscovered? How well can we predict consequences which cannot really be known until after the decision is made? And how would we know which consequences are more important than others? (A key reason for undertaking both the Upper Lakes and Lake Ontario-St. Lawrence River studies is to address the lack of consideration given to environmental consequences in past studies). Water resources planners have grappled with these questions for a long time (the Roman Emperor Claudius was reputed to ponder the consequences of the harbor improvements at Ostia) and there is a legacy of methods to formulate and evaluate plans, but some methods produce surer, more usable results. The IUGLS Board will consider the economic, environmental and social impacts of its recommendations. The IUGLS economic estimates of commercial navigation and hydropower are the surest; economic impacts to the shoreline, municipal and industrial water users and recreational boating are not as comprehensive or as simple. The ecological impacts of regulation plans may be even more difficult to distinguish and are unlikely to be measured in dollars. Finally, the issue of whether a new plan is equitable to all stakeholders is likely to be very important (it is the reason behind the balancing ideal of the current regulation plan, and was a key criterion in the Lake Ontario study), yet it is difficult to quantify. The Board’s judgment on social impacts will come from the reaction of stakeholders during the Board’s deliberative process. The shared vision planning process is designed to give stakeholders the tools they need to inform their positions in that dialogue.

There is a detailed discussion of plan evaluation by sector in Appendix 1 Plan Evaluation, starting on page 38. Details on the formulation of plans are included in Appendix 2 Plan Formulation, page 66.

2.1 Water supply sequences and the robustness of plan evaluations

The basic notion of shared vision planning or of rational analysis is to test decisions in the abstract, but as realistically as practical before committing to the real impacts of the decision. Water management decisions have been tested using fairly simplistic assumptions about the future water supply conditions
they will be applied to, but there have been sophisticated exceptions for decades and simplistic tests are now becoming the exception rather than the norm.

In the IUGLS, plans will be tested using a wide range of water supplies developed using stochastic methods. Plans will be also be tested by sensitivity analyses for possible climate variability and change, and an adaptive management strategy will be developed to accommodate the great uncertainty regarding the effects of climate change and variability on future water supplies and plan outcomes.

2.1.1 Traditional analyses

The traditional approach is to use historical (i.e., recorded) water supplies. The main virtue of using historical supplies is that they are realistic in their magnitude and timing. If there are multiple sources, recorded supplies are also acceptably cross correlated; the fact that stream A is flowing high and stream B is dry in the test is unquestionably realistic because it happened in reality. The main disadvantage of using historical supplies is that they will not be the supplies the new decision is tested by, nor do they represent the range of magnitude and timing that can be expected in the future. The Lake Ontario regulation plan 1958D had been developed using historical 1860-1954 supplies and almost as soon as it was put in place, there were drier and wetter supplies than any in the 1860-1954 period; the written plan rules had to be changed on an ad hoc basis (called “deviations”) to avoid undesirable outcomes. An absolute minimum release that balanced lake and river objectives when tested with the 1860-1954 supplies, for example, would have drained Lake Ontario too low in the drought of the 1960s, hurting both lake and river management objectives (LOSL Study Board, 2006).

For many years, evidence has become overwhelming that another traditional assumption, that recorded supplies were a sample from an unchanging population, is dangerously unsure. The example of drawing a few socks from a drawer to estimate the number of black and white sox in the drawer is a common statistical teaching analogy. Traditional water resources evaluations have seen the historical record as the few socks withdrawn from a drawer representing the climate; the drawer has an unknown but fixed number of black and white sox. The more modern view is that the drawer is actually a door covering a conveyor belt slowly moving socks past the door opening, and depending on when you sample, the ratio of black to white sox changes. Climate “change” models suggest that man has changed the mix of black and white sox, while the concept of climate “variability” includes the notion that there are quasi-periodic swings in the ratio of black and white sox. Given the weight of evidence, diligence requires that planners test their plans against the assumption of long standing climate variability as well as climate change induced by man’s actions.
2.1.2 Climate Variability

When Devils Lake in the mid 1990s flooded North Dakota homes that were eight miles from the shoreline when they were built, the assumption of many experts, including the U.S.G.S. at the time, was that the floods were caused by a rare sequence of three 100 year or greater return interval annual total runoff events. Paleologic evidence at the site and around the world showed evidence that closed basin lakes like Devils Lake rose and fell in semi-periodic fashion in response to naturally caused climate variability.

Now, more than a decade after those “100 year” floods, Figure 2 shows Devils Lake is even higher than it was then. In fact, the old gage had to be moved because it would have been covered in water, and it is accepted wisdom that the climate driving these levels is not stationary. This was recently demonstrated by NOAA scientist Scott Drummer’s appearance before the U.S. Senate Subcommittee on Energy and Water Development February 11, 2009 when he testified that “The current forecast calls for an almost 99 percent likelihood the water level at Devils Lake will exceed the recent record lake level of 1449.2 feet, set in May, 2006. There is also a 25 percent possibility the water level at Devils Lake will exceed 1452.1 feet, and a 2 percent possibility the water level will exceed a height of one foot below the current dike protection level of 1455.0 feet.”

The primary basis for plan comparison in the IUGLS will be at least a thousand 30 year long stochastically generated net basin supply sequences. Stochastic water supplies allow the calculation of the expected values (probability times magnitude) of impacts. The Hydroclimatic Technical Working Group is working with PEG to develop stochastic supplies. The historical supplies from 1900 to 2006 will be used as one supply set even though that duration is much longer than the 30 year planning horizon because so many people feel comfortable in comparing plans based on historical events – the droughts of the twenties and sixties, the high water of the fifties, seventies and eighties. Longer than 30 year sequences may also be chosen from the stochastic supply series if the evolving performance indicators related to ecological processes and erosion require them, but the period of analysis for discounting would stay the same.

2.1.3 Climate Change

Scientists are not unanimous on whether man is warming the earth because of increased carbon emissions, but the evidence is strong enough and the consensus great enough that it would be irresponsible not to consider how climate change could affect the outcomes from a plan that regulates Lake Superior releases over a 30 year horizon.
The LOSL study used four sample climate change water supply scenarios in a sensitivity analysis and plans that “failed” under climate change were discarded or modified. “Failure” was defined as producing Lake Ontario levels so low that flows into the St. Lawrence River stopped. The four scenarios, labeled “warm dry”, “warm wet”, “not as warm dry” and “not as warm wet” were developed from the downscaling of two variations each of two Global Circulation Models, one by the Canadian Centre for Climate Modeling and Analysis and the other by Hadley Centre for Climate Prediction and Research. Hadley is the climate change center of expertise within Great Britain’s central meteorological agency. The four sets of scaled climate variables were used to transform a 29 year sequence of recorded Great Lakes – St. Lawrence hydrology into four changed-climate sequences. (Croley,2003) No probability was assigned to any supply sequence.

Now, in 2009, climate change is an even greater concern. A recent study (Austin, 2007) showed that a small increase in air temperatures around Lake Superior can have a disproportionately large effect on evaporation from Lake Superior because of changes in lake inversion. Near record warm temperatures in most years of the last decade helped produce record low August and September Lake Superior levels in 2007.

Thirty year climate change sequences will be generated by the Hydroclimate TWG, but no probability will be assigned to those traces and they will not be used in any expected value calculations as there is no defensible way to estimate the probability of climate change induced water supplies or impacts. This was highlighted at a June 2008 Hydroclimate workshop in Cleveland where climate scientists agreed that the ability of Global Circulation Models to replicate current climate has not been shown to be an indicator of an ability to forecast future climates. Moreover, the forecasts for any GCM are based on the rate of increase in carbon emissions, which is in itself highly uncertain. Finally, there are many uncertainties in downscaling global and regional models to develop water supply sequences, and there is still doubt about whether climate change will bring lower lake levels, driven by warmer temperatures and higher evaporation, or higher lake levels, driving by greater variability in precipitation. For those reasons, the Board will address climate change primarily through adaptive management (page 32).

As a prelude to climate change planning, the IUGLS TWGs will prepare general summaries of existing contingency plans to high and low water levels in their contextual narratives and may produce more detailed assessments as part of the Adaptive Management Strategy. One part of that strategy (currently being considered by the Board, but not yet approved) is to create an institution connecting those who manage the impacts from lake levels to those who develop information about lake levels. If the Board does approve that direction, a more involved assessment of contingency plans would be necessary to design the information system so that it was effective in meeting its purpose, which would be to improve water management outcomes.
3. Plan Ranking and Decision Making

It is not clear yet how the Board will rank alternative regulation plans, but the ranking method will be developed and tested in public view and before it is used for final recommendation, following the “informed consent” process (see page 41). Figure 3 identifies the timeline of the informed consent process used in the LOSL study. A similar process will be followed in this study. Two practice decisions are scheduled for Year 3 to begin working with the Study Board on identifying their decision criteria. The development of the draft Decision Guidelines (starting on page 40) is an initial step in this process. There are definitely additional challenges provided by this Study that the PEG and Study Board will need to address as they begin to develop the Shared Vision Model and evaluation process. We must consider a method for comparing plans based on study site analysis rather than basin-wide assessment. We must recognize that not all performance indicators are likely to be in dollar terms and therefore not fungible across interests. We have very limited time for the gathering of new data and must rely to a great extent on what is available. How for example, will we determine if a plan is good or bad for an interest if different site studies are responding in different ways? How will we weight the importance of each site study? How too will we potentially trade the number of homes flooded with recreational boaters who can’t get their boats out?

On the other hand, it has also been demonstrated through the fencepost plans that the existing regulation plan has had much less impact on the historical levels and flows than was the case with the LOSL study and that is has limited ability to affect the levels of Lake Michigan/Huron. As a result, it is
very probable that the changes to regulation are more likely to be relatively minor and that major
tradeoffs between interests and regions will not be a significant issue. The one exception may be the St
Marys River where we know that small changes to the regulation plan could have a relatively significant
impact on flows in the river as shown in Figure 24 and Figure 25, page 68. Impacts to hydropower,
commercial navigation, fisheries habitat and migration, recreational boating, and possibly water intakes,
could show demonstrable impacts in the St. Marys River region and this may be of primary focus in this
Study.

Nevertheless, there is still the issue of climate variability and change to consider and how we might
regulate to address future conditions. As has been noted earlier in this document, the Study Board has
decided to address this through adaptive management.

3.1 Adopting an Evaluation Framework

In the evaluation framework, plans are quantitatively evaluated by measuring the success in meeting
stated goals and objectives. Key components for measuring success include the use of performance
indicators (PIs) and the relationship of those indicators to the water level and flow metrics of any
proposed regulation plan. These seven steps are being followed iteratively to develop panoply of
metrics that the Study Board will use to gage progress towards meetings its plan objectives (address
economic, social and environmental impacts, avoid disproportionate loss to any sector, and provide
flexibility to respond to unusual or unexpected conditions):

- Articulation of Study Planning Objectives and Review of Existing Criteria
- Identification of water level and flow metrics
- Identification of Performance Indicators
- Functional relationship between performance indicators and selected hydrologic attributes
- Generation of time series of performance indicators values
- Establishment of a method for generating composite values of the simplest hydrologic metrics
to express areal extent, frequency, severity, duration and persistence.
- Establishment of a method for the summation, display and comparison of composite
  performance indicator values..

But while the production of metrics for every plan will inform the Board’s judgment, judgment will still
be required to rank plans based on these metrics (for an illustration of this difficulty, see Figure 4, page
23). These steps have been modified somewhat to address the large size of the Study area and limited
time and resources available. This will be discussed further on in the document.

3.2 A Mock Evaluation and Plan Ranking

The peer review process has been designed to secure review while there is still time and money to make
improvements based on external criticism. However, because the Study Board has had to focus on the
St. Clair issue first, many aspects of the evaluation and plan ranking process are in flux.; some
performance indicators have not been finally specified and the Board has not had the time to thoroughly
test and revise their decision criteria. The Board entertained two “practice” decisions, but both were on the St. Clair issue. Consequently, the Plan Evaluation Group (PEG) prepared a “mock” decision for this review based on their experience in planning and with this Board, and their familiarity with the subject matter and the Great Lakes in general.

3.2.1 Alternative Plans
For purposes of this paper, only three alternative regulation plans will be evaluated and ranked. In the LOSL case study, hundreds of plans were developed and refined using well established performance indicators and decision criteria.

The three plans are Plan 77A (the current plan), Preproject (no regulation) and Plan 1.21, a plan developed during the Levels Reference Study (a 1990s IJC study of the Great Lakes) (Levels Reference Study Board, 1993). The plan is described on the next page.

3.2.2 Mock decision criteria, water metrics and performance indicators
The metrics and decision criteria used in the mock plan ranking are consistent with the PE1.1.2 Lake Superior Plan Evaluation Guidelines, page 41 with two types of differences; the water level metrics are specific examples of general categories in the guidelines and economic performance indicators have been estimated using simplistic benefit transfer methods. These changes make the mock plan ranking more tangible and easier to follow, but they will be replaced during the study by the metrics, indicators and decision criteria approved by the Board. Note also that to date, no simulations have been done using Plan 1.21 and the climate change or stochastic water supplies. In practice, these would be central to the Board’s ranking of plans.

In the mock evaluation, the water level indicators used (and the associated impact sectors) are:

1. Muskegon Circles of Influence preference for high and low Lake Michigan-Huron levels (coastal and recreational boating)
2. Maximum, minimum and average levels for each lake (coastal and recreational boating)
3. A measure of how well levels of Lake Superior and Lakes Michigan-Huron are balanced over time (equity)
4. Muskegon Circles of Influence, the difference of lake levels from unregulated levels (environment)
5. The average and maximum change in releases from one month to the next (environment)

The mock performance indicators are:

1. The value of recreational boating. These estimates are based on Lake Ontario studies and the ratio of the number of boats on each upper lake to the number of boats on Lake Ontario. There is a separate impact versus depth above or below chart datum for each lake and for each month in the boating season. These estimates are likely to be wrong because it is unlikely that the upper lakes have an identical distribution of marinas in critically shallow areas.
2. **The cost of shipping goods.** These estimates are based on Lake Ontario studies of the costs of shipping at different loadings and one year of actual origin to destination shipments. There are individual shipping costs versus depth above or below chart datum for each of nine “routes” and for each calendar month in the shipping season. Routes are defined by the lakes and rivers used between origin and destination. Costs are calculated based on the most critical water level within the route each month. Costs are Lake Ontario costs multiplied by the ratio of traffic on each route to traffic on Lake Ontario.

3. **The value of hydropower energy produced.** These values are based on market values from the Lake Ontario study, efficiency curves provided by hydropower producers, algorithms developed for the Levels Reference Study (a previous IJC Study) and average monthly head and flows. Because generation during the month varies so as to maximize the value of hydropower, a more sophisticated algorithm will be used during the next phase of evaluation.

These are the Study Board’s **decision criteria.** In each case, the better/worse choice is given assuming all other factors are equal.

1. Plans that balance levels of Lake Superior and Lakes Michigan-Huron are better. The balance is based on a comparison of the frequency distribution of lake levels measured as multiples of the reported standard deviation. Plans that created a much higher frequency of levels that would be unusually high or low without regulation for one lake at the expense of the other would rank low on this criterion.

2. Plans that minimize negative sectoral impacts are better

3. Plans that maximize economic benefits are better, unless they create disproportionate loss.

4. Plans that produce the smallest month-to-month changes in St Marys flows are better.

5. The simplicity of the plan rules; if everything else were equal the simplest plans would rank highest. Plan 77A rules are so complicated that it is difficult even for plan experts to create computer code that will produce the same releases as the official Plan 77A model. Great complexity makes it more difficult to develop trust and understanding in the plan.

6. Plans that produce levels and releases closer to the unregulated condition are better. This is related to the balancing objective but it addresses an environmental starting point that the current ecosystem developed based on natural hydrology.

It is difficult to guess how the Board would rank these plans because there is a conflict between economic and environmental outcomes. In this example, the environmental effect is captured in one number with only a general principle, with no data yet from Upper Lakes research to support it. On the other hand, a plan that keeps Michigan and Huron a little higher during droughts might help Georgian Bay wetlands (but we have no data to support that conclusion now).
Plan 1.21

Plan 1.21 is a modified version of Plan 1977A. It was developed in the Level Reference Study (1993) by Nanette Noorbakhsh. The plan goal of modifying the Lake Superior regulation plan was to better balance the levels of lakes Superior and Michigan-Huron; and provide benefits to the middle Great Lakes, in the form of a decreased frequency of extreme levels; without unduly affecting Lake Superior interests. (Task Team 1, Working Committee 1. 1993. Regulation Studies, Final Report, Levels Reference Study, International Joint Commission.

Plan1.21 incorporates the following modifications into Plan 1977A

1. Only 50% probability net basin supplies are used in the outflow forecasts, eliminating the use of extreme supplies (5% and 95%) at times of extreme levels.
2. The maximum winter outflow limit is raised to 2690 m³/s. (The Plan1977A limit is 2410 m³/s). This reflects an increase in the maximum winter gate opening in the Compensating Works of 1 gate from ½ gate.
3. Within the internal outflow forecasts, the following outflow limits are not applied:
   a. maximum winter outflow (2690 m³/s)
   b. minimum outflow (1560 m³/s)
   c. maximum flow change from month to month (850 m³/s)
   d. The outflows in the forecast, however, remained constrained by the capacity of the control works. In the determination of the final regulation outflow, after an average outflow has been determined from outflow forecast, the above noted limits are applied. The number of forecast months is as same as those in Plan77A (five months).
4. Plan 1977A balancing equation is replaced with an alternate equation.
5. The Lake Superior level standard deviation parameters used in the balancing relationship are increased by 3 centimetres (about 20 percent). This has the effect of increasing the variability and the range of Lake Superior levels. All other balancing parameters are the same as those used by Plan 1977A.
6. Criterion (c) of the Commission’s Order of Approval is not applied because(according to the Reference Study report) applying criterion (c) causes the plan to balance the levels of Lake Superior and Michigan-Huron less effectively. According to the results from the Reference Study report, Plan 1.21 reduced the minimum level on Lake Superior and increased the frequency of levels below chart datum on Lake Superior, but it raised the minimum levels on Lakes Michigan-Huron and Erie, and decreased the frequency of levels below chart datum on these lakes, and increased the frequency of high levels (above 183.70 m, IGLD 1985 ) on Lake Superior.
The figure above illustrates the judgment required by the LOSL Study Board to determine whether a plan balances competing objectives even when progress towards those objectives is quantified. Symbols appear in the green quadrangle if the selected plan outperformed the current plan for those metrics. For example, the blue triangle high in the green square shows that this plan (called 2007) outperformed the current plan (1958DD) both in the frequency and severity of violations of commercial navigation level and flow targets below the dam. This has to be balanced against the poor score represented by the yellow square representing hydropower at the dam and the red square for coastal above the dam. And these were just water metrics; the Lake Ontario board also had to consider the economic impacts of these plans (this plan scored very well for both hydropower and navigation and was a little better on coastal economics than Plan 1958DD).
### 3.2.3 Mock evaluation

#### Table 2 Mock evaluation of three plans

<table>
<thead>
<tr>
<th>Mock Evaluation of three plans</th>
<th>77A</th>
<th>Preproject</th>
<th>1.21</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water level metrics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muskegon Metrics; frequency, average failure (m.), average duration of failure (months)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above 580.5</td>
<td>9% 0.6m. 6 months</td>
<td>8% 0.62m. 5 months</td>
<td>9% 0.52m. 5 months</td>
</tr>
<tr>
<td>Above 580.0</td>
<td>8% 0.67m. 1 months</td>
<td>7% 0.69m. 1 months</td>
<td>10% 0.59m. 1 months</td>
</tr>
<tr>
<td>Between 577.5 and 580</td>
<td>73% 0m. 0 months</td>
<td>72% 0m. 0 months</td>
<td>71% 0m. 0 months</td>
</tr>
<tr>
<td>Below 577.5</td>
<td>6% 0.51m. 2 months</td>
<td>7% 0.56m. 2 months</td>
<td>7% 0.44m. 2 months</td>
</tr>
<tr>
<td>% below 577.0</td>
<td>4% 0.37m. 1 months</td>
<td>6% 0.37m. 1 months</td>
<td>3% 0.37m. 1 months</td>
</tr>
<tr>
<td>Naturalness (1 is perfect)</td>
<td>0.80</td>
<td>1.00</td>
<td>0.59</td>
</tr>
<tr>
<td>Superior/ Michigan-Huron/ Erie levels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>183.84 /177.51 /175.05</td>
<td>183.82 /177.48 /175.05</td>
<td>183.88 /177.45 /175.02</td>
</tr>
<tr>
<td>Minimum</td>
<td>182.85 /175.58 /173.38</td>
<td>182.72 /175.52 /173.33</td>
<td>182.79 /175.61 /173.39</td>
</tr>
<tr>
<td>Balancing score</td>
<td>26</td>
<td>41</td>
<td>21</td>
</tr>
<tr>
<td>Change in release (avg/max)</td>
<td>169/ 868 m3/s</td>
<td>92/ 321 m3/s</td>
<td>162/ 812 m3/s</td>
</tr>
<tr>
<td><strong>Performance Indicators; average economic net benefits, millions per year</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydroelectric Power</td>
<td>$0.00</td>
<td>$0.22</td>
<td>$0.95</td>
</tr>
<tr>
<td>Commercial Navigation</td>
<td>$0.00</td>
<td>-$0.04</td>
<td>$0.00</td>
</tr>
<tr>
<td>Recreational Boating</td>
<td>$0.00</td>
<td>-$5.84</td>
<td>$8.60</td>
</tr>
<tr>
<td>Total</td>
<td>$0.00</td>
<td>-$5.65</td>
<td>$9.55</td>
</tr>
<tr>
<td><strong>Ranks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muskegon Compression</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Muskegon Naturalness</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Range compression</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Balancing</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Net benefits</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Disproportionate loss</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Environmental health</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

The ranking of plans for “Muskegon Compression” favors Plan 1.21 because although the percentage of “failures” is about the same as the other plans, the severity and duration are smaller. The ranking on three lake range compression is based on an overall judgment, with first rank provided Plan 1.21 because its maximum Michigan-Huron and Erie levels are slightly lower, while its Superior is only slightly higher. Plan 1.21 also creates higher Michigan-Huron minima at the expense of a lower Superior minimum. While neither Plan 77A or 1.21 creates any loss, the act that 1.21 creates a net benefit for power and boating plus a benefit for navigation that is less than $1000 per year (rounded to $0.00 million).
Any Lake Superior regulation plan that would be supported by decision makers and stakeholders is likely to produce levels very similar those produced by the current plan. The small differences among acceptable plans make it more difficult to develop defensible estimates of plan related impacts. The most noticeable change from any new plan is likely to be in the discharges of the St. Marys River, which carries water from Lake Superior to Lakes Michigan-Huron, and the location of the control structures through which regulation is made. There are two reasons for this. The first relates to the hydrology of the lakes and the second relates to the criteria that have been adopted by the Board to guide its decision making.

Figure 6 shows the average and the variability of water supplies to or outflows from a Great Lake over the past century expressed in terms of an equivalent depth on a particular lake surface. The only portion of this water volume that can be controlled from month-to-month is the Lake Superior outflow. The variability in the volume of water added to Lakes Michigan-Huron by changes in the regulation of Superior releases is typically much smaller than the naturally-occurring volumes related to the rainfall and evaporation on those lakes, the runoff into them, and the uncontrolled releases from Lakes Michigan-Huron. The effect of Lake Superior regulation on Lake Erie levels is further muted.

The leftmost bar, for example, shows the average amount of the supply received by Lake Superior each month is equal to about 7 centimeters of water spread over the surface of Lake Superior, but this has varied from a low of minus 9 centimeters (the negative sign means that there was more evaporation

4. The central evaluation challenge: the small impact of regulation

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The leftmost bar, for example, shows the average amount of the supply received by Lake Superior each month is equal to about 7 centimeters of water spread over the surface of Lake Superior, but this has varied from a low of minus 9 centimeters (the negative sign means that there was more evaporation
that month than precipitation and runoff) to a high of 32 centimeters, a month with a lot of rain and melting snow.

The second bar from the left shows the long-term average of Lake Superior outflows is equivalent to seven centimeters of water on Lake Superior, the same as the Lake Superior supply shown in the leftmost bar, but the variation in the regulated Superior outflow is much less than the variation in the supply. The 12 centimeter maximum (just under 5 inches) represents the maximum amount of water that can be removed from the Lake Superior surface in a month through the control structures at Sault Ste. Marie. The minimum amount that has been released from Lake Superior is the equivalent of 4 cm (about 1-1/2”) off the lake surface.

The third bar from the left also represents Superior outflow, but this time spread over the larger surface area of Lakes Michigan-Huron; the equivalent depths are about a third less, as shown in the middle bar. The average monthly Lake Superior outflow is equal to about 5 cm (~2 in.) of water on Lakes Michigan-Huron and varies from about 3 cm (~1 in) to 8 cm (~3 in.). This means that over the past century, the water flowing out of Lake Superior never raised Lakes Michigan and Huron by more than 8 centimeters in any month. Compare that to the depth of water added to those lakes by the natural variability of the Basin supply to Lakes Michigan-Huron (second bar from the right), which has lowered the lakes by as much as 12 centimeters (~5 in.) in a month and added as much as 31 centimeters (~12 in.). The last bar
on the right shows that the outflow from Lakes Michigan-Huron does not vary much. There are no control works at the outlet of Lake Huron and the flow simply varies with water level of the lake.

The current plan (Plan 1977-A) captures the accumulated wisdom of the IJC and its analysts up until the late 1970s. By design, it is not very different from having no regulation at all (see Figure 7 and Figure 8, page 28). To explore the limits of regulation, the Study Board asked that “fencepost” plans be developed. These plans are discussed in detail in PF1.4 Fencepost Plans, page 67. These fencepost plans were developed to show the outer limits of how much regulation could change levels and flows, given the current structures, if regulation were designed to serve a series of single interests, with no concerns about the distribution of benefits.

The practical limits of regulation will be further proscribed by human judgment. The plans developed for Study Board evaluation and ranking will be less extreme as the Board will take into consideration the distribution of benefits and all three pillars of sustainability; economic efficiency, environmental health and equity:

- **Environmental health.** The current plan is not very different from having no regulation at all; a plan that created a much more regulated system might well be challenged because it would create a hydrologic regime much different from the regime under which the current ecosystems in the Upper Lakes were established.

- **Equity.** While the Study Board has not developed a complete set of decision criteria yet, it has gone on record as opposing plans that would help one group at the expense of a disproportionate loss by another group. This means the Board is not going to regulate large differences in Lake Superior elevations to produce small changes on Michigan-Huron, even though those changes might be beneficial to Michigan-Huron stakeholders and could well produce net economic benefits for the Great Lakes basin. While the Board has not formally structured an argument for this policy, it is generally understood that the Board finds such rebalancing of levels as inequitable.

- **Economics.** In extremely dry supply conditions, it might be possible to preserve 20th century water levels on Lake Superior by holding water on Superior even if Michigan-Huron were low, and creating a high discharge of water from Superior even when Michigan-Huron was already high. But the net economic impacts of such a strategy would be negative because the population, area and economic activity related to Lakes Michigan-Huron are much greater than the same factors for Lake Superior.
Figure 7 Simulated time series of Lake Superior levels, unregulated and as they are regulated now (historical water supplies)

The figure above shows that the current regulation of Lake Superior produces levels fairly similar to unregulated levels, unlike Lake Ontario, (not shown) where regulation has compressed natural variation significantly. Based on historical 20th century supplies, the average difference in plan levels is 8 cm, (about 3 inches). The maximum difference is 24 cm, or 9 inches.

Figure 8 Simulated time series of Lakes Michigan-Huron levels, current and no regulation, historical water supplies

The effect of the current regulation plan on Lakes Michigan-Huron compared to no regulation is even less because these levels are affected more by local runoff, precipitation and evaporation. Using 20th century supplies, the average difference between plans is 3 cm (an inch); the maximum difference is 13 cm (5 inches). The average difference on Lake Erie is ~5 cm (~2 inches), and the maximum difference is 8 cm (~3 inches).
The MH plan featured in Figure 9 and Figure 10 is one of the fencepost plans (see PF1.4 Fencepost Plans, page 67 for more details). They are called fencepost plans because they favor one sector with little regard to any other and so collectively define the outer limits of how lake levels could be changed through regulation of Lake Superior. Figure 9 shows how this plan keeps Michigan-Huron levels higher during a low supply period in years 20-29, and keeps levels lower during the wet years of the 70s and 80s. The average difference between plans is only 13 cm (5 inches) but the maximum difference is 62 cm or 2 feet. Notice that the MH plan, as biased as it is towards Michigan-Huron, finally has little effect on the maximum levels in the 80s which are actually lower (177.51 m or 582.4 ft IGLD) under the current plan than the MH plan (177.57 m or 582.6 ft., IGLD) because the capacity of Superior to retain water is much greater at that point under the current plan compared to the MH plan.

The MH plan has a much greater impact on Superior levels. The average difference between plans is 74 cm or 29 inches, greater than the maximum difference on Michigan-Huron, and the maximum difference is 1.5 metres (~5 feet).
4.1 From the Plan of Study - Great Lakes Hydrology/Water Balance

The Plan of Study will be provided to the reviewers. The following description of the basin is reproduced from the Plan of Study for convenience.

The upper Great Lakes (Figure 11) form a system of large natural reservoirs connected by rather short channels, given the size of the basins. The total basin area (measured above Cornwall, Ontario and Massena, New York) is about 774,000 square kilometers (299,000 square miles). Table 1 provides information on the sizes of the Great Lakes and their drainage basins. Lake Superior, which is the most upstream of the Great Lakes, flows into Lake Huron through the St. Marys River. Lake Michigan also flows into Lake Huron through the Straits of Mackinac. The straits are wide and deep enabling both Lake Michigan’s and Lake Huron’s water levels to stand at the same elevation and respond hydraulically as one lake. Thus, the two lakes are also referred to as Lakes Michigan-Huron. From Lake Huron, water flows into Lake Erie via the St. Clair River, Lake St. Clair and the Detroit River. Lake Erie then flows into Lake Ontario through the Niagara River and the Welland Canal. Lake Ontario, in turn, flows into the St. Lawrence River which connects with the Gulf of St. Lawrence. Figure 2 shows the general water surface profile of the Great Lakes – St. Lawrence River System. A rock ledge in the St. Marys Rapids of the St. Marys River acted as a natural submerged weir, controlling the outflows of Lake Superior. The hydropower development and construction of the St. Marys River Compensating Works in the early part of the Twentieth Century altered this part of the river, enabling humans to regulate the outflow from Lake Superior. The rate of water flow in the St. Clair – Detroit River system depends mainly on the level of Lakes Michigan-Huron and, to some extent, also Lake Erie’s level. Other factors affecting this system’s flow rate are aquatic growth in the river in summer and ice conditions in winter. Physical changes in the St. Clair and Detroit Rivers can have significant impacts on water flows of the river and Lakes Michigan-Huron water level. The flow of the Niagara River depends on Lake Erie’s level at its outlet. Hydropower operations at Niagara Falls have considerable water level impacts in the immediate river stretches both upstream and downstream of these facilities but insignificant impacts on Lake Erie’s level. Lake Ontario’s outflows are regulated by a hydropower dam and other control works in the international reach of the St. Lawrence River. Lake Ontario levels cannot affect the upstream Great Lakes water levels due to the almost 100-metre (328-foot) drop in elevation between Lake Erie and Lake Ontario, most of it located at Niagara Falls and cascades in the Niagara River.
Figure 11 Upper Great Lakes Basin
Adaptive management has generally come to represent an approach to management (the combination of planning, design, operation and regulation of a resource) that relies on a continuing accumulation of knowledge and information, through a monitoring and evaluation system, which is used to improve the suite of management decisions. An adaptive management plan must focus on those elements of the adopted operating plan that are most uncertain. Adaptive management essentially has two interrelated components or functions. One is to serve as a quality control and assurance mechanism to ensure that the predicted performance of a plan actually materializes. The other is to better deal with circumstances where decisions are routinely made based on information with a high degree of uncertainty.

### Table 3 Dimensions of the Great Lakes Basin

<table>
<thead>
<tr>
<th></th>
<th>Surface Area</th>
<th>Volume*</th>
<th>Max Depth*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water</td>
<td>Land Basin</td>
<td></td>
</tr>
<tr>
<td></td>
<td>km²</td>
<td>miles²</td>
<td>km³</td>
</tr>
<tr>
<td>Lake Superior</td>
<td>82,100</td>
<td>31,700</td>
<td>127,700</td>
</tr>
<tr>
<td>St. Mary’s River</td>
<td>230</td>
<td>90</td>
<td>2,600</td>
</tr>
<tr>
<td>Lake Michigan</td>
<td>57,800</td>
<td>22,300</td>
<td>118,000</td>
</tr>
<tr>
<td>Lake Huron</td>
<td>59,600</td>
<td>23,000</td>
<td>131,300</td>
</tr>
<tr>
<td>St. Clair River</td>
<td>55</td>
<td>21</td>
<td>3,300</td>
</tr>
<tr>
<td>Lake St. Clair</td>
<td>1,110</td>
<td>430</td>
<td>12,430</td>
</tr>
<tr>
<td>Detroit River</td>
<td>100</td>
<td>39</td>
<td>2,230</td>
</tr>
<tr>
<td>Lake Erie</td>
<td>25,700</td>
<td>9,910</td>
<td>58,800</td>
</tr>
<tr>
<td>Niagara River</td>
<td>60</td>
<td>23</td>
<td>3,370</td>
</tr>
<tr>
<td>Lake Ontario</td>
<td>18,960</td>
<td>7,340</td>
<td>60,600</td>
</tr>
<tr>
<td>St. Lawrence River</td>
<td>610</td>
<td>240</td>
<td>7,190</td>
</tr>
</tbody>
</table>

*Measured when the lake’s water level is at chart datum. Note: No value provided for Lake St. Clair.

(Source: Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 1977)

### 5. Adaptive management

Adaptive management has generally come to represent an approach to management (the combination of planning, design, operation and regulation of a resource) that relies on a continuing accumulation of knowledge and information, through a monitoring and evaluation system, which is used to improve the suite of management decisions. An adaptive management plan must focus on those elements of the adopted operating plan that are most uncertain. Adaptive management essentially has two interrelated components or functions. One is to serve as a quality control and assurance mechanism to ensure that the predicted performance of a plan actually materializes. The other is to better deal with circumstances where decisions are routinely made based on information with a high degree of uncertainty. In particular, the most uncertain data (unpredictable) are the climate/hydrologic inflows into the Great Lakes (IUGLS) system, and the impacts of lake level fluctuations on the ecology of the system. To a lesser
extent, there is uncertainty in the economics of recreational boating and the flooding and erosion impacts of lake level and flow variability.

The overall study approach in the IUGLS Study, which we term “Shared Vision Planning” encompasses all of the goals typically associated with adaptive management (Walters, 1986), in addition to providing a level of transparency and public feedback recommended by the U.S. National Research Council (2004):

1. Bounding of management problems in terms of explicit and hidden objectives, practical constraints on action, and the breadth of factors considered in policy analysis;
2. Representation of existing understanding of managed systems in terms of more explicit models of dynamic behavior, that spell out assumptions and predictions clearly enough so that errors can be detected and used as a basis for further learning;
3. Representation of uncertainty and its propagation through time in relation to management actions;
4. Design of balanced policies that provide for the possibility of continuing to produce the resources associated with water (hydropower energy, cooling water for other types of energy and industrial production, conveyance for shipped goods, etc.) while monitoring and adaptation address undesirable outcomes or risks over time.

In its report on “Adaptive Management for Water Resources Project Planning”, the U.S. National Research Council (NRC; 2004) noted that “adaptive management entails a spectrum of approaches. These range from ‘passive’ programs, which focus on monitoring and evaluating outcomes from a particular policy choice, to more formal and rigorous ‘active’ adaptive management, which designs management actions to test competing models of system behavior so that models can be improved for future decision making.” A form of passive adaptive management is reflected in the operational decisions of the International St. Lawrence Control Board, which routinely deals with a fairly significant amount of uncertain information. The NRC then went on to recommend three necessary components of any adaptive management plan:

- post-project(plan, program) evaluations should be a standard for adaptive management
- stakeholder collaboration should be an integral component of adaptive management
- independent experts should be periodically enlisted to provide advice on adaptive management initiatives

### 5.1 Adaptive Management of Lake Levels

The Board will consider both adaptive changes to Lake Superior regulation and consideration of the regulation of other Great Lakes or the St. Lawrence River in response to future changes in climate, environmental or economic conditions. Within any plan recommended by the Study Board there will be several key areas which are candidates for an ‘active’ adaptive management plan. The adaptive management plan would be periodically (no less frequently than 10-year intervals) reviewed by the IJC and the Control Board, with the involvement of stakeholders and independent experts. The Control Board would need to accommodate the new adaptive management functions, associated with the implementation of a new plan by the IJC, through a reorganization of its technical support currently provided by the Corps of Engineers and Environment Canada. This may include broadening U.S. and
Canadian federal agency representation to provide the added technical and financial support and responsibility for carrying out the key adaptive management plan actions, to include NOAA, NMFS, USGS and perhaps EPA, and their counterparts in Canada. The basic components of a practically achievable adaptive management plan which addresses a review of the performance of an operating plan consist of the following:

- **Forecasting** technology, methods and models need to be constantly assessed, tested and periodically updated and incorporated into the water control operations of the Control Board. Climate and hydrologic forecasting is a key and critical element in effective water management and regulation, particularly in the tightly controlled circumstances within the LOSLR system.
- **Mitigation measures** that are deemed necessary for implementing a particular plan. Depending on the selected Plan, these have been identified to potentially include erosion and flooding damages, wetlands habitat losses, and several species, as well as one species at risk (Plan A).
- **Reform and coordination of regulatory permit procedures** is an essential component of adaptive management that is required to update permit requirements to conform to the new flow and lake level design limits of each plan.
- **Ecohydrology** is the fundamental scientific basis for enhancing the ecological integrity of the LOSLR system. The hypothesis that hydrologic variability is essential to improved wetland structure and function which, in turn, increases species diversity and abundance, needs to be validated, and the predictive models which are based on these premises need to be constantly updated as new information is collected and developed. Consideration should be given to establishing a permanent network of monitored wetland sites and data collected and analyzed as part of IERM model improvement. An equivalent monitoring of selected species at risk might also be considered.
- Shoreline erosion rates should be monitored, as well as recreational boating responses in terms of usage, benefits and costs.
- **Coordination**, evaluation and incorporation of the necessary actions cited above, including the integration of ongoing monitoring programs of numerous federal, provincial and state agencies should be the responsibility of the Control Board and the IJC.

### 5.2 Providing Information on lake levels so that others can manage adaptively

Evaluation of fencepost plans with preliminary climate change water supplies shows that the ability to mitigate the impacts from climate change through the regulation of Lake Superior will be very limited. Accordingly, the IUGLS adaptive management program will also be designed to help others to adapt their behavior to future conditions including, but not limited to climate change and variability. The Study Board has approved other parts of an adaptive management strategy for the Upper Great Lakes but has not yet approved Tasks 6 (develop non-regulation strategies) and 8 (conducting a two part institutional analysis) pending an assessment of how effective non-regulation adaptation could be. If these tasks are undertaken, the goal would be to create a dialogue between lake level managers and those who would need lake level information to manage their responsibilities:

1. Research to develop monitoring and analysis methods to determine when climate, as reflected in the water supply regime of the lakes, and/or physical processes had changed.
2. Modeling and analysis to understand the impacts of those changes.
3. The creation of an institutional framework including an organized information network of stakeholders and managers who address the impacts of lake levels under climate change by...
changing behavior, investments and policies. The IJC and its Study Board would provide information on lake levels for this network.

The Study Board has requested the PEG to take the lead on the Adaptive Management initiative. An adaptive management discussion paper was developed and a draft year 3 work plan has been proposed. The Study Board has given initial approval for the funding of an experts workshop to review the adaptive management strategy proposed work plan. Both the discussion paper and proposed work plan are included as appendices.

6. References


http://www.iugls.org/en/mandate/Mandate_directive.htm


Appendix 1 Plan Evaluation

PE1.1 Factors driving the evaluation process design

The IUGLS Study Board is designing an evaluation framework based on their management goals for the Upper Great Lakes. There is an active, dynamic effort to give stakeholders a voice in designing the framework, and expert advice is employed to make sure the evaluation is defensible. Figure 12, next page, illustrates these relationships.

The overall goal is to create a sustainable management plan for Lake Superior releases. The concept of sustainability is difficult to define, but in this context it means that the Study Board wants to design a regulation plan that balances economic, environmental and social impacts in the near and long term, over at least the next 30 years. On the Lake Ontario study, the balance was struck differently by different Board members (see Figure 13 LOSL Study Board Screening Factors, page 40), resulting in three options for regulation that were tolerable to the majority of the Board. The IUGLS Board will face similar difficulties in defining sustainability.

The shared vision planning process is a rational analytic process that supports decision making by simulating the impacts of alternative decisions. There is always a difference between the simulated and real outcomes of a decision, but there are at least five factors that make uncertainty about the future this study is concerned about greater than normal. These include (1) economic and (2) environmental uncertainty, (3) available study resources, (4) the minimal impact of regulation on Lakes Michigan-Huron and Erie, and (5) climate uncertainty. Because of this, the Board is using a limited plan evaluation process and placing a greater than normal emphasis on adaptive management. The section on Forecasting, period of analysis, and discount rate (page 26) includes a more thorough discussion of uncertainty and the five factors.

There is no universal evaluation process for water management decision processes. The closest in the U.S. is the federal “Principles and Guidelines” (P&G) for water resources planning that requires an assessment of the net economic development benefits (“increases in the net value of the national output goods and services, expressed in monetary units”) for the water management purposes of the proposed project, and provides methods for estimating those benefits that make them fungible across purposes (U.S. Water Resources Council, 1983). In Canada, the 1987 Federal Water Policy has the overall objective of encouraging the use of freshwater in an efficient and equitable manner consistent with the social, economic and environmental needs of present and future generations (Environment Canada, 1987). The policy also contains a number of specific statements regarding a wide variety of water issues. These include:

- Achieving a net gain of productive fish habitat.
- Conserve and enhance Canada’s wetlands.
- Alleviating human suffering caused by floods and minimizing the costs of flood damages.
- Minimizing damages caused by natural erosion along shorelines by discouraging settlement and investment in areas subject to natural erosion.
Plan selection under the P&G, barring some extraordinary exception, is based on maximizing the difference between benefits and costs in an environmentally acceptable fashion. But these guidelines are not followed even for federal projects authorized under a variety of environmental purposes, and most water management decisions – for water supply permits, Total maximum daily load (TMDL) plans, watershed agreements, drought response plans, basin management plans - are not made using the P&G evaluation process or the Canadian Federal Water Policy.

The IUGLS recommendation will likely guide the IJC’s choice of a new Lake Superior regulation plan, and the implementation of the new plan will have real economic, environmental and social impacts. The IUGLS Study Board designed its evaluation process to predict, as much as possible, the real world implications of its decisions using management goals and criteria (see the initial set starting on page 40). The possibility of doing that is reduced by the size and complexity of the Upper Great Lakes, the high degree of uncertainty in estimating the future of the Great Lakes, and the fact that the new regulation plan is likely to produce lake levels of within a few inches of the old plan.

The shared vision planning process was designed and first used for drought management, typically involving multiple decision makers, so unlike the U.S. Federal Principles and Guidelines, the SVP method includes a process for determining a collective set of decision criteria derived from the legislated responsibilities of each decision making participant and reflective of the public interest that would inform the execution of those responsibilities. The development of those criteria is linked dynamically to the model and research design so that the research and model will provide the information decision
makers need and the decision will be transparent. In the LOSL study, for example, the shared vision model included a matrix (Figure 13.) that showed the criteria individual study board members would use, and those criteria were hyperlinked to sections of the model that displayed performance indicators (such as economic benefits) for different alternative regulation plans, and those indicators were linked to study research used to develop the algorithms used in the model (Werick et al, 2008) The research agenda and SVM were modified as necessary when the Study Board refined its decision process. For example, late in the study the LOSL Study Board agreed it had to have a quantified threshold for its requirement that the new regulation plan would not cause “disproportionate” loss, so study economists developed metrics for the economic magnitude of each sector affected by the new plans.

The PEG is helping to guide the Study Board through the design and application of the decision making process. The first step was to develop a common understanding among the Study Board about what they are supposed to decide. The PEG interviewed each of the Study Board members to help articulate their expectations and to identify the factors each Board member would use in evaluating regulation plans. The first interviews included the “St. Clair” decision, not considered here. Based on this, an initial set of decision guidelines have been developed to lay out a structure for the Study Board’s decision making for both the St. Clair and the Superior regulation tasks. Clear guidelines help the Board make better decisions and make the decisions more transparent to stakeholders. The initial guidelines, still under review by the Study Board, as they relate to the general study process and to the Lake Superior regulation component of the study are shown below.

**PE1.1.1 Overall Study Process Guidelines**

1. Study findings, conclusions and recommendations will be based on the best available data, science, knowledge, scientific interpretation, and state-of-the-art technology recognizing Study budgetary and time constraints.
2. Study decisions will be open and transparent, involving and considering the full range of interests affected by any decisions with broad stakeholder input.
3. Data and modeling uncertainty will be acknowledged and reported on in the Study findings and conclusions and be taken into consideration in the Study decisions and recommendations.
4. The decision process shall be based on “informed consent” whereby the Study Board articulates its decision factors in an open and transparent manner, aligns study conclusions with the research, and refines their findings and decisions as the research conclusions become better understood.
5. The Board will vigorously try to reach consensus on all findings/decisions. If the Board fails to produce consensus, then the results of that process, including the opinions and reasoning of dissenting Board members will be included in the Board’s report.

PE1.1.2 Lake Superior Plan Evaluation Guidelines
These guidelines are a mixture of process rules (number one, for example) and decision criteria (number three). Any change to the Orders of Approval and regulation plan for Lake Superior outflows will:

1. Be based on the best assessment of impacts that can be done given the relatively small effect that Lake Superior regulation has on water levels, and size of the Great Lakes basin relative to the budget available for assessment studies.
2. Address to the extent possible, ecological, economic, and social impacts associated with the regulation of outflows from Lake Superior.
3. Minimize disproportionate losses to all interests and regions, including disproportionate water level changes on one lake at the expense of another.
4. Be designed so that the International Lake Superior Board of Control and the IJC can respond to unusual or unexpected conditions affecting the Great Lakes system.

PE1.1.3 Long-Term Management Guidelines
Recognizing that climate and water supplies in the next few decades may be significantly different and that regulation of Lake Superior outflows, while potentially having a significant effect on Lake Superior levels, will have little effect on water level changes caused by these climate shifts on Lakes Michigan-Huron and Erie, the Board will develop an adaptive management plan that will:

1. Allow as much adaptation of the Lake Superior Regulation plan to future climates as the Board feels is permissible without a full scale international study
2. Identify and to the greatest extent possible affect the long-term monitoring and systems modeling necessary to support that adaptation.
3. Recommend long term partnerships between the IJC and other Great Lakes managers and stakeholders that would facilitate non-IJC adaptive behavior based on information developed by the IJC, Environment Canada and the Corps of Engineers about changing water levels.
4. Consider the on-going application and accessibility of the data, tools and models developed for the Study such that they support adaptive management.

The Study Board will use a process sometimes referred to as “informed consent” to develop its final recommendations to the IJC. The informed consent process requires “practice decisions” from almost the beginning of the study so that the Study Board articulates its decision factors early and not only aligns the conclusions of the research but also refines the decision factors as the Board becomes more familiar with the research conclusions and debates the wisdom of tradeoffs in each practice decision.
The concept of practicing the decision was a key philosophy used in the Lake Ontario – St. Lawrence River Study (Werick et al., 2008). Practicing the decision does many important things. It forces everyone to make sure the studies being done produce the information needed to support a decision in a timely fashion. It stimulates debate about how to balance competing interests. It allows the Study Board to focus on one part of the decision at a time. And it allows the Study Board the opportunity to identify the key pieces of information and display formats needed to help them with their decision. The Plan Evaluation Group will host a number of practice workshops beginning with two workshops in year 3.

**PE1.2 The Interest Groups**

The Plan of Study identified six interest sectors for the Study to examine. These include the three traditional interests included in the Boundary Waters Treaty of Hydropower production, Commercial Navigation, and Municipal and Industrial Water Uses as well as Coastal Zone interests (those living on the shoreline) Recreational Boating and Tourism, and the Environment. The environment is a broad category that covers plant, fish, birds, mammals and herptiles, including species at risk.

**PE1.3 Establishing the Triangular Approach – Water metrics vs. Performance Indicators**

The current written plan (1977A) was approved in 1990 after the levels and flows the plan would produce were compared to set hydrologic criteria. The criteria had been established in the 1970s as part of the revised Orders of Approval for the regulation project. The Orders of Approval criteria are objectives expressed in terms of desired water levels and flows. In this study, the strategy the Study Board will use to evaluate regulation plans can be considered as a triangle with the vertices being the regulation plans, the hydrologic criteria and the performance indicators. This triangle symbolizes the iterative process that begins by identifying preferred water level and flow metrics related to the planning objectives, develops plans to address those objectives and evaluates the plans against the performance indicators.

Regulation Plans are written rules for making releases from Lake Superior into Lakes Michigan-Huron. There will be numerous alternative regulation plans developed and evaluated. Plans will be tested using three different hydrologic datasets representing the water supplies to the upper Great Lakes. The first is based on the actual supply conditions since 1900. The second is based on the historical data (like the first) but is expanded using statistical methods to create samples with periods with rare extreme wetter and drier conditions than have occurred in the last 100 years. The third is based on an assumption that climate change will occur during the life of the regulation plan and will be used, not as a forecast, but as a sensitivity analysis to see how well a regulation plan adapts to changing climate.
Water level and flow metrics are statistical characteristics of the lake levels, river stages and connecting channel flows that will result from a modeled plan based on a variety of water supply conditions. Examples include monthly average, maximum and minimum lake levels and flows, level and flow exceedance frequency, and the relationship of levels to releases (examples shown in Figure 24 and Figure 25, page 68).

Performance Indicators are measures that describe the economic, environmental, social, cultural, etc. impacts that result from a particular level/flow or series of levels/flows. They are based on something that can be measured and must have units (e.g. dollars, wetland area etc.) associated with them. The performance indicators for this study are still under development with some clearly identified (hydropower and commercial navigation), and some still being debated (coastal, recreational boating, municipal and industrial water supply, and environmental). Examples from the Lake Ontario study are shown in Figure 15 and Figure 16).
### Average Annual Net Discounted Economic Benefits (Stochastic Analysis)

<table>
<thead>
<tr>
<th></th>
<th>A+</th>
<th>B+</th>
<th>D+</th>
<th>2007</th>
</tr>
</thead>
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<tr>
<td><strong>TOTAL</strong></td>
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<td>$4.72</td>
<td>$4.43</td>
<td>$5.52</td>
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<td><strong>Ontario</strong></td>
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<td>$2.75</td>
<td>$0.15</td>
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<td>$-2.16</td>
<td>$-0.17</td>
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<td></td>
<td></td>
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<tr>
<td>Erosion to</td>
<td>$-0.23</td>
<td>$-0.17</td>
<td>$0.02</td>
<td>$0.02</td>
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<tr>
<td>Unprotected</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developed Parcels</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>$0.01</td>
<td>$0.01</td>
<td>$0.01</td>
<td>$0.01</td>
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<tr>
<td>Lawrence River</td>
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<tr>
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<td>$0.09</td>
<td>$0.08</td>
</tr>
<tr>
<td><strong>Shore Protection</strong></td>
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<td>$2.13</td>
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<tr>
<td>Maintenance</td>
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<td></td>
</tr>
<tr>
<td><strong>Hydro Power</strong></td>
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<td><strong>NYPA-DOE</strong></td>
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<td>$2.22</td>
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<td><strong>Alexburg</strong></td>
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</tr>
<tr>
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<td>$0.05</td>
<td>$0.05</td>
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<td>Lawrence</td>
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</tr>
<tr>
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<td>$0.00</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

1 - Not modeled using stochastic hydrology because historic results were similar for all plans.

#### Figure 15 Economic performance indicator table, Lake Ontario Study

<table>
<thead>
<tr>
<th>Environmental Performance Indicators</th>
<th>A+</th>
<th>B+</th>
<th>D+</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetland Meadow Marsh Community</td>
<td>1.02</td>
<td>1.44</td>
<td>1.17</td>
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<td>0.89</td>
<td>0.95</td>
<td>0.94</td>
<td>0.94</td>
</tr>
<tr>
<td>High Veg 24C - spawning habitat supply</td>
<td>1.05</td>
<td>1.00</td>
<td>1.01</td>
<td>1.01</td>
</tr>
<tr>
<td>Low Veg 24C - spawning habitat supply</td>
<td>1.00</td>
<td>1.02</td>
<td>1.00</td>
<td>1.01</td>
</tr>
<tr>
<td>Northern Pike - YOY recruitment</td>
<td>1.02</td>
<td>1.00</td>
<td>1.05</td>
<td>1.02</td>
</tr>
<tr>
<td>Largemouth Bass - YOY recruitment</td>
<td>0.94</td>
<td>0.98</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>Least Bittern (DIXE) - reproductive index</td>
<td>0.08</td>
<td>0.14</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Virginia Rail (RALI) - reproductive index</td>
<td>0.96</td>
<td>1.11</td>
<td>0.99</td>
<td>0.96</td>
</tr>
<tr>
<td>Black Ten (CHNI) - reproductive index</td>
<td>1.03</td>
<td>1.12</td>
<td>0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>Yellow Rail (CONO) - preferred breeding habitat</td>
<td>0.96</td>
<td>1.01</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>King Rail (RAEL) - preferred breeding habitat</td>
<td>1.05</td>
<td>1.10</td>
<td>1.03</td>
<td>1.04</td>
</tr>
<tr>
<td>Low Veg 18C - spawning habitat supply</td>
<td>0.91</td>
<td>1.01</td>
<td>1.01</td>
<td>1.01</td>
</tr>
<tr>
<td>High Veg 24C - spawning habitat supply</td>
<td>1.03</td>
<td>1.01</td>
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</tr>
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<td>Low Veg 24C - spawning habitat supply</td>
<td>1.01</td>
<td>1.01</td>
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</tr>
<tr>
<td>Northern Pike - YOY recruitment</td>
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<td>1.03</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Largemouth Bass - YOY recruitment</td>
<td>0.99</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Northern Pike - YOY net productivity</td>
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<td>1.27</td>
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<tr>
<td>Virginia Rail (RALI) - reproductive index</td>
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<td>1.00</td>
<td>1.00</td>
<td>0.97</td>
</tr>
<tr>
<td>Golden Shiner - suitable feeding habitat area</td>
<td>0.87</td>
<td>0.90</td>
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<td>0.81</td>
</tr>
<tr>
<td>Wetlands fish - abundance index</td>
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<td>1.03</td>
<td>0.97</td>
<td>1.00</td>
</tr>
<tr>
<td>Least Bittern - reproductive index</td>
<td>1.03</td>
<td>1.06</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Virginia Rail (RALI) - reproductive index</td>
<td>0.94</td>
<td>0.97</td>
<td>1.06</td>
<td>1.06</td>
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<tr>
<td>Migratory wildlife - productivity</td>
<td>1.06</td>
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<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Black Ten (CHNI) - reproductive index</td>
<td>0.84</td>
<td>0.77</td>
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<td>1.00</td>
</tr>
<tr>
<td>Northern Pike (ESLU) - reproductive area</td>
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<td>0.94</td>
<td>0.90</td>
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<tr>
<td>Frog sp. - reproductive habitat surface area</td>
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<td>0.87</td>
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<tr>
<td>Eastern Sand Darter (AMPE) - reproductive area</td>
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<td>1.03</td>
<td>1.13</td>
<td>1.13</td>
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<td>Spiny Softshell Turtle (APSP) - reproductive habitat surface area</td>
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<td>1.06</td>
<td>1.03</td>
<td>1.06</td>
</tr>
<tr>
<td>Brown Shiner (NOB) - reproductive habitat surface area</td>
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<td>0.97</td>
<td>1.00</td>
<td>1.03</td>
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<tr>
<td>Muskrat (DNZI) - surviving houses</td>
<td>1.04</td>
<td>0.88</td>
<td>0.96</td>
<td>0.96</td>
</tr>
</tbody>
</table>

### Figure 16 Environmental Performance Indicators, Lake Ontario Study

Percentage "good" scores for each plan:
- 6% 19% 13% 13%
- Joe Depinto’s Pretty Good Overall Environmental Index: 1.03 1.34 1.10 1.12
The Mock Shared Vision Model

A “mock” shared vision model was built at the beginning of the study to stimulate the study team members’ imaginations in designing the true shared vision model. The “mock” descriptor is used to make it clear that this computer model is not a consensus product, but more akin to a developer’s “model home” – something built ahead of time to help people think about what they will build for themselves. Mock models and reports have become a standard part of shared vision planning since a mock version of the National Drought Atlas in 1991 revealed that each Atlas team member had imagined a different end product, and those differences were creating unnecessary disagreement and were inhibiting progress on the project. (U.S. Army Corps of Engineers, 1991)

The mock model for IUGLS is a large, elaborate Excel spreadsheet that makes it easy to compare “fencepost” plan results for several different water supply sequences. Fencepost plans are extreme plans that serve to reveal the extent of what is possible through regulation given the existing structures (refer to plan formulation section for more information, PF1.4 Fencepost Plans, page 67)). Water levels and flows for each plan and each water supply sequence are imported from a separate regulation and routing model as one worksheet of data. Economic benefits for hydropower, recreational boating and commercial navigation are all calculated within the model using the routing model data and economic benefit algorithms transferred from the Lake Ontario study. The transfers are crude but not unrealistic. Stage-value curves generated for Lake Ontario recreational boating are transformed for use on the other lakes. Water levels are transformed as gage readings (that is, distance above or below low water datum rather than distance above sea level) and the value functions were scaled by the estimated number of boaters on each lake. The primary source of error is probably due to the lake to lake differences in the availability of deep water marinas.

Stage-cost curves for commercial navigation were transformed in a slightly more sophisticated way for commercial navigation. Water levels were already referenced to low water datum. Actual origin-destination shipping data were used to estimate the number of tons of cargo carried by ships of various drafts, and ship rental and operation costs from the Lake Ontario study were used to calculate shipping costs for the tons carried. Separate cost curves were developed for each calendar month and for nine different route groups (such as “confined to Lake Erie”, “transit between Michigan and Superior”).

Hydropower benefits were calculated based on head and flow at Sault Ste Marie and Niagara Falls. For the Sault power, the generating utilities provided efficiency tables and curves for use in standard hydropower formulas. Niagara Falls energy was calculated using an algorithm developed and approved for the Lake Ontario study. Benefits were calculated by multiplying the energy produced each month by the marginal value of that energy as estimated for the Lake Ontario study.

Coastal and environmental impacts were represented by comparing plan water levels and flows to desirable water levels and flows for different ends.
Figure 17 Mock SVM Benefit Display for MH Plan and dry climate change scenario

This is one display from the mock shared vision model, designed to stimulate thinking about how the plans would be evaluated. The user selects a water supply scenario (in this case, the Warm, Dry Climate Change scenario) and an alternative regulation plan (“MH”, the Superior for Michigan-Huron plan described in the fencepost plan section on page 68). This particular display shows economic benefits, but there are other choices (top left); the head between Huron and Erie, all the lake levels, a test of how well this plan “balances” lake levels, and graphs of the releases versus lake levels (these are shown later in this report, on page 68). Benefits are net, compared to the baseline plan, 1977A. The “WDCC” column and the “Same Supply 77A” graph show the net difference between the MH and 1977A plans, both run with the warm dry climate change supplies, while the “Historical” column and the “Historical Supply 77A” graph compare the benefits of the MH Plan, warm dry climate change and Plan 77A, historical supplies. Taken together, these two columns show that a radically different regulation plan would create a $37 million per year change in economic benefits but that climate change impacts would be much larger (over half a billion dollars per year). As noted in the main text, these economic benefit estimates are crude, based on benefit transfer methods using Lake Ontario study information.
PE1.5 Stakeholders and the Shared Vision Model Evaluations

Shared vision planning uses “circles of influence” workshops to determine the metrics stakeholders will use in ranking alternative plans, and to develop stakeholder trust in the model and planning process. Through these workshops PEG tries to get the interest groups to define specific metrics that capture what they think would be important in a revised regulation plan and to define critical thresholds for those metrics (for example, water level elevations that make it too difficult to travel by boat, cause flooding, or interfere with the fish habitat and fish spawning). These metrics are coded into the Board’s evaluation model so that the interest groups can use their own metrics to compare proposed regulation plans. The identified threshold values may or may not be critical in plan rankings. The experience of the LOSL study showed that stakeholder criteria that shaped plan rankings were critically reviewed. For example homeowners along the shore objected to high lake levels, while high levels were good for

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![Breakdown of navigation impacts by routes](image1.png)

**Figure 18 Mock Commercial Navigation Benefit Analysis**

**Figure 19 Metrics from the Muskegon Circle of Influence Workshop**
power generation, navigation and the environment. The highlighting and quantification of this conflict led to a partial resolution through further analysis (high summertime levels were far less dangerous to homeowners) and plans that could address both objectives.

**PE1.6 Interest Satisfaction Curves**

Interest satisfaction curves fall between water level metrics and performance indicators. They can be useful before performance indicators are established, they can help in the conceptualization of performance indicator algorithms, and they can even be used in optimization models to formulate new plans. They provide a simple, non-fungible measure of outcomes, yet they can be based on consensus professional judgment rather than long, expensive studies. But the same numeric scores from two interest satisfaction curves cannot be considered as having the same value, though. A hypothetical example of an interest satisfaction curve is show in Figure 20. In this hypothetical example, the generic interest is best satisfied by water levels between 176.2 and 176.9; water levels between 175.9 and 177.2 have positive scores, meaning that the levels are acceptable if not ideal. Levels above 177.2 and below 175.9 are undesirable in proportion to the score. For instance, levels below 175.6 are much worse than levels between 175.8 and 175.9. All TWGs will develop interest satisfaction curves based on professional judgment. Stakeholders will help develop these curves through the Circles of Influence workshops. Although cruder than economic benefit functions, interest satisfaction curves provide a simple, easier to obtain design tool for plan evaluation and formulation, including quasi-optimization formulation processes.
**PE1.7 Establishing Performance Indicators**

Each of the six interest specific Technical Working Groups is assigned with identifying the specific performance indicators and metrics they intend to measure in order to evaluation plan performance relative to their interest. This study will examine economic, environmental and social impacts. Not all of these will be quantifiable in dollar terms, but all must be measurable and all must reflect the impacts of a change to a regulation plan. They must reflect a sensitivity to changes in a regulation plan, be significant to the interest they represent, and they must reflect certainty in the research.

**PE1.7.1 Site Studies**

With fewer funds and a greater geography to cover than the LOSL study, it quickly became apparent to PEG and the rest of the Study team that the Study area is simply too large and budget and time too small, to permit a comprehensive Basin-wide evaluation. It is also known that the regulation of Lake Superior outflows has a lesser impact on Lake St. Clair and Lake Erie. Without the funds for extensive data collection the Study must pick study sites based on known problems and data availability. With the Study schedule, the TWGs have until about September 2010 to complete the work on their performance indicators which leaves very little time for new research – particularly for the environment.

Each of the TWGs have been asked to develop a strategy for selecting their Study sites. This will be discussed further in subsequent peer reviews of the economic and environmental performance indicators. However, it does have a considerable impact on the evaluation process as it does not permit a basin-wide evaluation of impacts between alternative regulation plans.

The site selection criteria are more thoroughly discussed in two subsequent peer review documents provided to the IRG for evaluation on July 14, 2009:

- Socio-Economic Sector Evaluations of Lake Superior Regulation Plans for the International Upper Great Lakes Levels Study, July 14, 2009

**PE1.7.2 Contextual Narratives**

Contextual narratives are being developed by each of the Technical Working Groups to provide a general overview of the interest, including the baseline condition, key trends in an area of interest, how the interest might be expected to adapt to changing water levels, and how they are affected by a regulation plan. The TWGs have been asked to use their best professional judgment in identifying the most likely trends, outcomes and ways of adapting to changing water levels. The study has also retained the services of two reviewers to assure that the contextual narratives are objective and provide the breadth of context the Board needs for its deliberation. In addition to the six interest-specific contextual narratives, an overview contextual narrative is being developed that includes population projections over the next 30 years for Ontario and the eight Great Lakes states; projections of the number and types of jobs and incomes, and disaggregation of their population and employment projections by coastal counties. The purpose is to provide a general overview of the economic and social state of the Great Lakes Basin. More information regarding the contextual narratives for individual sectors and the issues to be addressed in the narratives can be found in the sector by sector discussions that begin on page 54.
PE1.8 Economic and Social impacts

PE1.8.1 Economic Advisors
As the Technical Work Groups began to define their performance indicators, a number of economic issues began to arise. The need for consistency on approaches between the TWGs became very apparent. It was decided that some expert advice on the most problematic economic issues was needed. The idea is similar to the Economic Advisory Committee (EAC) used in the LOSL Study, made up of economic experts that provided an arm’s length review of the economic analyses being conducted within the study and advised on how to deal with specific economic issues. In IUGLS, there are two advisors; Steven Renzetti of Brock University is already engaged and efforts are underway to secure a U.S. economist.

PE1.8.2 Forecasting, period of analysis, and discount rate
Decisions to build significant water management structures such as dams or levees are traditionally evaluated based on their costs and impacts. Impacts farther into the future are discounted compared to near term impacts using a discount rate that reflects the preference for benefits now as opposed to later. The P&G describes the discount rate as an approximation to the average real rate of return on private capital, but a more appropriate conceptualization might be the long run rate on government debt. The period of analysis is often fifty to one hundred years. The choice of discount rates is important and controversial; a lower rate gives more weight to future costs and benefits, often making it more likely that average benefits will exceed annualized costs, the majority of which are near term for construction. In order to do such an assessment, it is necessary to forecast future conditions, even if the forecast is that the future will be just like the present. There can be a high and often inestimable degree of uncertainty in the forecasts. Uncertainty about discount rates and forecasts create uncertainty about whether the decision is as wise as the net benefits calculation suggests, but this rational analytic approach is still used because it can provide a best estimate of whether we are better off suffering the impacts the project was designed to avoid. A flood control project, for example, requires an imminent cost for construction and the loss of the services of the land it occupies, including environmental services. The benefit cost test helps address the question of whether it would be better to suffer future damages if, when and as they happen than to accept the more certain and near term project costs. Consideration of construction projects inevitably requires the possibility of certain and irreversible losses in return for doubtful future gains (for example, the certain loss of natural wetlands in dam construction mitigated by the potential of constructed wetlands to replace their services). Fortunately, in this case the change will be to a regulation plan and the Board intends to structure an adaptive framework for its application, so those issues are moot in this study. But there will be no forecasts used in the evaluations in this study because the decision is flexible and the uncertainty is large. The study decision will not involve new structures or significant first costs; the Board will recommend changes in a regulation plan, which can be changed if conditions change. In fact, the Board intends to develop an adaptive element to the plan. There is an unusual degree of uncertainty in both future economic and environmental conditions.

1. The economic future of the Great Lakes is particularly uncertain at this time. The Upper Great Lakes region includes U.S. counties with unemployment rates of over 20% (Figure 21), and the future of General Motors a one hundred year old corporation, once thought of as the symbol of American industry, is bleak even when compared to its long term decline. The Depression era unemployment rates and unprecedented industrial collapse threaten the viability of Great Lakes...
commercial shipping, state and local revenues affecting recreational boating, coastal zone
development and floodplain management, and the Great Lakes environment.

2. The environmental future of the Great Lakes is particularly uncertain at this time. The greatest
ongoing threats are invasive species and pollution. Downturns in the regional and national
economy could threaten efforts to clean up the Great Lakes. Improvements in invasive species
would require both treatment of the current effects of invasives already lodged in the Great
Lakes as well as the reduction in future invasives. The most likely future is that invasives will
continue to be a big problem because not enough will be spent to reduce the current problem,
while the measures taken to reduce the risk of new invasions are not expected to be 100%
effective. Pollution improvements are also uncertain; the great investments required would
seem impossible except that there may be growing public pressure to make these sorts of
investments. The primary air pollutant is heavy metals, especially mercury, that bio-
accumulates, increasing the damage at the top of the food chain to fish, birds and humans. Any
significant improvement would require a large reduction in airborne pollution from coal fired
power plants west of the lakes, an expensive proposition, but one that might occur if energy
prices or carbon emission costs increase. Acid rain is also a significant problem, especially over
Lake Erie and Lake Ontario. While recent measures should reduce the introduction of new
invasives in ships’ ballast water, the most visible threat is the Asian Carp which have infested the
Mississippi River and its tributaries and could be introduced to the Great Lakes in several ways.
These carp can weigh over 50 pounds and eat half their body weight per day, and the
introduction of this large “flying” fish is expected to greatly impact the Great Lakes environment
as the carp begins to dominate the lakes’ ecosystems by eating the plankton normally eaten by
the species that support salmon and trout. (watch
http://www.youtube.com/watch?v=yS7zkTnQVaM). While the future threat of the carp is
feared, the reality of the impacts of the quagga and zebra mussels (introduced in the late 1980s
in Lake St. Clair) has been measured in the billions of dollars. In both cases, the threat began as a
surprise, a warning that the future impacts of invasives are impossible to predict.
3. This study has less money to study a much greater area than the Lake Ontario study. The overall IUGLS budget is $15 million U.S., compared to $20 million U.S. for LOSL, even though the IUGLS geographic area and population is much larger.

4. The impact of Lake Superior regulation on water levels is much less than the impact Lake Ontario regulation has. The LOSL study concluded that regulation had eliminated much of the natural variability under which the Lake Ontario coastal environment had developed over centuries, while the lake levels produced by the current Lake Superior regulation plan are somewhat similar to the unregulated levels. Furthermore, the Study Board has made a preliminary determination that it will not recommend a plan greatly different from the current plan, for two reasons. First, the current plan is based in large part on a desire to balance Lake Superior and Lakes Michigan and Huron (which are hydraulically the same lake) levels, meaning that the intent is to keep Superior and Michigan-Huron about an equal number of standard deviations from their means. While regulation cannot achieve that objective - the main influence on Michigan-Huron levels is the net basin supplies to those lakes, which is typically several times larger than the change in Superior release designed to balance the lakes – it is unlikely that the Board will move away from that objective. Second, the benefits of regulating to produce very different lake levels are, at least at this early stage, not likely to be large or well distributed. Regulation is most effective at maintaining Lake Superior levels within ranges preferred by boaters and coastal landowners; it is much less effective in controlling Michigan-Huron levels and has even less effect on Lake Erie. The vast majority of the Great Lakes population lives around the lakes below Superior, the vast majority of hydropower energy is produced at Niagara Falls, not at Sault Ste Marie, (but regulation of Lake Superior has minimal

Figure 21 Great Lakes US unemployment, December 2008 (NY Times based on Bureau of Labor Statistics)
effect on Niagara power generation) and commercial navigation benefits are largely dependent on multiple lake levels (only about 2% of total Great Lakes tonnage is confined to Lake Superior).

The future climate of the Great Lakes is uncertain. This is discussed in more detail in the
5. 2.1.2 Climate Variability and 2.1.3 Climate Change sections, starting on page 16.

Without economic forecasting, there might seem to be no point to selecting any particular period of analysis or using a discount rate. But while forecasting would introduce variability in exogenous variables, the rate at which one plan or the other erodes the shoreline and shoreline protection structures is an endogenous variable that can be used to rank plans only if the plan evaluation framework discounts impacts that happen farther into the future. If the Coastal Processes TWG does develop a metric for either component of erosion, either in physical terms (movement of the top of bluff) or economic terms, then discounting will be used to distinguish between plans that take five years to erode a meter of bank and plans that take ten years to cause as much erosion.

Considering all these factors together, PEG recommended and the Board approved the evaluation of plans based on the current economic, social and environmental condition. A 30 year planning horizon will be used so that serially dependent phenomena such as erosion can be analyzed (see PE1.8.7 Coastal Processes, page 59 for more details), but the study setting will not evolve; the viability and scale of navigation, the amount of water withdrawn for cooling, the popularity of recreational boating, the investment in hydropower production, and the current list of invasive, threatened and endangered species will remain as they are today. The discount rate and planning horizon can be varied as part of a sensitivity analysis to determine if plan ranking is sensitive to the choice of these parameters. A contextual narrative will be developed for each sector; while not forecasts, these are intended to give the Board information about the state of and trends in the contextual settings for all the performance indicators. More information about the contextual narratives is included in the sector descriptions below.

PE1.8.3 Hydropower

The hydropower contextual narrative will be written in draft by Dr. David Patton, of Potomac Economics, with the assistance of Dr. Robert Sinclair, also of Potomac Economics. There are three hydropower stations at Sault Ste. Marie, a pumped storage generating station on Lake Michigan, and several hydropower stations at Niagara Falls and along the Welland Canal. The stations at Sault Ste. Marie, along with the locks and compensating works, form the principal control structures affecting flows and levels on the upper Great Lakes. The draft narrative will address:

- The general socio-economic context, including annual electricity production by the Sault Ste. Marie hydropower stations, the economic value of production, including the value derived from peaking operations; the number of stakeholders in Michigan and Ontario; discussion of peaking operations, and interconnections between these operations and commercial shipping operations in the St. Marys River; the societal value of hydropower and perceptions of the hydropower sector; significant public policy drivers and constraints, including how hydropower peaking operations are constrained to facilitate commercial shipping in the river; a brief history of hydropower at Sault Ste. Marie; trade flows and current market conditions in the Ontario and Michigan markets; and the effect of high and low water conditions on hydropower production

- A primer on potential performance indicators that could measure progress towards the operating objectives for a regulation plan, including the maximization of electricity production, and its value, predictable and stable flows (important in scheduling maintenance) and the formation of a stable ice cover (which is desirable even though it may limit energy production during the winter when prices are high).
Key baseline conditions that characterize electricity production at Sault Ste. Marie stations in the context of current electricity market conditions in Michigan and Ontario.

Key trends in terms of the public policy drivers and market forces that are likely to influence the value and direction of hydropower operations in the near to long-term. Among these, in October 2008, Michigan enacted the Clean, Renewable, and Efficient Energy Act (P.A. No. 295, 2008); in Ontario, Bill 150 (the Green Energy and Green Economy Act, 2009) is currently before the Legislative Assembly, and the province is seeking to phase out its coal-fired generation by doubling the capacity and supplies of renewable energy over the next 20 years.

The expected consequences of changes to regulation, an overview of how changes in regulation would change flow or head, and the ability to peak, and how that would affect the amount and value of electricity generation.

Adaptive behaviors, including the ability of the hydropower station owners to adapt to changing flows and levels, or adapt to changes made to regulation to address other interests, e.g., commercial navigation and environmental interests.

Risk assessment of the principal variables that are most likely to change over the near-term and long-term, and how changes to those variables could affect the interest, e.g., flows and levels, electricity prices.

The contextual narrative will also characterize hydropower operations at other locations other than Sault Ste. Marie. Because the effects of regulation at the St. Marys River are not, for practical purposes, measureable on Lake Michigan and in the Niagara Falls area, the predominant focus of plan formulation and evaluation will be upon the hydropower stations at Sault Ste. Marie.

The primary performance indicator for hydropower will be the value of hydropower electricity production. There is no evidence that regulation plan changes will have any effect on the production of electricity by other means; based on preliminary research, the amount of water available will be the same for all plans. In the initial mock shared vision model, the amount of energy produced by the hydropower stations at Sault Ste. Marie each month was calculated based on the average monthly head and flow using efficiency curves provided by the dam owners. But the SVM did not reproduce historical electricity production well enough when run with historical supplies, probably because variations in head within the month can produce different monthly energy totals for the same average monthly head. As a result, Environment Canada (Dr. Yin Fan) is now developing regression curves based on historical monthly energy production and if these prove reliable, these regression equations will be used in the SVM.

Estimated changes in value of electricity production will be based on expected marginal values for hydropower on a month-to-month basis. In the mock and initial versions of the SVM, market values from the LOSL study will be used. In Year 3 of the study, an independent analysis of electricity prices will be carried out to obtain current and forecasted monthly prices.

**PE1.8.4 Commercial navigation**

The contextual narrative for commercial navigation will be written in draft by Dr. Frank Millerd. The most significant questions regarding the future of commercial navigation are the health of the Great Lakes economy and the competitiveness of Great Lakes shipping compared to rail and other multimodal shipping routes. Short-term cost increases associated with low water levels may be absorbed by the
shipping companies or the owners of the cargoes, but the prospect of extended periods of low water levels and reduced loads could result in a shift to other modes. The narrative will attempt to identify possible break points at which there would be a major and possibly irreversible change in the commercial navigation system, and will characterize specific areas of uncertainty in predicting future changes. The narrative will also briefly address lesser, related issues. Fluctuations in water levels can lead to operational and structural difficulties at harbors. Low levels can expose timber piles, leading to decay, while high levels can cause overhead clearance problems.

The narrative will include:

- A description of the present situation or baseline conditions for commercial navigation on the Great Lakes-St. Lawrence River system, emphasizing the upper lakes.
- Possible future conditions that may affect commercial navigation in the Great Lakes-St. Lawrence River system, independent of any water flow or level changes.
- Climate change and commercial navigation on the Great Lakes-St. Lawrence River system.
- Possible methods for commercial navigation to adapt to changing water levels and flows, either due to climate change or due to modifications to Lake Superior outflows. Discussion of the use of transportation costs as a performance indicator.

The primary performance indicator for commercial navigation will be changes in the cost of shipping. This is the same metric prescribed by Principles and Guidelines for evaluation of U.S. navigation projects, and it represents the broad public benefit of reduced costs for the goods that are shipped, not savings, profits or revenues for shippers or traders. The indicator will be modeled as stage-cost functions for each of ten route categories, with a separate function for each calendar month. The functions will be based on actual data for ship movements during recent years. The Waterborne Commerce Statistics Center, part of the Corps of Engineers’ Institute for Water Resources, has so called “origin-destination” data on individual ship movements through the United States, including data on the ships and the loads. This will be augmented by Canadian data on ships moving between Canadian ports. There are extensive data on ship operating and rental costs, as well, allowing the estimation of the costs of moving each ton of cargo at the actual loaded depths. A model developed by the Huntington, Detroit and Buffalo district Corps of Engineers to determine how maintenance dredging budgets can best be applied to reduce navigation costs throughout the Great Lakes will be used to develop 1,800 transportation depth-costs curves. The curves may or may not be aggregated in the SVM; the raw number of 1,800 allows tracking of individual cargo types such as iron ore or grain, and that may or may not be of interest to the Board. The Buffalo model will be run holding water levels constant to determine the shipping costs at that level. Multiple runs of the model will be made at multiple fixed levels. The ten route groupings represent the ten possible combinations of water bodies ships pass through (for example, all within Lake Erie, transit between Lake Erie and Lake St. Clair, etc.). Shipping costs in each month of the SVM simulation will be a function of the minimum clearance available for that group. For example, in the Lakes Erie-St. Clair group, the SVM will compare the “gage readings” (depth above or below low water datum, which the elevation from which the shipping depths are designed) on the two lakes and the connecting channels and will select the lowest gage reading to define the depth of water available. The curve for that month for that group is a two column table for that calendar month, with clearance by centimeter in the first column incremented inch by inch (converted to meters) and aggregated costs in the second column. The shipping costs for that plan for that month are the sum of the 10 route group costs. The benefit of a particular plan is the average annual reduction in shipping costs for one plan compared to current plan using a wide range of stochastically developed net basin supplies.

The conceit of the benefit analysis is that the amount shipped will be the same despite water levels, but that the cost of giving up one inch of load on a ship because of one inch lower water levels is the
fractional portion of the ship loading costs. This is judged a reasonable approximation to reality in the case of shorter term periods of relatively small loading depth problems, but persistent and severe loading problems could cause shippers to move cargo to rail, move it on barges through inland waterways to the Gulf of Mexico or not produce or ship the goods (other exogenous factors would also drive this change). Because the performance indicator is designed to test the relative differences between regulation plans, which will produce only slightly different water levels, this is not considered a problem for plan ranking. It is an unresolved problem, however, to the degree that the Board tries to estimate the impacts of climate change or extreme drought under the current climate. The contextual narrative will begin the dialogue on how to assess those impacts, which may involve modal changes and loss of competitiveness and production for some Great Lakes industries and farming.

PE1.8.5 Municipal and Industrial (M&I) Water Use
The contextual narrative for M&I water use is being written by Kim Shaffer of the USGS, Ohio Water Science Center. Water supply is a great concern among the public. The Great Lakes states and provinces have recently completed an eight year process in developing the legal framework to protect the waters of the Great Lakes from diversions out of the basin and to improve management of the waters in the basin through water conservation and management of new or increased withdrawals. While this may not be important in ranking regulation plans, the public interest, and in some cases public misinformation, will force the Study Board and PIAG to deal with this in their dialogue with the public, so this subject will be addressed in the contextual narrative. The indications from existing studies and a new study for IUGLS is that the effect of M&I use is barely noticeable in comparison to the renewable flows in the Great Lakes water balance and will remain that way for the foreseeable future. In addition, some research has shown that only a very few incidences of M&I water use operational problems have occurred during the recent lower water levels, and those that did occur were generally associated with seiche events. But in the context of evaluating regulation plans, the greatest M&I concern is that low water levels would make it more difficult to withdraw water needed for M&I use. The M&I TWG has conducted one inventory which listed from state and provincial databases about 550 M&I intakes in the Upper Great Lakes. The TWG will follow up with a more focused assessment on about 100 intakes of the potential for intakes in the Upper Great Lakes to experience operating problems such as cavitation and debris blockage because of low water levels. The assessment will focus on areas of the Upper Great Lakes with shallower waters in the nearshore area as well as some of the larger systems on the Upper Great Lakes.

The performance indicator for M&I will likely be developed based on estimates of the short (pumping costs, water shortage impacts) and long term (intake relocation) costs of dealing with low water problems at the few intakes that might be affected by low water. A challenge for the study is that all intakes are fairly unique in design and limiting factors on withdrawal capability will differ among intakes.

PE1.8.6 Recreational Boating and Tourism
The contextual narrative for recreational boating is being prepared by Dr. Edward Mahoney. The primary contextual issues are the sensitivity of pleasure boating to even slightly lower than normal water levels, the changing demographics of boating which is expected to counter its growth in popularity since the 1960s, and the relative paucity of data that can be used to estimate benefits of changed regulation, especially on the Canadian side. The narrative will also address the related and connected field of tourism, including activities such as fishing and beach use that may be associated with boating and other activities that compete for boaters’ time.
The primary performance indicator for boating will be the change in the value of recreational boating because of changes in water levels. On the LOSL study, this was done based on extensive field surveying of the water depths available at marina slips and entrances throughout Lake Ontario and the St Lawrence Seaway; every marina was visited and many slips measured directly, while the bottom elevations of the remaining slips were interpolated from measured elevations. Boating surveys and a review of the literature established credible estimates of the number of hours spent boating in each calendar month and the willingness to pay for that recreational opportunity. Based on reasonable assignments of boats to slips (extrapolated where necessary from US data on the distribution of boat size and type, which was more complete), an estimate could be made of the number of boats that could not go from slip to open water at various water surface elevations, and this could be translated to the value of the lost recreational opportunity. Similar but simpler analyses yielded similar functions for boats docked at private homes and boats trailered and launched. But a similar analysis would be much more difficult for this study, both because the larger geographic area would make it much more expensive (with fewer dollars available) and because the influence of regulation on water levels is expected to be much smaller, making it more difficult to confidently determine any difference between plans. Consequently, a partial estimate of recreational boating impacts will be done, using sites selected by recreational boating experts. The sites (Figure 22) are not meant to be a random sample; the experts chose areas they felt are most likely to have water level related problems. Major boating areas such as Chicago will not be surveyed because the experts felt that water levels do not inhibit boating there. This sampling approach is considered the best use of limited funds, given that the Study Board will not rank...
plans based on the algebraic sum of net benefits in each sector (hydropower, commercial navigation, recreational boating, etc.).

There may be tourism impacts beyond the impacts to recreational boating. Our experts feel that something like 80% of all tourism activity/revenue associated with the Great Lakes is not directly associated with recreational boating. The study will survey four of the study zones (3 on the Canadian side and one on the U.S.) to determine if water level changes have significant impacts on those other industries. The survey will at least show the concerns and the economic impact on those other tourism related businesses (hotels, restaurants resource-based tourism lodges and resorts, campgrounds and cottages).

There will also be a brief assessment of the Cruise Ship industry that will be incorporated into our overall report and the Contextual Narrative.

PE1.8.7 Coastal Processes

The contextual narrative for coastal impacts has been prepared in draft by Christian Stewart in April 2008 (Stewart, 2008). Based on an educated guess average present-day market value of $300,000 to 500,000 per shoreline property, Stewart estimated the market value of riparian property on the upper Great Lakes in 2010 as between $28 to $47 billion. Once the tax contribution to local, state/provincial and federal governments by these riparian properties is factored into the total, the production value would be even higher. On Lake Ontario, this contribution was estimated to be 30-50% of the overall production value of the riparian group (Baird & Associates, 2006). If we thus assume a 40% contribution on average for all the upper lakes, the estimated total riparian production value in 2010 will range from $39 to $66 billion. Those stakeholders are represented by among others, the International Great Lakes Coalition, a non-profit corporation whose membership consists of individual coastal property owners throughout the Great Lakes Basin in both Canada and the United States, “Save Our Shoreline” based primarily in Michigan and Ohio Lakefront Group in Ohio. PEG is working to identify the issues these groups are concerned about and will develop water level and flow metrics they can use to rank plans according to their parochial concerns.
Table 4 Number of developed riparian properties, 1990 and 2010 (projected)

<table>
<thead>
<tr>
<th>REGION</th>
<th>1990 CENSUS</th>
<th>TOTAL</th>
<th>EST. 20 YEAR TREND %</th>
<th>EST. 2010 TOTAL</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Superior</td>
<td>6,050</td>
<td>1,500</td>
<td>7,550</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>St. Mary’s River</td>
<td>2,000</td>
<td>1,100</td>
<td>3,100</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Lake Michigan</td>
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<td>21,057</td>
<td>20</td>
<td>n/a</td>
</tr>
<tr>
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<td>17,600</td>
<td>30,971</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>St. Clair River</td>
<td>1,300</td>
<td>500</td>
<td>1,800</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Lake St. Clair River</td>
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<td>1,100</td>
<td>4,788</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Detroit River</td>
<td>700</td>
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<td>1,200</td>
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<tr>
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<td>26,800</td>
<td>83,458</td>
<td></td>
<td>63,688</td>
</tr>
</tbody>
</table>

Figure 23 Coastal study sites would be chosen from the areas where GIS data will be collected
Coastal Performance Indicators have not been finally selected or designed, but there is a process in place to design both water level metrics and (potentially) performance indicators for flooding, erosion of beaches and bluffs, shore protection damage, and low water impacts at sites where these issues are known to exist (Figure 23 shows all sites where GIS data will be gathered; the coastal impact assessment sites will be a subset of the data sites). As with recreational boating, the assessment will not estimate the overall impact to the Great Lakes, just impacts to the most sensitive areas. In high or low water times, these are issues that carry great political interest, but regulation has little effect on them. Lake Superior flood and erosion damages in the United States totaled close to $130 million, including over $43 million in damages during the 1950s and 1970s high water periods and close to $85 million in the mid-1980s (1987 U.S. dollar values as estimated in DeCooke 1988, 1990 and 1991). Damages along the Canadian shoreline of Lake Superior are poorly documented for these time periods, primarily because damages during these water level periods have been viewed as relatively minor. 1950s and 1970s high water periods accounted for nearly $260 million in damages along the Lake Michigan shoreline and $60 million along the U.S. shore of Lake Huron, while damages from the 1980s high water period were on the order of $62 million and $20 million, respectively (1987 U.S. dollar values as estimated in DeCooke, 1988). The bulk of these damages were related to shoreline erosion, most notably along the Wisconsin, Illinois, Indiana and Michigan shorelines in the southern half of the Lake. Conversely nearly all the damages along the U.S. shore of Lake St. Clair and the St. Clair and Detroit Rivers were due to flooding; just over $50 million in the 1950s and 1970s, and $66 million on the 1980s (1987 U.S. dollar values as estimated in DeCooke, 1988). The Canadian shoreline of Lake Huron, flooding and erosion damages have tended to be the highest along the southeastern portion of the shoreline from the City of Sarnia north to the town of Bayfield, a stretch marked by highly erodible coastal bluffs. Reported damages from the 1970s high water period in these areas were on the order of $1.6 million (Boulden, 1975). These same shorelines also suffered considerable erosion damage in the 1980s high water period, although exact dollar estimates are not well documented. Another area that has suffered flood and erosion damages in the past is the southern shoreline of Georgian Bay (Nottawasaga Bay), particularly the resort community of Wasaga Beach. Boulden (1975) reported nearly $400,000 of damages here during the 1970s high water period. This area also experienced a significant amount of damages (unestimated) during the 1980s high water period (Stewart et al., 1987). The south shore of Lake Erie suffered over $220 million and $55 million in damages in those two high water eras (1987 U.S. dollar values as estimated in DeCooke, 1988). There is also discussion of low water impacts, but it is not as clear that the different regulation plans will make enough difference to low water periods to have a measureable impact.

As of this writing, the Coastal TWG has identified the following potential water level and flow metrics and performance indicators. The TWG will determine through iterative investigations whether the small differences in water levels between regulation plans would produce differences in coastal impacts larger than the uncertainty in modeling them. In their parlance, Stage 1 metrics are screening level assessments to consider whether more detailed analysis is warranted. They measure the change in the physical process relative to the existing regulation plan (i.e. difference in exceedance water levels). Higher stage metrics move from water measures to performance indicators, incorporating some measure of significance in terms of societal impact and may be required depending on observed level of sensitivity.

**Flooding**

Stage 1 – differences in specified exceedance water levels (by month) relative to existing regulation plan (1977A) (includes wind setup/ storm surge) as measured in elevation (e.g. cm, m)
Stage 2 (if necessary) – difference in specific exceedance water level (between 1977A and new plan) as measured by mapping water level and determining the change in the number of structures within the hazard zone.

Stage 3 (if necessary) – for protected shorelines, a count of the change (and severity) in overtopping magnitude as measured using existing USACE overtopping categories.

**Low Water**

The changes in property value ($) for a given change in water level as demonstrated through stage-impact curves for each study site. The impact curves will be determined through a hedonic pricing model approach in which the service value of the property would be broken into its constituent characteristics, the values of each characteristic would estimated and then added. The underlying assumption is that property value variation over time for a given shoreline section is in part a reflection of changing water levels.

**Erosion**

Non-eroding bedrock shorelines – no performance indicators will be used as no measurable impacts are anticipated (note that highly erosive bedrock shores will be considered with cohesive shorelines)

**Stable Dynamic Beach**

Stage 1: Extent of extreme event cutback relative to 1977A (m)
Stage 2 (if necessary) - difference between 1977A and new plan as measured by mapping cutbacks and determining additional structure footprints within hazard zone.

**Erosional Sandy Beach**

Stage 1: order of magnitude comparison of longshore transport rates for various water levels (to understand sensitivity)
Stage 2 (if necessary) – plan specific transport rates

**Erosional Cohesive Bluff**

Stage 1: % change in erosion rates (m/yr) for new regulation plans relative to 1977A

Stage 2 (if necessary) - difference between 1977A and new plan as measured by mapping predicted 100 year erosion zone and determining % change in the number of structure footprints within that zone.

**Shore Protection**

Stage 1 - % change in failure rate of theoretical shore protection structures for a new regulation plan relative to 1977A (potentially broken down by failure type (e.g. overtopping, undercutting, etc.)
Stage 2 - % change in failure rate of actual shore protection structures in a given shoreline reach for a new regulation plan relative to 1977A (potentially broken down by failure type (e.g. overtopping, undercutting, etc.)

**PE1.9 Ecological Impacts**

An environmental contextual narrative is being prepared by a small writing team led by Don Uzarski, Central Michigan University. The narrative addresses the following subjects for the present and future of the Great Lakes:
- General context, including a literature review of the economic valuation of Great Lakes environmental services (the tentative Board decision is to not estimate economic values of ecological impacts, but some TWG members disagree and want to investigate this notion more), an assessment of the number, organization and perspectives of people who would be considered environmental stakeholders, and an assessment of how interest in the environment waxed or waned in recent high and low water periods.

- Performance indicators derived from the white paper, which is the source of the potential performance indicators listed in Table 6, page 65.

- Secondary impacts not addressed by performance indicators, following on an ecological outcome (for example, expanded wetlands) or an economic outcome (reduction in commercial navigation).

- Key baseline conditions, including the current climate, current species mix, current habitats, function and health, and current laws and initiatives.

- Key trends, looking back 10-15 years and using a 30 year future time horizon. For example, will invasive alien species (in numbers and/or distribution) alter the sensitivity of the environment to water level changes?

- Expected consequences of changes, in terms of the ability of the environment to adapt, the regional distribution of impacts, and adaptive measures that could be taken to minimize the impacts.

- Adaptive behavior, connecting the IUGLS Adaptive Management effort to look at triggers and responses.

- Risk and uncertainty, including an overview of the risks involved in making decisions about the environment with limited data and the potential use of sensitivity analysis to reduce those risks.

The first attempt to define environmental **performance indicators** was put forth in a December 2008 white paper developed for IUGLS by Jan J.H. Ciborowski and Gerald Niemi, Valerie Brady, Susan Doka, Lucinda Johnson, Janet Keough, Scudder Mackey and Donald Uzarski (Ciborowski et al 2009). The paper summarized what is now known about the relationship between water levels and coastal ecosystems. A summary of these indicators is shown in Table 5, page 64; proposed study sites where these functions would be developed are shown in Table 6, page 65.

The performance indicator selections and definitions are in flux as of this writing, but have come closer to definition through an experts’ workshop held in February, a modeling workshop April 3, 2009, and the initial IERM design workshop, held September 3, 2009 in Ann Arbor.

The Board will ultimately have to consider values as well as performance in selecting a new regulation plan. For example, as pointed out by the peer reviewers, Lake Superior ecosystems are generally more pristine than those in the lower lakes, and some might consider it more important to preserve the hydrologic regime in pristine environments. Clearly, we will not have modeled estimates of biological outputs on any of the lakes, so the Board will not be able to decide whether to preserve Superior hydrology based on evidence that it would be more productive.

The IUGSL ecological peer review document addresses the technical aspect of this, stating that the selection of sites for ecological evaluation will consider the pristine attribute.
<table>
<thead>
<tr>
<th>Category</th>
<th>Proposed Performance Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrology</td>
<td>Seasonal inundation timing and magnitude shifts</td>
</tr>
<tr>
<td></td>
<td>Frequency of connection; lake and tributary, lake and wetland, tributary and wetland</td>
</tr>
<tr>
<td>Wetland Vegetation</td>
<td>Areas of different vegetation zones</td>
</tr>
<tr>
<td></td>
<td>Percent of wetland area dominated by invasive plant species</td>
</tr>
<tr>
<td>Invertebrates</td>
<td>Biomass per hectare</td>
</tr>
<tr>
<td></td>
<td>Taxa richness of long-lived wetland obligate species</td>
</tr>
<tr>
<td>Fish</td>
<td>Habitat-weighted suitable areas for various fish guilds and species</td>
</tr>
<tr>
<td></td>
<td>Population densities at various life stages for walleye, yellow perch, others (TBD)</td>
</tr>
<tr>
<td></td>
<td>Number of species</td>
</tr>
<tr>
<td>Birds</td>
<td>Water level based habitat condition index predictive of obligate breeding marsh birds</td>
</tr>
<tr>
<td></td>
<td>Water level based habitat condition index predictive of obligate water birds</td>
</tr>
<tr>
<td></td>
<td>Change in sand and cobble beach habitat for Piping Plover</td>
</tr>
<tr>
<td>Herptiles</td>
<td>Frog and toad habitat or water level based habitat condition index predictive of frog and toad</td>
</tr>
<tr>
<td></td>
<td>population density</td>
</tr>
<tr>
<td>Mammals</td>
<td>Density of muskrat houses in early spring</td>
</tr>
<tr>
<td></td>
<td>Area of sedge-fen habitat, used by meadow and heather voles</td>
</tr>
<tr>
<td>Species at Risk</td>
<td>Habitat area suitable for coaster brook trout and one other species (TBD) for various life</td>
</tr>
<tr>
<td></td>
<td>stages</td>
</tr>
<tr>
<td></td>
<td>Habitat area for least bittern, black tern, king rail and yellow rail</td>
</tr>
<tr>
<td>Algal productivity</td>
<td>Water column chlorophyll a</td>
</tr>
</tbody>
</table>
PE1.9.1 Upper Great Lakes IERM

Work will begin shortly to create an Integrated Ecological Response Model (IERM) that would calculate these performance indicators for every alternative plan. The IERM would be the environmental wing of the Shared Vision Model. Calculational requirements may mean that it will not be an Excel spreadsheet, depending on the nature of the algorithms, but every effort will be made to make the IERM hew to SVM design objectives – easy to use, defensible, and transparent. With some possible exceptions on the St. Marys River, the information used in this study will be drawn from existing studies, not new field work. Much of the work done in support of the IERM will be the synthesis of what is known about ecological responses to lake level changes.

More details on the IERM are included in “Ecological Evaluation of Lake Superior Regulation Plans for the International Upper Great Lakes Levels Study”, July 14, 2009. The IERM is still conceptual and is not ready for computer coding. Additional review of the IERM development was discussed at the Ecological Peer Review meeting on July 22, 2009 in Detroit and a model design meeting in Ann Arbor on September 3, 2009 at which time a recommendation was made to use the IERM to hypothesize, based on existing data, the ecological response at the various selected sites to the more extreme lake levels likely to be encountered in the future and addressed, if at all, under adaptive management. This design concept is in stark contrast to the Lake Ontario IERM, which was designed to estimate the differences in ecological impacts between regulation plans.

PE1.10 Using Perfect Forecasting to refine stakeholder preferences

The PEG has already asked and received guidance from different stakeholders and experts about the water levels they would consider ideal. For example, Muskegon area shore property owners like water
levels close to average (see Figure 19, page 47), but given the relatively small effect that the regulation of Lake Superior has on levels below it, these shore property owners would not realize their ideal even if maintaining more average levels on Lake Michigan was the only regulation objective. Nonetheless, plan formulators can produce water level series from each new plan, and shore property owners can apply their own criteria to rank plans. No plan will meet their criteria all the time, but they can rank plans based on which meet the criteria more often or fail less dramatically when they do not.

But stimulated by peer reviewers encouragement to use perfect forecasting more broadly, PFEG proposes to use perfect forecasting to develop an evaluation tool between the plan outcomes and the impossible ideal; and, has developed a conceptual approach to do so.

One or two knowledgeable representatives from each technical working group will be presented with actual 20th century water level elevations. Based on what we already know, PFEG will present periods of that history that different TWGs would have preferred to change. For instance, the 1950s and 1970s water levels will be of interest to representatives from the Coastal TWG because these high water periods accounted for nearly $260 million in damages along the Lake Michigan shoreline and $43 million in U.S. damages on Lake Superior. PFEG will develop an interactive water balance model that will allow Coastal experts to change water levels within the possible envelope afforded by the limits of regulation. Water levels would be calculated using the actual supplies that occurred, so participants would be limited only by the physical characteristics of the control structure. The results of these exercises could be used to describe tradeoffs (for example, the tradeoff between damages on Superior and the lower lakes), and to refine interest satisfaction curves.

Appendix 2 Plan Formulation

Plan formulation is the process of inventing alternatives to the current rule set. There is a strategy for formulating plans on the IUGLS, based on the Lake Ontario approach but modified to fit the particular issues on Lake Superior.

**PF 1.1 Formulation Strategy**

The primary goal of the plan formulation strategy is to systematically explore alternative regulation plans in such a way that decision makers, experts and stakeholders feel confident that there is little chance that the undiscovered plans are much better than the plans that are evaluated. A secondary goal is to inform the tradeoff process, showing stakeholders what the limits of regulation are in meeting their objectives, and whether or how objectives are in conflict. The idea is that having semi-independent teams competing to see who can develop the best plans will make it more likely that better plans will be invented. Formulators are allowed to use any formulation approach and software they prefer. The competition is collaborative, however. At benchmarking workshops, formulators will compare plan results and share insights on how rule sets affect outcomes. All formulators will use the Shared Vision Model to evaluate plans very quickly, so design iterations can be efficient and fast. The following sections describe the plan used now to regulate releases and the activities undertaken to find a better plan.
PF1.2 The baseline plan, 1977A

Lake Superior releases are now regulated by a plan called 1977A. The design goals of 1977A are to balance Lakes Superior and Michigan-Huron while honoring past interpretations of water use priorities. Plan 1977A is spelled out conceptually at different levels of specificity, but its explicit interpretation is encoded in a complex FORTRAN model that is difficult for even the modelers to understand. The following conceptual plan description is meant to provide a basis of understanding for some of the plan formulation guidance and plan evaluation interpretation.

The rules of Plan 1977A are designed to adjust the levels of Lake Superior and Lakes Michigan-Huron so that they are proportionately close to their long term averages. The plan was also designed to meet the following criteria set out in the IJC’s supplemental order of approval of 1979:

- **Criterion (a):** Keep Lake Superior within 182.76 metres (IGLD 1985) and 183.86 metres based on supplies of the past, with no greater probability of exceeding 183.86 m than would have occurred under the 1955 Modified Rule of 1949 (Rule of 49).
- **Criterion (b):** Maximum level at US Slip gage must not exceed 177.94 m if the flow is greater than the pre-project flow;
- **Criterion (c):** Maximum outflow is pre-project flow if Lake Superior below 183.40 m.

The plan designers also set the following “requirements” based on either physical limits of the structures or preferences of the interests. These are stated here in abbreviated form:

- **Requirement (a):** The maximum May through November release shall be limited to the capacity of the 16 gate compensating works plus 2320 m³/s flow through the side channel.
- **Requirement (b):** The maximum release December through April shall not exceed 2410 m³/s.
- **Requirement (c):** The minimum release shall be no less than 1560 m³/s, unless criterion c governs.
- **Requirement (d):** Consistent with other requirements, reduce the frequency of high Michigan-Huron levels.
- **Requirement (e):** Consistent with other requirements, reduce the frequency of low Michigan-Huron levels.
- **Requirement (f):** Consistent with other requirements, reduce the frequency of high Lake Erie levels.
- **Requirement (g):** Consistent with other requirements, reduce the frequency of low Lake Erie levels.

PF1.3 Range of levels and flows

There is not likely to be much difference in lake levels because of the new regulation plan, although flows in the St. Marys River could change considerably. The reasons for this are explained in “4. The central evaluation challenge: the small impact of regulation Error! Reference source not found.”, starting on page 25.

PF1.4 Fencepost Plans

The IUGLS team developed three so-called “Fencepost” plans first, and evaluated and compared results for these plans, along with Plan 1977A and the “Preproject” (unregulated) Plan in the mock SVM evaluations. Fencepost plans are extreme plans, usually in the service of one objective or group of stakeholders. By modeling them first, researchers can better define the domain of their lake level.
impacts and show damages caused by focusing on one objective (it is unlikely that plans worth serious consideration will have levels above or below the extreme plans) and the limits of what regulation can do are better understood. Figure 24 and Figure 25, below show seasonal connecting channel flows as a function of the contributing lake elevation for two fencepost plans.

**PF1.4.1 Superior for Michigan-Huron (MH) Plan**

This plan attempts to reduce the range of fluctuation of Lakes Michigan-Huron by using Lake Superior as a reservoir and allowing more variation in the month to month flow from Lake Superior and more variation in the Lake Superior level. This plan is a variant of Plan 1977A, with that plan’s parameters adjusted to place more emphasis on keeping the level of Lakes Michigan-Huron closer to its average. Rules were added to limit high and low levels of Lake Superior. Levels of Lake Superior are allowed to be outside those specified in the orders of approval and criterion c of those orders was ignored, as were month-to-month flow change constraints. The plan was successful in keeping the levels of Lakes Michigan-Huron closer to average more often than Plan 1977A, but the overall range of its levels is not appreciably reduced. This may be because of the constraints in the Lake Superior outflow capacities and levels limit the ability to affect levels in periods of sustained high or low supplies to lakes Superior and Michigan-Huron.
Example Plan Description

Plan 5: Modified Superior for Michigan-Huron

Objectives

The Modified Superior for Michigan-Huron Plan intends to constrain the range of lakes Michigan-Huron, but still consider user benefits and limit the range of extreme (high and low) levels on Lake Superior.

Approach

An optimization approach is proposed to determine a regulation schedule that optimizes user benefits and limits the ranges of extremes on both lakes. The basic approach will resemble the Cornell Matrix Plan, although adaptations to the Upper Lakes will likely result in some significant departures from the methodology used in the LOSLR. The objective will be to minimize penalties for deviating from minimum and maximum target levels to be defined by IUGLS task groups. The penalties for both lakes will be combined using a weighting approach, allowing a trade-off analysis to be conducted by varying the weights. The model will optimize releases for some period into the future (likely 1-2 years), and then report the release for the first period as the release rule for that monthly period. Since monthly forecasts for up to two years are far from perfect, a probabilistic approach will be considered in which the model optimizes over a number of “scenarios” (possible NBS traces).

Criteria and Limits

The plan will not necessarily adhere to the existing IJC Orders of Approval, especially with regards to Criteria B and C, although the plan may be assessed with respect to these criteria. Constraints will be incorporated to maintain Lake Superior levels so as not to overtop the Compensating Works or fall below the point where the minimal physical flow relationships for the structures cannot be maintained. Maximum winter flow constraints will also be used.

Input Data

The plan inputs include the month of regulation, beginning-of-month Lake Superior and Lake Michigan-Huron levels, physical flow/level constraints, and forecasts of monthly NBS.

Operational Details

The plan will have a monthly regulation interval, with Lake Superior releases determined based on beginning-of-month lake levels and the month of regulation. The use of other antecedent information or NBS forecasts as additional operational parameters may also be considered.

Plan leads: Dave Watkins, Matt McPherson
PF1.4.2 Superior for Superior (Sup4Sup) Plan
This plan attempts to keep Lake Superior’s level as close as possible to its monthly long-term average levels (1900-2002), regardless of the consequences for the downstream lakes, hydropower, or the environment. Specifically, Criterion B and C were not used nor were month-to-month flow constraints. The goals of this plan are achieved by adjusting the outflow from Lake Superior. When compared with the results of Plan 1977A run using historical supplies, the Superior for Superior plan successfully reduced the range of levels and the standard deviation of the levels on Lake Superior. As expected, this came at the cost of increased range and variability of levels and flows in the St. Marys River and Lakes Michigan-Huron.

PF1.4.3 Dependable Flow (HP) Plan
This plan is designed to release a constant flow of 2030 m$^3$/s plus a ½ gate open setting in the Compensating Works, unless the level of Lake Superior is more than set amounts above or below its seasonal average level. A near constant release provides a dependable flow for hydropower, and under the historical supplies series, maintains a relatively high level of Lake Superior that results in more hydropower production. This plan results in more variation in the Lake Superior level. Rules were included to limit high and low levels of Lake Superior. Levels of Lake Superior are allowed to be outside those specified in the orders of approval and criterion c of those orders was ignored, as were month-to-month flow change constraints. Although this plan achieves its intended aim with historical supplies, it does not perform well with other supply series.

PF1.4.4 Fencepost Plan Results Using Historical Water Supplies
The fencepost plans can have a significant effect on the water levels of Lake Superior as shown in Figure 25 and Figure 26. Both the Superior for Michigan-Huron plan (MHPlan) and the dependable outflow plan (HPPlan) result in more months with high levels and more with low levels. The Superior for Superior plan (SupPlan) reduces the range of levels, and maintains the levels very near their seasonal averages. Compared to the fencepost plans, the Pre-project plan produces levels similar to those of Plan 1977A, although with Plan 1977A the level of the lake is generally several centimeters higher than it would have been under pre-project conditions, although the higher levels occur about as often. The Sup4Sup Plan and HP Plan result in median (50%) levels several centimeters higher than Plan 1977A. The MHPlan tends to take water from Lake Superior in order to maintain nearer to average levels of Lakes Michigan-Huron, and this results in a lower median level of Lake Superior. The greater variability in the levels resulting from the PPlan and especially the MHPlan is also evident. The frequency of levels below Chart Datum (183.2 m) would increase substantially with the MHPlan, to about 47% compared with about 15% with Plan 1977A.

The Lake Superior outflow would be significantly affected by the fencepost plans. Plan 1977A and the pre-project plan have a similar flow distribution, except that Plan 1977A has more frequent flows of 1560 m$^3$/s, a threshold flow within the plan, and fewer flows around 2600 m$^3$/s due to the increment in the gate setting with hydropower flow at capacity. The HPPlan, by design, tries to maintain a constant outflow of about 2030 m$^3$/s (plus a ½ gate open to supply the rapids) for dependable hydropower production, and tends to pass very high flows only when the Lake Superior level is at the point of overtopping the structures. The Sup4Sup Plan and MH Plan have more variable flows to try to maintain levels near average on either Superior or Michigan-Huron. Compared to the effects on Lake Superior, the fencepost plans have relatively little effect on the levels of Lakes Michigan-Huron as shown in Figure 27.
Figure 26 Lake Superior Water Levels produced by the fencepost plans and 77A

Figure 27 Lakes Michigan-Huron Water Levels produced by the fencepost plans and 1977A
The Lakes Michigan-Huron levels graph shows that only the MHPlan has a significant effect on the frequency of more extreme low and high levels. For example the frequency of levels below Chart Datum (176.0 m) is reduced from roughly 12% with Plan 1977A to about 2% with MHPlan, while the frequency of monthly levels above 177.0 m is reduced from roughly 6% to 3% with the MHPlan. The Sup4Sup Plan increases the variability of Lakes Michigan-Huron levels only marginally compared to the decreased variability it causes on Lake Superior levels.

Figure 27 also indicates how similar Michigan-Huron water levels are under the current plan, 1977A and no regulation. In fact, 1977A releases under Criterion C are often the same as pre-project releases. The levels of lakes St. Clair and Erie are affected even less than those of Lakes Michigan-Huron by the different fencepost plans; only the MHPlan has a noticeable impact on their levels compared to the rest, but with a more moderate reduction in the frequency of high and lows. For example the frequency of levels below Chart Datum would fall from about 3% to 1% of the months.

PF1.4.5 Fencepost Plan Results Using Warm Dry Climate Change Supplies
Because it was necessary to route flows through the upper lakes to produce good stochastic and climate change supply sequences for Lake Ontario, there were a number of alternatives to the historical supply sequence available for evaluations of the fencepost plans.

The Warm-Dry climate scenario was the most severe of the four climate change scenarios developed for the LOSL study, with average net total supplies to Lake Ontario only 5,946 m$^3$/s, compared to 7,057 m$^3$/s for historical, a 16% reduction. In order to develop the inflows into Lake Ontario, it was necessary to model the impact that changed precipitation and evaporation would have on the entire Great Lakes basin, so the climate change inflows to the Upper Lakes were already available (though now dated; new water supplies will be developed using newer global and regional circulation models and an improved understanding of historical net basin supplies, including improved data). Note that in the LOSL analysis the historical time series of meteorological variables were scaled by the differences in the average monthly means of these variables between the base and climate change cases. Thus only the difference in the mean monthly net basin supplies of the base and climate change cases should be compared.

Channel conditions and diversions into and out of the system were assumed to be constant, and the same as the historical case, for the simulation period.

The markedly lower supplies in this climate change scenario caused the levels of the lakes with unregulated outlets (all but Lake Superior) to be lower than the historical case and similar for all of the regulation plans. Lake Superior average levels, however, varied greatly among the different regulation plans. Since the regulation plans developed with the historical net basin supply conditions were not modified prior to testing with the climate change scenario, the markedly lower supplies in this climate change scenario caused much lower mean Lake Superior levels with some of the plans. The Lake Superior levels resulting from Plan 1977A and the Preproject plan were almost identical since Plan 1977A limits its outflow to be not more than the pre-project relationship whenever the Lake Superior levels are below 183.40 m, which is generally the case with this dry climate case. For both of these plans the median Lake Superior level declined to about 183.15 m, about 0.20 to 0.25 m lower than in the historical case. The MH Plan, which attempts to maintain the same average levels of Lakes Michigan-Huron as in the historical climate case, drains the water from Lake Superior in order to try to maintain the historically higher levels on Lakes Michigan-Huron. This causes the median level of Lake Superior to drop to about 181.85 m, since it is constrained from falling lower by the low physical limit imposed by the capacities of the control structures at Sault Ste Marie. The HP Plan which strives to maintain an outflow from Lake Superior of about 2030 m$^3$/s, which is greater than the average supply in this climate change scenario, also drains
Lake Superior. In contrast, the Sup4Sup Plan maintains the Lake Superior median level close to its historical climate median of 183.4 m. The median level of Lakes Michigan-Huron for all of the plans with this Warm-Dry climate change scenario climate is about 175.75 m, compared to the median of 176.45 m for the 1900-2000 historical climate case.

**PF1.5 Plan Formulators and Initial Plans**

While the fencepost plans provide the extent of what is possible with regulation, they are unlikely candidates as they do not attempt to balance interests or lakes. They do show that regulation can significantly affect Lake Superior levels but have relatively little effect on Lakes Michigan-Huron. A team of plan formulators has initiated the development of plans that are considered more realistic than the fencepost plans in that they are designed mindful of tradeoffs and constraints. The plan names, main objectives and the names of the people formulating the plans are as follows:

- Reduced extremes plan (Travis Dahl) tries to constrain the range of extreme (high and low) levels on lakes Superior and Michigan-Huron
- Modified Superior-for-Superior plan (Matt McPherson) seeks to maintain the long-term average of Lake Superior even in a drier climate, but allow some inter-annual variation needed for the environment.
- St. Marys flow plan (Missy Kropfreiter) tries to improve the flow regime in the St Marys River, in terms of fisheries needs in the St Marys Rapids, reduced spillage (or variation from month to month) through the rapids (i.e. dependable flow for hydropower), and river levels for navigation.
- Modified natural flow plan (Yin Fan) is a realistic alternative plan that starts with pre-project outflows and attempts to mimic natural outflow, but also considers impacts to other interests and the capacities of the control structures. Dr. Fan will also model the pre-project outlet case, or the natural flow plan to be used as a basis for comparison for various purposes.
- Modified MH plan (Matt McPherson with Dave Watkins) attempts to constrain the range of Lakes Michigan and Huron, but still respects the conditions on Lake Superior i.e. not as biased as the fencepost MH plan.
- New balancing plan (Rob Caldwell and Yin Fan) is a simplified Superior-Michigan-Huron lake level balancing plan. i.e. the same goal as Plan 1977A but using a simplified approach if possible.
- Measure 1.21 (Yin Fan) has been completed. It is a plan from a previous IJC Study (the Levels Reference Study) It is a modification to Plan 1977A, increased maximum winter outflow limit, use of a new balancing equation that modifies balancing parameters for Lake Superior, and no Criterion C to limit flows.
- 1955 Modified Rule of 1949 (Travis Dahl and Missy Kropfreiter). This was the active regulation plan from 1955-1973 and was the basis of comparison in the IJC’s 1979 order. This is the plan referenced in Criterion A of the current Order when it requires that the probability of exceeding 183.86 m on Lake Superior are no more than would have occurred under the 1955 Modified Rule of 1949 (Rule of 49) with supplies of the past.

**PF1.6 Plan Constraints**

Plan formulators must stay within certain constraints. Some are linked to safety and are essentially inviolable (higher levels would cause dam failure) while some are linked to economic thresholds (higher levels would increase flooding damages greatly) and could only be breached if new research showed damages would not occur or that some greater benefit would occur for some other reason. Some constraints reflect agreements that are technically negotiable, but for all practical consideration are not.
PF1.6.1 Critical Levels

For integrity of the structure, on a monthly mean average plans must keep about 10 cm of freeboard below the top of the lowest gate (184.02m IGLD85) in the spillway structure known as the Compensating Works. This level will still result in overtopping on certain windy days, and extended durations at this water level may jeopardize an earthen berm section on the Canadian side. This “safe” monthly mean elevation can be considered equivalent to 183.9m at the S.W. Pier gage. Modeling results should report S.W. Pier level, which can be evaluated for exceedance frequency and duration above 183.9 m. For shorthand comparisons, assume a corresponding Lake Superior level of 184.12m.

Upstream minimum level, assumed, at the Southwest Pier is 181.43 m.; below this flow is assumed to be 0. This is the base level used in the pre-project equation.

Downstream maximum – US Slip <= 177.77 m top of Edison Sault hydropower plant tailrace tunnel – avoid flooding plant. (This is an operational constraint, but at some point ESEC’s ability to control discharge would be lost)

There is no real physical limitation on downstream levels. For purposes of evaluating damages in the Soo Harbor area, including the Edison Sault facilities, the plans will report U.S. Slip elevations. The damage threshold used in Orders of Approval is 177.94m.

Downstream minimum assumed = 175.96 m at US Slip to avoid cavitation at Edison Sault (operational constraint)

PF1.6.2 Critical Flow Limits

Maximum (Summer) – 2,320 m³/s sidechannel plus 16 gate capacity

Maximum (Winter) - Assumed 2,410 m³/S – to prevent ice jams in the lower river (Dec – April) This is the maximum side channel flow of 2320 m³/s plus a ½ gate setting. At present the winter gate setting is limited to ½ gate open.

Some uncertainty remains regarding how “hard” to make this constraint. Appears to have originated due to some bad experiences with ice jams in the early 20th century, and confirmed as prudent policy by model studies once or twice since then.

Minimum Summer Flow - Summer side-channel min. assume 280 m³/s – May-Nov Also need to consider flow through Compensating Works gates, at present min is ½ gate plus 15 m³/s through gate 1. Will count occurrences <280 m³/s.

For physical minimum = 10 m³/s because the power plant requirements aren’t really a physical constraint, they are an operational constraint. Side channel minimum assumed 1,150 m³/s used Dec – April; not likely to change the 50:50 split in the Treaty during minimums, but maybe during the maximums

PF1.7 What is wrong with Plan 1977A?

Any new plan(s) recommended by the Study Board are not expected to differ greatly from the current plan. Accordingly, to supplement the design direction based on desirable water levels and outcomes,
study team members have been asked to stimulate design ideas by enumerating what is wrong with the existing regime, plan 1977A. For instance, 1977A rules are too complicated to be understood by experts let alone the public. A much simpler rule set could produce nearly identical levels. 1977A requires sudden large changes in the number of gates that are opened to release water through the compensation works; the rules could be changed to allow a gradual change. The current plan uses a simplistic method for “forecasting” future lake levels and water supplies in calculating the balancing flow equation. These were acceptable when computers were rare and less was known about the mean and standard deviation of lake levels, but these could be improved now. It is also expected that some will want the levels resulting from the present plan to be altered, but the extent that they are due to Plan 1977A versus the hydrologic conditions will have to be determined.

**PF1.8 Optimization and Simulation**

The overarching IUGLS strategy on plan formulation is to encourage competition to improve the chances of finding and implementing a plan superior to 1977A in every way for every stakeholder. This strategy includes not just openness to different ways of formulating plans, but conscious design to encourage it. In its broadest meaning, optimization is the act of producing optimal outcomes, an overall best. In water resources management optimization typically refers to computer programming to solve for the water levels or flows that maximize the value of a function that relates water levels or flows to an objective. The objective function can be linear or non-linear, and non-commensurate objectives (for example, environmental benefits not expressed in a universal metric such as dollars) can be included as constraints or costs.

Optimization provides a uniquely valuable but limited tool for finding the best regulation plan. The advantages of optimization are that it forces formulators to think mathematically about objectives, weighting one against the other, mindful of timing, place and fungibility. But as objectives become more complex it may be difficult or essentially impossible to solve for an optimal solution. On the Lake Ontario study for example, two of the three recommended plans had been formulated using two different optimization techniques. The fact that these two plans survived the final ranking of the Study Board shows how useful the technique can be. But the plans were not the direct result of just an optimization model, nor were they able to consider some important metrics directly (the most important environmental metric was the ratio of meadow marsh area produced by an alternative after dry years to the area produced by the base plan under the same conditions. The calculation of this metric was difficult in a forward direction during a simulation; it was essentially impossible to formulate as an objective in either optimization approach.

At least one of the plan formulation teams – Matt McPherson (Hydrologic Engineering Center) and Dave Watkins (Michigan Technological University) the Modified Michigan Huron plan will use optimization.

**PF1.9 The Use of Perfect Forecasting in Plan Formulation**

Peer reviewers suggested the IUGLS follow the example of the Lake Ontario regulation study and use perfect forecasts to estimate the potential of better forecasts to improve the outcomes of regulation.

PFEG has subsequently stated work with plan formulators and other technical working groups on ways to incorporate perfect forecasts into the analysis. The teams are using different approaches in formulating plans in a competitive but collaborative approach, with each team trying to satisfy the same array of management objectives through a different formulation approach. Some are making changes to control parameters in the current regulation plan; some begin with unregulated levels and then add
regulation selectively to reduce damaging high and low levels. All teams may make use of perfect forecasting in their development process to both gain insights to improve their methodologies and also to demonstrate what is possible. For example, the current Plan 1977A attempts to balance the lakes using simple forecasts of water supplies in the next five months. The team changing parameters on Plan 1977A can substitute the actual water supplies to determine not only how much better the plan could be with better forecasting, but also determine how to accommodate the risks associated with forecast error into their methods. It is expected that the value of hydrological forecast improvements, something between the simple method now in use and perfection, will also be demonstrated through this approach.

**PF1.9.1. Optimization Approach**

One plan formulator (Dr. Dave Watkins, Michigan Technical University) will use perfect forecasting in his optimization approach. Dr. Dave Watkins is trying to optimize levels for the given objectives, and this should allow the most systematic use and most effective assessment of the value of perfect forecasting. Dr. Watkins is planning to use both a perfect foresight and a "stochastic" model. The stochastic model will choose the optimal release from Lake Superior in the current month based on multiple possible forecasts of future supplies. The array of possible supplies underlies the risks of using a release strategy; depending on the rules for using the forecast arrays, the results will be closer or farther from the best possible outcome.

The perfect foresight version might have different configurations, such as optimizing for the entire historic record in one run or optimizing over a limited, but rolling horizon, as was done for Lake Ontario simulations.
Appendix 3. Adaptive Management Strategy

DRAFT

ADAPTIVE MANAGEMENT WORK PLAN

Partially Approved by the Study Board

September 10, 2009

(Executive Summary updated Sept. 15 to reflect Study Board decisions of Sept. 10)
Executive Summary

This appendix includes a replacement of the April 2009 Adaptive Management strategy with the September 2009 version, which has been partially approved by the Study Board at its September 2009 meeting. This executive summary begins with a section detailing how the new adaptive management strategy was reshaped in response to peer reviewers’ comments on the earlier Adaptive Management appendix.

Overview

The Adaptive Management strategy is a proposal for an integrated series of IUGLS work elements to develop an adaptive management plan for dealing with future uncertainty regarding Great Lakes levels and flows. Uncertainties include uncertainty in the world (natural variability, including economic, social, climatic and environmental) and uncertainty in the way we reduce the world to mathematical models. In the Lake Ontario-St. Lawrence River Study (LOSL), model uncertainties were of the greatest concern because the effects of mistakes in modeled impacts could influence decisions on plans. In the Upper Great Lakes study, the selection of a regulation plan in the near future is not expected to be as sensitive to the way we have modeled the impacts. Consequently, the adaptive management plan for IUGSL is designed to deal primarily with uncertainties about economic, environmental and climate conditions a little further into the future.

The work proposed here is to identify plausible future conditions under which stakeholders could not cope using existing policies and infrastructure and then to design a strategy for triggering policy changes and investments in time to address the changing conditions. Future coping mechanisms could include a new plan for regulating Lake Superior, new control structures elsewhere in the Great Lakes, or policy or investment changes made outside of water level regulation and the beyond mandate of the IJC. The scope of this adaptive management effort includes the identification of likely non-IJC responses, consideration of climatic trigger points and a communication strategy for informing non-IJC response measures, but not the evaluation of those measures. The development of triggers and communication outside the IJC is limited to those areas where there is some promise of stakeholder interest and an effective response.

The tasks are laid out in sequence, but they will be iterative, with some revisiting of earlier tasks as we go forward.

1. Task 1 will be for the TWGs to define the A-B-C water level zones; “A” is the preferred zone, “B” the zone that is difficult but can be coped with under current management regimes, and “C” the zone where management would have to be adapted to avoid serious negative consequences.

2. We will next describe problematic scenarios, both in terms of water levels and economic and environmental future conditions that would require adaptation.
3. In Task 3 we work with the Hydroclimate Group to determine how plausible the “C” zones are, and also inquire as to how soon we can identify a hydrologic regime shift. This will produce a group of water supply sequences that we can use to model impacts and test alternatives.

4. We formulate, evaluate and rank plans in Tasks 4, 5 and 6. In Task 4 the focus is Superior Regulation plans. To the degree possible the evaluation will take advantage of the performance indicators developed to evaluate and rank plans under the current climate regime.

5. Task 5 focuses on new regulation structures elsewhere in the Great Lakes. The evaluation will be in terms of hydrology only, examining the influence of structures on levels and flows. Economic and environmental analysis will be based on the coping zones established in Task 1. Where it is defensible we’ll use existing impact functions, however, these will be applied with considerable caution.

6. And Task 6 focuses on adaptive responses other than regulation of lake levels. In this case, the level of evaluation is more rudimentary, but we will do a preliminary assessment of the completeness, effectiveness, acceptability and efficiency of these measures.

7. We will then identify long term monitoring and modelling that would be required for these measures, and where it makes sense, fold this back into the plan evaluations.

8. Formal adaptive management requires pre-establishing the mechanisms for management. In this task we will do an assessment of what changes would be needed to adaptively change Superior regulations or construct new structures, and what it would take institutionally to manage non-regulation adaptations.

9. The last step is to support the Board’s decision process for selecting its preferred adaptive management approach and to publish agreed upon adaptive management plans.

The estimated costs of this proposal over the next three years total $650,000. These are new costs that would have to be met by reduced expenditures elsewhere. However, many of the items have no costs listed because these costs are for work that more specifically directs the work that PFEG and the other TWGs had already budgeted for.

Response to Peer Reviewers

Peer reviewers generally supported the adaptive management strategy but made suggestions that were factored into the revised strategy in two major categories:

- Use of perfect forecasting
- Combined economic, ecological and hydrologic scenarios

Perfect forecasting
Clearly, we have limited skill at forecasting climate regime shifts, or even confirming these shifts as they are occurring. At the same time, the central notion of adaptive management for climate change on the Great Lakes is that if we knew when and how water level regimes or impact regimes were going to shift, we could change the regulation plan, consider new or additional regulation structures, or adapt policies and behaviors on land to reduce the negative and increase the positive aspects of changes in climate or ecological and economic conditions. PEG wants to use perfect forecasting to test that notion before recommending the use of study funds to improve the forecasting of regime shifts.

The approach will be similar to the approach used in producing ideal water levels (previous section) except that the duration would be longer, including the use of an interactive model in which decision makers can specify any water level sequence possible with the supplies of a particular scenario, without having to develop a series of plans that approach the desired levels. For example, there might be a water supply scenario that transitions from the current to a very dry climate, producing very low water levels on Lake Superior. PEG might invite ecologists to design the Lake Superior levels they would like to see during the dry period to preserve Lake Superior ecosystems. Perhaps this would be done with and without a downstream control structure. The interactive model would limit the lake level changes to those possible given the supplies and structures. The resulting water level and flow time series would be evaluated using all the performance indicators and hydrologic attributes used in traditional plan evaluations, and the differences between this evaluation and the Plan 1977A evaluation for the same supplies would provide an estimate of the upper limit of what adaptive regulation could provide. With some additional work this approach could be used to evaluate policy changes other than regulation, such as changing the fleet of commercial vessels or re-drawing the 100 year floodplain.

3. Scenario Suggestions: The study may wish to consider a scenario-driven analysis in which specified extreme event scenarios are used in the analysis. Noting that most stakeholders prefer levels closer to average, reviewers asked that the IUGLS team report on the current status of drought and high water contingency plans and building from there, consider a scenario-driven analysis using specified extreme events. These scenarios could consist of a water supply trace and an economic condition. A dynamic scenario could be created, tracking for instance, lower levels from climate change causing less commercial navigation, followed by a change in the depth requirements for shipping.

Combined economic, ecological and hydrologic scenarios

Acting on the suggestion from peer reviewers, a more formal scenario analysis process has been designed into the adaptive management strategy.

As part of the new Adaptive Management Strategy, PFEG will ask each TWG to imagine unprecedented but plausible scenarios that would stress a particular service or resource. The broadest array of future scenarios would be generated, but an iterative process would be used to quickly eliminate future scenarios that do not require further planning. For instance, some people believe that navigation traffic could expand significantly in the future, so it makes sense to ask whether we would need to adapt our management policies if demand for Great Lakes shipping was expanding just as climate change was lowering the depths available for loading. However, an simple initial sensitivity analysis might show that the only way to help navigation under climate change was to build additional control structures below Buffalo and below Montreal (i.e., that Lake Superior regulation or non-regulation measures would be ineffective). If the Board had decided that the cost of building and operating those structures would far exceed any imaginable benefit, no further study would be done.
Study Board Decision (Sept 10, 2009):
The following draft work plan was presented to the Study Board Meeting on Sept. 10, 2009 in Chicago. At that meeting, the Study Board approved Tasks 1-5 plus Task 7 of the proposed work plan and provided $340K from uncommitted funds over the remainder of the Study towards Adaptive Management. Discussions with the TWGS in October, 2009 will determine what adjustments may have to be made to their budgets to address the approved tasks (note, no additional funding was identified for the TWGs). Tasks 6, 8, and 9 were not approved at the Sept. 10 meeting. The Board asked that more detail be provided on these tasks and presented at their next Board meeting in December, 2009.

The following outlines the Adaptive Management Plan as it was presented to the Study Board on Sept 10, 2009. However, adjustments to the budget will be required to reflect the approved amounts and additional scoping of Tasks 6, 8, and 9 will be necessary. The Board appointed Wendy Leger as the Canadian co-lead for a new Adaptive Management Group (AMG) to lead this effort. A U.S. lead is pending. The Plan Evaluation Group will continue to be led by Bill Werick, but will join with the Plan Formulation Group led by David Fay to form the Plan Formulation and Evaluation Group (PFEG). Both the AMG and PFEG will report through the Superior Task Team led by Syed Moin and Tony Eberhardt. The group names have been updated in this document to avoid confusion.
ADAPTIVE MANAGEMENT WORK PLAN

Overview

The following is an updated Adaptive Management work plan as required by the Study Board at the February meeting. It represents the most current thinking based on input from a June 2-3, 2009 workshop designed to provide advice to the Board on this subject. The work is laid out in nine tasks.

<table>
<thead>
<tr>
<th>Project Title: Adaptive Management Work Plan</th>
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<tbody>
<tr>
<td><strong>Purpose:</strong> Develop a Board recommendation for adapting lake regulation and non-regulation policies to future water supplies and changing economic and environmental conditions.</td>
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<table>
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<tr>
<th>Key Deliverables:</th>
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<tr>
<td>• Year 4. Report with coping zone definitions, initial assessment of forecasting, initial framework for adapting regulation rules, initial assessment of the ability of new structures to influence levels and flows, enumeration of problems regulation cannot address, initial monitoring framework, preliminary inventory of coping agencies</td>
</tr>
<tr>
<td>• Year 5. Report with strategy for adapting regulation rules, forecasting method, practice decision for regulation adaptation, monitoring plan, final institutional analysis with willingness of agencies to cooperate, and an annotated outline for the adaptive management plan,</td>
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| Schedule: Sept. 11, 2009 through March 31, 2012 |

<table>
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<tr>
<th>Summary of Estimated Costs</th>
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<tr>
<td>Totals - Year 3 through March 2010</td>
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<tr>
<td>Proposed – Year 4 April 2010 – March 2011</td>
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<td>Proposed – Year 5 April 2011 – March 2012</td>
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<td><strong>Total</strong></td>
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1 Background

The Study Board initially identified Wendy Leger and Bill Werick to lead the development of an IUGLS adaptive management strategy. An initial adaptive management discussion document was presented for Board consideration at its December 2008 meeting and followed-up with an initial draft scope of work at the Feb 2009 Board meeting. If approved, the Board would form a new Adaptive Management Group (AMG) to lead the effort and be responsible for the staff work necessary to support the adaptive
management effort and for working with study team members in developing a strategy; formal discussions with people outside the study would be led by the two study directors.

This is a revised approach for adaptive management. The changes from the first draft are largely because:

- The Board added a new requirement. In its draft St. Clair report, the Board recommended that “The need for mitigative measures in the St. Clair River be examined as part of the comprehensive assessment of the future effects of climate change on water supplies in the upper Great Lakes basin in Report 2 of the Study, on Lake Superior regulation.”
- The Board decided to sponsor a June 2009 workshop to secure advice on how to conduct the adaptive management efforts.

There are many definitions of adaptive management, but in its broadest sense, adaptive management is a formal process for continually improving management policy and practices by learning from their outcomes, as described by Taylor et al. (1997).

The U.S. Department of the Interior uses a definition adopted from the National Research Council (NRC, 2004) in their Adaptive Management Technical Guide (Williams et al., 2007) as follows:

Adaptive management [is a decision process that] promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a ‘trial and error’ process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders. (Williams et al., 2007)

2 Impact of the mitigative structures decision

As noted, the St. Clair draft report (IUGLS Study Board, May 2009) recommends the examination of mitigative measures (that is, new structures to regulate other lake discharges besides Lake Superior) as part of the Lake Superior task team efforts of assessing future effects of climate change. To do this, the Board will be able to draw on assessments of multiple lake regulation done during the Levels Reference Study, but will also need to update and expand that work to meet its second recommendation. Additional work includes:

- Clarifying the goals and principles of the analysis
- Specifying the capacity of previously defined alternative regulation structures to affect Great Lakes levels.
• Modifying the Great Lakes routing model to include release rules for each of these structures.
• Development of a quasi-optimization of multiple structures to affect the best overall results throughout the system.
• Developing trigger conditions to begin different tasks of the development of these new structures, and assessing the risks of delaying or advancing those phased decisions.
• The development of water supply sequences that represent the range of conditions that might occur in the future.

This work is woven into the tasks described below.

3 Impact of the June 2-3, 2009 Adaptive Management Workshop

At the Study Board’s request, an adaptive management workshop was held on June 2-3, 2009 in Windsor, ON, bringing together climate experts and resource managers to help consider whether and how to craft an adaptive management strategy. A distillation of that advice follows.

Linda Mortsch from Environment Canada outlined the difficulties in determining what climate change scenarios are most relevant for various applications; she said that there is no one “best guess scenario”, so it will be necessary to come up with multiple futures to explore a range of possible future conditions. This was reemphasized by Mike Lewis, a visiting scientist with the University of Rhode Island, who demonstrated that paleo-records show that water levels had been twenty meters lower than today even in the early post glacial era, pointing to the variability in climate even without the impact of CO2 forcing (he does not envision levels that low, though, noting that these levels were in part a by-product of arctic ice that does not exist today).

Sue Doka from Fisheries and Oceans Canada provided a comprehensive overview of how adaptive management is defined in the literature. Al Douglas from the Ontario Centre for Climate Impacts and Adaptation Resources enumerated the climate change research projects he oversees in the province of Ontario, and Patrick Doran from the Nature Conservancy described TNC’s climate change adaptation for the Great Lakes which had its first meeting this year.

Casey Brown from the University of Massachusetts argued that we should reverse the accepted climate change evaluation procedures. Rather than generate hydrologic scenarios selected based on climatologists assumptions about the future and then crunch through them to find problematic scenarios, he suggested that resources experts work with hydrologists and climatologists to plan for problematic scenarios that climatologists affirm are plausible. This approach was supported and reemphasized by the Independent Review Panel during their July 20-21 review of the socio-economic and ecosystem evaluation strategies.

The traditional approach is to generate some water supply sequences based on various climate assumptions and test our ability to cope with those supplies. But this approach may overstate the risk or omit water supply conditions that are much more dangerous and plausible.

Climatologists cannot estimate the probability of wet and dry conditions in the future. Long term natural variations are not precisely periodic, so it is practically impossible to use the past to forecast
when a dry regime will shift to wet or vice versa. And there is irreducible uncertainty in every task of the
development of climate change water supplies:

- GCM’s predictions beyond 2040 are driven by carbon emission forecasts that are very uncertain
  because they depend on future economic conditions, policy changes and innovation, all things
  that are all hard to predict;
- GCMs are global, and the gross scale means that the GCMs do not see significant Great Lakes
  phenomena such as lake effect precipitation.
- GCMs provide credible evidence of futures we should be concerned about. However, we
  shouldn’t overestimate their predictive abilities. The skill of GCMs varies based on the
  parameter used and no model does well across all parameters (e.g. T, P); We cannot estimate
  the skill of a GCM for predicting future climate based on its skill in replicating current climate.
  We cannot estimate the probability that the GCM outcomes will be correct.
- At best, GCM’s produce large scale and generalized estimates of how climate parameters like
  precipitation and temperature will change; analysts have to create monthly sequences of
  precipitation, evaporation and runoff into the lakes, and that translation requires a series of
  assumptions.
- If the sequences are created by adjusting historical water supplies to reflect forecasts of
  precipitation and evaporation from the GCMs, the sequences will not reflect expected changes
  in frequency distribution or inter-annual variability;
- Regional climate models address the gross scale issues of the global models, but are subject to
  many of the other uncertainties.

Water supply sequences created from the climate change perspective may represent some portion of
what climatologists believe is possible based on their assumptions, but they are only a sub-set of the
analysis (others include stochastic analysis, climate variability, paleo analysis) and therefore, may not
represent future conditions that are also possible and beyond our ability to cope under current
management policies and with existing infrastructure.

Dr. Brown suggested a bottom-up approach that begins with the system or decision and follows three
steps:
1. Identify system/decision vulnerabilities to climate (problematic water supplies)
2. Characterize the plausibility of those climate hazards
3. Use systematic decision approach to address climate risks

The workshop included an opportunity for all participants to provide input to a proposed strategy that
originally included four tasks including:

1. Climate change warning system
2. Methods for improving Impact assessment
3. Rules for modifying levels and flows
4. Mechanism for initiating actions to adapt to levels and flows.

Based on the advice provided by the experts and from the input received by workshop participants, and
review of existing adaptive management documents, the adaptive management strategy has been
restructured to consider a more bottom-up approach as suggested by Dr. Casey Brown. Subsequent
discussions and correspondence with Jim Bruce provided an existing risk management approach (Black,
June 2009) that, when modified slightly to accommodate Brown’s concept, informed and provided additional detail for the proposed process. A nine task proposal with about the same overall effort (except for the additional costs for the assessment of multiple regulation structures) is now being proposed:

Task 1: Define system vulnerabilities  
Task 2: Develop risk scenarios  
Task 3: Define plausibility of risks  
Task 4: Develop existing regulation strategies to address future risks  
Task 5: Evaluate the ability to influence levels and flows through new structures  
Task 6: Develop non-regulation strategies to address future risks  
Task 7: Identify long-term monitoring and modelling requirements for adaptive management  
Task 8: Conduct an institutional analysis  
Task 9: Develop adaptive management plans for regulation and non-regulation response

4. Descriptions of Adaptive Management Tasks

Task 1: Define hydrologic zones of increasing vulnerability

1a. Develop Socio-Economic coping zone definitions/current “management range”. AMG and PFEG will work with the TWGs to differentiate between three water level regime zones:  
Zone A: Levels, which, if not ideal then are acceptable and within the tolerance and expectations of the interest. This may vary by location, but is likely to be within the historical range. Most Lake Superior regulation plans will work well enough in this zone.

An example: Sketching out Zones A, B and C for Commercial Navigation

Shippers have stated their preference for water levels above low water datum because it means they can load each ship with more cargo, making them more competitive and reducing overall shipping costs in the US and Canada. These are acceptable levels. But the lower water levels drop and the longer they stay low, the greater the impact would be on shippers. They have coped by reduced loading and by scheduling transits on the St. Marys during peaking releases. Levels from chart datum to perhaps the record minimum of the twentieth century might be considered the coping zone, where shippers struggle but are still able to operate in a competitive shipping environment. But if water levels were to drop two feet lower than twentieth century lows and stay lower for years, the scale and nature of the response from and for the shipping community would be markedly different. In order for there to be shipping it might be necessary to deepen harbors and channels, build new control structures, invest in a new shipping fleet, or rebuild navigation structures. Traditional coping measures would be insufficient to avoid a significant collapse of Great Lakes commercial shipping.

The zones at this stage will be descriptive (for example, “more than five years in a row with average levels more than 50 centimeters below low water datum”). The next task includes the development of the actual water supply sequences that will be used in the shared vision model.
Zone B: Water levels which stakeholders can cope with under existing policies and infrastructure. Stakeholders may suffer negative impacts or incur costs for avoiding those impacts in this zone, but can survive and prosper if water supply conditions return to the “A” zone. This zone probably begins towards the extremes of the historical range, but it may be that with current plans and policies some interests could cope with even higher or lower levels. Different plans for the regulation of Lake Superior may make a significant difference in impacts. This zone may be important in ranking alternatives for the next Lake Superior regulation plan.

Zone C: Water level regimes outside of the coping zones. In this zone major policy changes or investments are needed to avoid significant negative impacts. This is the zone that requires planning for adaptive management measures.

The AMG and PFEG will work with the Hydropower, Commercial Navigation, Recreational Boating, Municipal and Industrial Water Supply and Coastal Technical Working Groups to identify these zones. We will examine past impacts during high and low water level periods and how interests have addressed impacts in the past to help define coping zones. We will also try to estimate, based on the current physical and socio-economic conditions, how able they might be to cope in the future with more extreme water level regimes. This task will help to identify the location and sensitivities of those most vulnerable.

The economic relationships between water levels and impacts may not hold true when water levels are far outside the historical range. PFEG will work with the TWGs to identify the limits of the domain of the economic evaluation functions used for evaluation with historic supplies. For example, commercial navigation might say that their economic evaluations are no longer valid when levels persist at 70 cm, below average levels for more than three years, but might also say that if water levels persist 1 m below average for two or more years that shippers might begin to abandon the Great Lakes. While these thresholds cannot be more than educated guesses, they can be used in later tasks to evaluate adaptation strategies and as triggers for new monitoring or external adaptation.
1b. **Establish Ecosystem coping zone definitions:** This task is similar to 1a, but will focus on understanding the vulnerability of various ecosystem components to water level regime changes in the Upper Great Lakes and establishing water-level magnitude or timing thresholds above which, or below which, harm will be done to various ecosystem components and the Great Lakes ecosystem. The objective of this approach is to identify water-level ranges and thresholds that minimize adverse impacts to biotic communities and ecosystem function, i.e. a range of water levels and water-level variability that supports diverse biotic communities and ecosystem functions. When those thresholds are crossed or exceeded, there are significant adverse impacts to the ecosystem. Moreover, these thresholds are solely a function of the underlying biotic community responses and fundamental structure of the ecosystem; knowledge of proposed water-level regulation plans and/or potential climate change induced water-level regime scenarios is not necessary to identify these thresholds.

![Descriptive Framework of Biological Condition](image)

*Figure 29 Descriptive Framework of Biological Condition*
1c. **Prioritize vulnerabilities.** Based on the coping zone definitions developed, identify thresholds at which the current coping zones would be exceeded and prioritize vulnerabilities by interest and location based on the severity of potential socio-economic and environmental impacts.

Responsibility: Technical Working Groups  
Timeline: Sept. 2009 thru Sept. 2010  
Cost: Re-profiling of TWG budgets plus Yr 3 $10K

**Task 2: Develop risk scenarios**

Once the TWGs had identified the three zones, the AMG and PFEG would work with the Hydroclimate Group to develop water supply sequences representing those zones and would work with the TWGs and economic advisors to develop plausible economic and environmental regime shifts. The alternative future climate, economic and environmental conditions would be designed so that they could be used singly or in combination to determine future system vulnerabilities.

2a. **Develop a range of water supply sequences for zones B and C that cross from preferred to coping to extreme regimes.** This work would be led by the Hydroclimate Group and PFEG who would act as liaison with plan formulators and the evaluation TWGs. The Hydroclimate Group would generate variations on the historic supplies or variations on the larger stochastic water supply set, using the same roughly 30-40 year long period and same monthly timestep. The sequences would be generated from the component supplies (evaporation, runoff, precipitation) so that the plausibility of these sequences could later be determined from climate modeling and other hydroclimate analyses. The transition water supply sequences will begin with supplies characteristic of the historic range and transition to supplies characteristic of extreme high or low supplies.

Responsibility: HC TWG/PFEG  
Timeline: Sept 2009 – May 2010  
Cost: Reprofiling of HC TWG and PFEG budgets – if funds available.

2b. **Develop socio-economic and environmental scenarios.** AMG will hire an outside contractor to work with the TWGs and Economic Advisors to develop a series of economic growth forecasts and environmental scenarios that could influence the way society may choose to regulate water levels in the future. The Independent Review Panel suggested the following economic scenarios be considered.

- The current economy going forward for 30-40 years, with and without climate change (no economic trends)  
- The current economy going forward for 30-40 years, utilizing current economic trends, with and without climate change.  
- A high economic growth scenario going forward for 30-40 years, with and without climate change.

Environmental scenarios might be just as important, such as the invasion of a new invasive species.

Responsibility: AMG/PFEG
Task 3: Risk Evaluation – define the frequency/plausibility of the risk

3a. Define plausibility of risks: Based on first two steps estimate the plausibility of exceeding the coping zones-management range. AMG will hire a risk manager to work with the hydroclimate TWG and the economic advisors to identify the plausibility of future risk scenarios.

The Hydroclimatic Group would work with the risk manager and other TWGs to develop estimates of the plausibility of the water supply sequences generated in the previous task. The details of how to do this have yet to be worked out in detail but the general process is as follows:

- Determine the change from historic precipitation, runoff and evaporation in the component supplies of the sequences
- Characterize the array of precipitation and temperature estimates in terms of averages, standard deviations, seasonality, temporal and spatial correlation from every possible GCM run available. In addition to runs done specifically for IUGLS, there is a database available of statistically downscaled and bias corrected GCM runs (112 of them) that can be used to supplement the IUGLS data
- The plausibility of a sequence will be defined as proportional to the percentage of climate modeling forecasts that predict the precipitation and evaporation patterns necessary to create those water supplies.

The incidence of model predictions is not the same as probability, because we have no way of measuring the skill of these models at predicting future water supply conditions. But they are a measure of the degree to which current science establishes the potential for these conditions. In effect, we will place less emphasis on preparing for hydrologic future conditions as the frequency of scientific prediction of those scenarios declines. Accordingly this approach will give us a rational, defensible and graduated assessment of the risks associated with not planning for these possible futures.

Once the plausibility of the risk scenarios has been defined, we can build a risk evaluation matrix as shown in figure 2 (Black et al, 2009) of frequency/probability from low to high risk water supply sequences and socio-economic scenarios with severity of impact. A series of workshops will take place beginning in January 2009 between the Study climate experts and the various TWGs and other experts as required to ensure coordination and collaboration throughout the process.

Responsibility: HC TWG, and Superior Task Team
Timeline: Sept 2010
Cost: Yr 3 $25K Yr 4 $45K

3b. Investigate our ability to forecast hydrologic shifts. The effectiveness of adaptation may depend on the accuracy and forewarning time of forecasts. At this time, the Board and the IJC have no defensible method for determining whether recent lake levels are explained by the
normal supply variation within a stationary climate, the variation caused by multi-decadal non-periodic climate cycles, or by climate change induced by carbon emissions. Scientists have begun to question whether or not we will be able to sense these shifts early in the transition (cite the GEO article). There is no evidence that we have any skill at knowing when we are entering or leaving a climate regime. The objective of the scope of work in this task will be to attempt to develop one or more mathematical approaches that would produce useful assessments of whether the Great Lakes were at the beginning of a new climate and water level regime. This work will be led by the climatologists, hydrologist and statisticians and will have to take into account risk and uncertainty. The Hydroclimate Group would be asked to survey the literature and conduct mathematical experiments to make an educated guess at the answer.

Responsibility: HC TWG
Cost: Yr 3 $10 K Yr 4 $20K

Figure 2: Risk Evaluation Matrix

Source: Black et al. June, 2009
Task 4: Develop existing regulation strategies to address future risks

4a. Develop adaptive regulation strategies. PFEG will develop adaptive regulation rules that change based on climate related triggers. Experimental and perfect forecasts will be used to determine the value of better forecasts and the limits of regulation to reduce impacts.

The approach will include the use of an interactive model in which decision makers can use the risk evaluation matrix to specify any water level sequence possible with the supplies of a particular scenario, without having to develop a series of plans that approach the desired levels. For example, there might be a water supply scenario that transitions from the current to a very dry climate, producing very low water levels on Lake Superior. PFEG might invite ecologists to design the Lake Superior levels they would like to see during the dry period to preserve Lake Superior ecosystems. The interactive model would limit the lake level changes to those possible given the supplies and structures. The resulting water level and flow time series would be evaluated using all the performance indicators and hydrologic attributes used in traditional plan evaluations, and the differences between this evaluation and the Plan 77A evaluation for the same supplies would provide an estimate of the upper limit of what adaptive regulation could provide. With some additional work this approach could be used to evaluate policy changes other than regulation such as changing the fleet of commercial vessels or re-drawing the 100 year floodplain.

Responsibility: PFEG
Time line: Initial strategies Mar 2010. Several iterations of strategies: Sep 2011
Cost: $0 - will change the focus of some or all of the plan formulators. More funding may be required

4b. Evaluate and rank adaptive regulation strategies. To the degree possible, PFEG will revise/modify the SVM to use hydropower and commercial navigation economic benefits, as well as the frequency, vulnerability and resilience of avoiding selected hydrologic thresholds developed by the ecosystem, coastal and water supply TWGs to evaluate adaptive strategies to modify levels and flows to minimize impacts. The AMG and PFEG will work with the Study Board and hold practice decision workshops for evaluating the various proposed strategies. Recommendations for an adaptive management strategy will be included with the Board’s recommendation of a new regulation plan.

Responsibility: AMG and PFEG
Timeline: Evaluations and Practice decisions Sep 2010-Mar 2011
Cost: $10K yr 3 $10K Yr 4
Priority: High – As the consideration of climate change is a key item identified in the Study Directive, tasks 1 through 4 are required to respond to that mandate.

Task 5: Evaluate the ability to influence levels and flows through new structures

5a Clarifying the goals and principles of the analysis. The Board, working in collaboration with the AMG and PFEG will define the goals of the new structure (for example, maintain levels closer to average on MH or Erie, while not causing harm to downstream interests). The Board will need to
discuss the implications of Boundary Waters Treaty and whether mitigation structures downstream are to be included. Cost should be small, perhaps an extra day or two of meeting time by the Board and a week or so by PFEG.

5b **A literature review** to summarize the past research on this issue, including specific structures and the domain of control – for example, whether or not there was excavation required that would allow greater than natural flows, whether there were structural elements that allowed variable control. This work would define the range of operating rules for those structures. Contract: $15k Yr 3

5c **Modify the Great Lakes routing model:** The model would have to be modified to allow for the new control and a new formulation effort would be required to develop operating rules that, in combination with the St Marys structure, provided a variety of ways to manage levels throughout the Great Lakes. The effect on Lake Ontario and the St Lawrence River levels would also be considered. These new alternatives would be run with stochastic and climate change series with an eye to at least determining how much they could mitigate extreme levels, and perhaps for other objectives, such as moderating levels so they were more like historic levels. Contract $20k Yr 3

5d **Run alternatives with multiple control structures.** The plan formulation team over years 3-4, would run alternatives with multiple control structures. They would be expected to use some sort of quasi-optimization, probably with the goal of keeping all lake levels within recent historical ranges and defined coping zones. They would also run alternatives with just the existing St Marys structure using insights based on their optimization runs. Contract: $60K over 2 years

5e **A risk management and decision support approach for extreme and uncertain water supplies** would be developed that would address several challenges. To what extent will the next generation regulation plan (for 1, 2 or 3 structures) reduce extreme levels? How do we estimate risks from extreme levels when the probability of those levels changes in some unknown way because of climate variability and change? How would we establish triggers for changing the regulation plan (for example, switching from one estimate of the mean lake level in a rule set like Plan 77A to another estimate)? Contract: $60K over 2 years

5f **Investigate triggers for new policies:** The HC TWG working with PFEG and the risk manager would investigate how new policies would be triggered. The team will have to investigate whether and how the risks of adopting too soon or too late to climate change can be managed by changing management (Superior regulation, new structures, stakeholder adaptation) based on an uncertain reading of shifting means or other statistical measures of recent water supplies. Contract: $25K Yr 4

5g **Modify the SVM to represent multiple structure outcomes:** PFEG will modify the SVM to represent the multiple structure outcomes, and develop an approach with the risk manager for the Board to use in developing its recommendations on when, if ever, to trigger the next phase of development of the new structures. The multiple structure issue would have to be factored into circles of influence work and there would be some interaction with the sectoral TWGs about impacts, even though a full performance indicator evaluation cannot be done because there is no history of impacts to the extraordinary levels anticipated. PFEG $50K Yr 4
Responsibility: PFEG with support from HC TWG
Timeline: Tasks 5a and 5b by Mar 2010. Tasks 5c through 5f by Mar 2011
Total: Year 3 $85K  Year 4 $155K
Priority: High – This is a key recommendation from the St. Clair Report

Task 6: Develop non-regulation strategies to address future risks

6a. Identify levels related problems regulation cannot address. There are two parts to this; problems that cannot be addressed through regulation of Lake Superior, and problems that cannot be addressed with an additional regulation structure in the St. Clair or Niagara River. This effort will focus on comparing the coping zones developed by the TWGs in Task 1 with the water supply sequences that cross from preferred to coping to outside coping regimes identified in Task 2 and then assess through plan formulation, the ability of existing regulations structures, or new structures to minimize the frequency and duration of the interests being pushed outside of their coping zones. This task will identify the situations or problems that could not possibly be addressed through mitigative measures to modify of levels and flows. (Yr 4 $20K)

6b. Identify responsible management agencies and their decision framework (laws, policies, past practices, etc): This task would focus on agencies that are responsible for non-regulation management issues for the most vulnerable sensitivities of the system. This task would involve a survey of identified agencies to determine their current decision making framework including laws, policies and past practices that influence how they manage risk of high and low water level impacts. (Yr 3 $20K, Yr 4 $30K)

6c. Identify a mechanism for the development of a coordinated adaptive management strategy. This will look at different proposals for how a coordinated mechanism for adaptive management for the implementation of resiliency actions. (Yr 4 $20K)

Responsibility: Superior Task Team
Timeline: Sept 2010
Cost: Yr 3 $20K  Yr 4 $70K (This may be low)

Task 7: Identify long-term monitoring and modelling requirements for adaptive management

7a. Identify long-term monitoring requirements for taking action. One of the first conclusions from the IUGLS is that more observations of the components of water supplies, levels and flows are needed to assess and manage the risks of extreme water levels. The St. Clair portion of IUGLS showed we have not collected enough data to know when conveyance of the St. Clair changed. Evaporation measurement on Lake Superior began only because of IUGLS. Evaporation rate change is expected to an important part of the oncoming climate change, but unless measurement continues on all the lakes, we will only be able to guess whether it is changing in the future. If future levels are much different, studies may be needed to identify what happens to lake ecosystems or marinas or water supply systems when water levels move
outside interests coping zones. This task would be led by AMG but conducted primarily by the TWGs, who would imagine what research and monitoring efforts would be most important for identifying when hydrologic thresholds were crossed and the subsequent impacts once they have been crossed. This would be required both for understanding when action might be possible to modify levels and flows to reduce impacts and maintain coping zones, and for understanding when alternative actions will be necessary.

7b. **Identify long-term modelling requirements for taking action.** While monitoring is extremely important, updates, improvements and additions of system models and impact models are also critical. This task will identify what the critical models are and what long-term requirements will be needed to support those models. Part of this task will be to consider the on-going application and accessibility of the data, tools and models developed for the IUGLS such that they support on-going adaptive management.

Responsibility: Superior Task Team  
Timeline: Sept 2010  
Cost: Within TWG budgets

**Task 8: Conduct a Two-part institutional analysis**

8a. **Part 1: institutional analysis for modifying a regulation plan or building new structures.** The focus for this Study would be on an adaptive management strategy for adapting the rules for changing the regulation, or otherwise modifying the levels and flows of the Upper Lakes to minimize the impacts of climate risks (see Tasks 4, and 5). This effort will include the exploration of what is necessary in terms of data, information, resources and institutional arrangements to provide for the rules for modifying a regulation plan or building new structures in the face of climate change.

8b. **Part 2: Institutional analysis for non-regulation resiliency strategies.** This Study provides an opportunity to identify the agencies that would make decisions on taking resiliency actions, and begin working with them to identify a mechanism for the development of a coordinated adaptive management strategy for addressing climate change/variability by changing behavior, investments and policies to build greater resiliency into the system. The IJC and its Study Board would help facilitate this process but the responses would typically be undertaken outside the IJC by various levels of governments and the private sector. The institutional analysis would look into what would be required from an institutional and policy perspective in terms of setting up some kind of mechanism for coordinated adaptive management.

Responsibility: AMG  
Timeline: Mar 2011  
Cost: Yr 4 $25K Yr 5 $45K

**Task 9: Develop adaptive management plans for regulation and non-regulation response.**  
Based on the previous tasks, AMG would develop two draft documents for the Board and would shepherd an active review process leading to two recommendations from the Board to the IJC.
9a. **An adaptive regulation strategy.** It would be an adjunct to the Board’s recommendations for a new regulation plan. This document would include:

- An explanation of why adaptive regulation rules are needed
- Rules for changing the regulation plan, including language that could be included in a new order
- A trigger strategy for study and development of an additional Great Lakes regulating structure, to the degree the Board supports that position.
- A budget for ongoing and conditional monitoring and research

9b. **Adaptation beyond regulation to new level regimes.**

This document would identify a trigger and response plan, with the triggers generated by the IJC and its hydrologic and hydraulic support agencies, and the responses generated by others including private enterprise, NGOs, and federal, state, provincial, local governments. It would identify the responsible agencies and their institutional framework and provide recommendations for a mechanism for the development of a coordinated adaptive management strategy. It would be written as a recommendation from the Study Board to the IJC with letters of support from the potentially responding agencies.

Responsibility: AMG  
Timeline: Nov 2011  
Cost: Yr 4 $30K Yr 5 $60K
5. Comparison of IUGLS Strategy and Risk-Based Guide developed for Alberta Municipalities

<table>
<thead>
<tr>
<th>UGLS AM Proposal</th>
<th>Risk-Based Guide Steps</th>
<th>Differences</th>
<th>Priority for IUGLS</th>
</tr>
</thead>
</table>
| 1. Define system vulnerabilities  
  - Develop coping zone definitions  
  - Prioritize vulnerabilities | Step 1: Getting Started  
  - Define the hazards and vulnerabilities, and their potential management implications | Similar. | **High.** Necessary for all following steps. |
| 2. Develop risk scenarios  
  - Develop water supply sequences  
  - Develop socio-economic and environmental future scenarios | Step 2: Preliminary analysis  
  - Develop risk scenarios and a preliminary analysis of their probabilities and consequences | Similar | **High.** Required for any climate change analysis |
| 3. Risk evaluation – define the frequency/plausibility of the  
  - Define plausibility of risk  
  - Investigate ability to forecast hydrologic shifts | Step 3: Risk estimation  
  - Assign appropriate levels of frequency to each event in the risk scenario  
  - Calculate the expected loss or other consequence for each risk scenario. | IUGLS will characterize plausibility using computational approaches that are far more computer intensive than needed because they are about producing the most defensible guess rather than generating a lot of pretty good guesses.. We want to investigate how able we are to forecast a hydrologic shift so we can know whether the extreme levels are short term variations, or longer term climate changes | **High.** Assigning plausibility could have the greatest benefit to the risk management analysis. The effectiveness of adaptation may depend on the accuracy and forewarning time of forecasts. |
<p>| 4. Develop adaptive | Step 4: Risk Evaluation | Similar – However, the evaluation | <strong>High.</strong> The IJC Directive includes |</p>
<table>
<thead>
<tr>
<th>UGLS AM Proposal</th>
<th>Risk-Based Guide Steps</th>
<th>Differences</th>
<th>Priority for IUGLS</th>
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<tbody>
<tr>
<td>• Develop adaptive strategies for existing regulation</td>
<td>Evaluate the risks in terms of costs, benefits and acceptability</td>
<td>will be to identify the best strategy under various future scenarios and the triggers for policy changes.</td>
<td>assessment of climate change as part of the regulation review.</td>
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<tr>
<td>• Evaluate and rank adaptive regulation strategies</td>
<td></td>
<td>This is an added step in the IUGLS, however, it is in keeping with tasks Risk Evaluation phase of the Risk-based guide. It just looks at other alternatives. However, no economic/environmental analysis is intended for this step in the IUGLS due to time and resource constraints.</td>
<td>High: Study Board made a public recommendation in St. Clair report to do this.</td>
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<tr>
<td>5. Evaluate the ability to influence levels and flows through new</td>
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<td>Medium: There is no mandate in the Directive, however, the Study presents an opportunity to help get this started and recognizes that regulation has limited impact on levels and flows.</td>
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<td>• Review past structure proposals</td>
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<td>• Modify GL routing model</td>
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<td>• Run alternatives with multiple control structures</td>
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<td>• Investigate how new policies would be triggered</td>
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<tr>
<td>• Modify the SVM to represent multiple structure outcomes</td>
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<tr>
<td>6. Develop non-regulation</td>
<td>Step 5: Risk Controls and Adaptation or Risk Control Options, in terms of costs, effectiveness, stakeholder acceptance and other criteria.</td>
<td>The risk-based Guide addresses multiple adaptive management strategies and would be helpful to individual states and provinces or counties and municipalities choosing to act. However, this part of the IUGLS plan it to lay the groundwork for some coordinating mechanism for adaptive management (non-regulation) post Study. It is not intended to evaluate feasibility in</td>
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<td>UGLS AM Proposal</td>
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<td>Differences</td>
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<td>7. Identify long-term monitoring and modelling requirements</td>
<td>Similar. Both strategies recognize the need for long-term monitoring to reduce uncertainty.</td>
<td>High: Particularly for addressing triggers for changing regulation rules or building new structures.</td>
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<td>8. Two-part Institutional analysis</td>
<td>As the Risk-based Guide was intended for use by municipalities, the institutional implications were not as critical as those for the Great Lakes where there are 8 stat, two provincial, and two federal levels of governments, plus county and municipal governments.</td>
<td>Medium: This will be needed at some point. The SB needs to decide how much it is willing to contribute</td>
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<td>9. Develop adaptive management</td>
<td>Similar, although the adaptation beyond regulation will be looking more into the implementation of a coordinated mechanism rather than the actions themselves which are the responsibility of agencies outside the IJC</td>
<td>Med-High: This is the product. The SB will have to decide how far they go in moving an adaptive management strategy forward.</td>
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## 6. Cost estimate

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AMG: Adaptive Management Group  
STT: Superior Task Team  
PFEG: Plan Formulation and Evaluation Group  
HC: Hydroclimate TWG  
TWG: Technical Working Group  
ETWG: Ecosystem Technical Working Group
References:


