Chapter 5

Framework for Developing a New Lake Superior Regulation Plan

Draft
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Lake Superior Regulation:
Addressing Uncertainty in Upper Great Lakes Water Levels

Final Report to the International Joint Commission
by the International Upper Great Lakes Study
Chapter 5 describes the Study’s approach to formulating candidate plans for Lake Superior regulation. It identifies the objectives for a new regulation plan and outlines the framework for evaluating and ranking plans to meet those objectives.

5.1 Regulating Lake Superior Outflows

5.1.1 Introduction

During its 100-year history, the International Joint Commission (IJC) has progressively evolved its management approach for the Great Lakes in response to changing economic, environmental and social needs across the basin. Throughout this evolution, a core set of management principles has developed through a series of updated regulation plans for Lake Superior and the Great Lakes system in general. These principles are embodied in the form of official Orders of Approval and Supplementary Orders from the IJC. Each iteration of Orders has reflected a specific need (e.g., hydropower, navigation, environment) or addressed a particular problem of either high lake levels or low water conditions.

As a result, when the IJC establishes a new study to develop a new set of regulation plans that seek to improve the effectiveness of lake level management, there already exists a substantive hierarchy of management principles that can be transformed into a set of planning guidelines, plan performance objectives and evaluation criteria. In this sense, the existing plan, 1977A, in effect since 1990, represents the culmination of nearly 75 years of lake level management experience and evolving needs.

5.1.2 History of Regulation

Developing a new regulation plan that will perform better than the existing plan was a significant challenge. A useful starting point for the International Upper Great Lakes Study (the Study) was to identify the rationale for various types of plans that led up to the development of plan 1977A, the characteristics of all the preceding plans and the conditions that led to changes in those plans.

Preproject Releases

The “preproject” releases from Lake Superior represent the hypothetical condition of the absence of any regulation control structures, a standard against which the impacts of any regulation plan can be measured. It is not possible to know exactly what those releases would be, as the system has not been in a natural state since about 1887 and there is little reliable information about the flows, levels or physical configuration of the controlling sections of the river at that time. However, a hydraulic equation (i.e., discharge rating curve) has been developed to estimate the flows (see box).

Preproject flow releases are triggered by the existing plan when water levels become low. The preproject release rule is an important reference because it can be used to estimate what the lake levels and consequent impacts on riparian interests would have been prior to the Boundary Waters Treaty of 1909. It also can serve as a benchmark for estimating natural environmental conditions.

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1 This chapter is based on peer-reviewed work undertaken by the Study’s Plan Formulation and Evaluation Technical Work Group (TWG). See the TWG’s final report for more information on the methodology and analysis (International Upper Great Lakes Study [IUGLS], 2012).
Estimating Preproject Releases

Preproject release (in m³/s) = 824.7 × (Lake Superior water level in m - 181.43 m)¹.⁵

Where:

• 824.7 is a constant computational parameter related to the lake’s outflow width and weir coefficient
• 181.43 m is the sill elevation at the Lake Superior outlet below which outflow will cease
• 1.5 is a power exponent to depict weir flow at the lake outlet prior to the construction of the compensating works

Evolution of Plans

As described in Chapter 1, the IJC issued Orders of Approval in 1914 for hydropower development on the St. Marys River and the first Lake Superior regulation plan was implemented in 1921. Since 1921, seven different regulation plans have been used to determine Lake Superior outflows:

• Sabin Rule (1921-1941);
• Rule P-5 (1941-1951);
• Rule of 1949 (1951-1955);
• 1955 Modified Rule of 1949 (1955-1979);
• Plan SO-901 (“guide” 1973-1979);
• Plan 1977 (1979-1990); and,
• Plan 1977A (1990-present).

The early generation of regulation plans considered only the level of Lake Superior in determining the outflow, because they were designed to comply with the 1914 Orders.

In the 1940s, construction of the Long Lac and Ogoki Diversions brought an average additional 160 m³/s (about 5,650 ft³/s) supply of water into Lake Superior starting. These diversions were constructed as part of WWII requirements for more hydroelectricity for industrial production and increased reliability for navigation. The additional supply of water required a change in the regulation plan because the rule curves used in the previous plan, Rule P-5, would otherwise have underestimated the release needed at any Lake Superior elevation, causing a permanent rise in Lake Superior.

Although the Rule of 1949 was intended to adjust the release to accommodate the extra water, it actually lowered Lake Superior levels. The new plan was modified in 1955 to correct these releases. This 1955 Modified Rule of 1949 Plan was used for 22 years and represents the last plan based solely on Lake Superior levels. The relevance of this plan is that it provides a useful baseline for measuring the impacts of the IJC’s management principle of balancing the needs of the various key interests across the basin.

During an IJC study from 1964 to 1973 (International Great Lakes Levels Board, 1973), an experimental plan was developed that used the concept of balancing the levels of lakes Superior and Michigan-Huron.

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² The Long Lac and Ogoki diversions direct southward to Lake Superior a portion of water that otherwise would have flowed north into the Hudson Bay drainage system.
That plan, known as Plan SO-901, was used as a guide for Lake Superior outflow regulation during the mid-1970s.

**Plan 1977A**

In May 1977, the IJC requested that the International Lake Superior Board of Control prepare a revised regulation plan that would provide benefits to the interests throughout the Great Lakes system without undue detriment to Lake Superior interests. In September of that year, the Board of Control submitted a report on the development and evaluation of plan 1977, which was a refinement of SO-901. Plan 1977 was officially adopted in October 1979. Further improvements led to the development of plan 1977A.

Plan 1977A has a number of outflow limitations to meet the regulation criteria and requirements of the IJC Orders. For example, one outflow limit serves to prevent excessive lowering of the levels of Lake Superior, while another prevents high water level conditions in the lower St. Marys River at Sault Ste. Marie. The regulation plan also has a limit on maximum allowable outflow in the winter to reduce the risk of ice jams and associated flooding in the lower St. Marys River.

In the monthly Lake Superior outflow, as specified by plan 1977A, a small allocation is first made to meet the needs of municipal and industrial waters uses, operate the navigation locks, and provide sufficient flow to maintain the aquatic habitat of the St. Marys River. The remainder of the flow is allocated equally to hydroelectric facilities in the United States and Canada to generate electricity. If the amount of water available for hydropower generation exceeds the capacities of the hydropower plants, the excess is released by opening one or more of the 16 gates in the compensating works on the St. Marys River (Figure 5-1).

To meet the demand for hydroelectricity, which fluctuates over the course of the day and week, the St. Marys River hydroelectric generating plants adjust the average monthly release allotment to match the demand, flowing more during the day on weekdays (“peaking”), when demand for electricity is higher, and reducing the releases at night and on weekends (“ponding”) when electrical demand is lower. These flow variations cause water levels to fluctuate downstream of the plants and in the lower St. Marys River. Peaking and ponding operations are carried out with the approval of the IJC, but they must still meet the downstream depth conditions for navigation.

The International Lake Superior Board of Control is responsible for implementing the plan and monitoring the hydrological conditions of the upper Great Lakes basin. Under certain conditions, the IJC approves deviations from the regulation plan or changes to gate settings at the compensating works on the advice of the Board of Control. These deviations may include flow changes to: accommodate repairs at the hydroelectric facilities or the compensating works; support flow measurements; allow sea lamprey trapping that typically takes place in the summer; or, deal with unusual water supply conditions. Deviations from plan 1977A have been rare.

**Figure 5-1**

*Compensating Works on the St. Marys River*

Photo to be added
Supplementary Orders

In 1978, a Supplementary Order permitted the redevelopment of the Canadian hydroelectric facilities at Sault Ste. Marie, ON and the protection of the St. Marys River fishery.

The 1979 Supplementary Order updated a number of the conditions governing the regulation of outflows through the structures at Sault Ste. Marie. This Order recognized that the Lake Superior water levels could not be regulated within the narrow 0.46 m (1.5 ft) range specified in the 1914 order and, while it maintained the upper level limit of 183.86 m (603.2 ft) of the 1914 order, it lowered the minimum level limit to 182.76 m (599.6 ft), near the historical minimum Lake Superior level recorded since regulation began.

This Order also required that the regulation plan “provide no greater probability of exceeding elevation 183.86 m than would have occurred using the 1955 Modified Rule of 1949” (the plan in use immediately prior to the 1979 Order) when tested with water supplies of the past adjusted for diversions into the lake. It also maintained the criteria from the 1914 Orders that required that if the Lake Superior level was below 183.40 m (601.7 ft), then flows could not be greater than those that would have occurred with the channel discharge capacities of the St Marys River of 1887, and that flows not be greater than the 1887 channel capacities if the level of Sault Ste. Marie harbour was above 177.94 m (583.8 ft). More significantly, the 1979 Supplementary Order requires that the water levels of both Lake Superior and Lake Michigan-Huron must be taken into account in determining Lake Superior outflows. This more system-wide consideration sought to provide benefits throughout the upper Great Lakes system.

5.1.3 Rationale for Reviewing the Current Regulation Plan

Several important factors have emerged since plan 1977A was implemented in 1990. Taken together, these factors provide a sound rationale for reviewing the current regulation plan.

First, as described in Chapter 4, there is considerable uncertainty about water supplies or net basin supplies (NBS)\(^3\) and corresponding water levels in the Great Lakes basin in the future as a result of natural climate variability and human-induced climate change. Compounding the effects of climate variability and change is a second force affecting water levels – the adjustment of the earth’s crust, known as glacial isostatic adjustment (GIA). As described in Chapter 1, the differential adjustment of the earth’s crust has the effect of gradually “tilting” the Great Lakes basin over time. The impact of GIA is particularly noticeable along the shorelines, where features on the rising or subsiding land can be compared directly to water levels and near-shore depths. Plan 1977A has never been tested under a variety of potential climate change scenarios, nor was it designed to take into account the effects of GIA, the importance of which has only recently been identified. As a result, the IJC did not know how well plan 1977A would perform under extreme conditions that are outside the historical record.

Second, there is much better information available today than 20 years ago about the hydrology and hydraulics of the Great Lakes. Researchers have more confidence in the current models that describe how the system performs under a variety of conditions. New knowledge has also been gained through recent investigations, such as the Study’s own analysis of the changes in the conveyance of the St. Clair River (IUGLS, 2009). This improved knowledge and modelling was able to be factored into the development of a new Lake Superior regulation plan.

\(^3\) Net basin supply (NBS) is the net amount of water entering a lake, consisting of the precipitation onto the lake minus evaporation from the lake, plus groundwater and runoff from its local basin, but not including inflow from an upstream lake.
Finally, there is a much better information base about the different water-using sectors and public interest concerns that any new regulation plan must address. As described in Chapter 3, under the Boundary Waters Treaty of 1909, the interests of domestic and sanitary water uses, navigation and hydroelectric generation and irrigation are given an order of precedence in water uses in the development of regulation plans. However, it is now recognized that the needs of other interests, such as ecosystems, coastal zone uses and recreational and tourism uses must be taken into account, as well. This information on the various key interests served by the upper Great Lakes basin is needed to develop a sound and replicable comparative basis for impact analysis of the various plans, consistent with the IJC’s principle of balancing the needs of the key interests.

5.2. Study Approach

5.2.1 IJC Directive to the Study

The IJC Directive to the Study Board dealing with the regulation of Lake Superior was to:

“...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”

Figure 2-3 in Chapter 2 illustrates the overall regulation plan formulation and evaluation analytical framework developed by the Study to address its mandate under the Directive.

5.2.2 Regulation Plan Objectives

To address all the issues set out in the IJC Directive, the Study Board first had to develop and agree on a planning process – the management goals for a new plan and the structure of the plan formulation and evaluation process. These were further refined as a set of guiding planning principles and plan performance objectives that established the desired characteristics for a new regulation plan.

Planning objectives are specific statements of water management principles – what the public, user interest groups and planners would like to have happen regarding a particular resource in a particular place over a particular period of time. The following objectives for a new Lake Superior regulation plan – and for the upper Great Lakes basin as a whole – were developed by the Study Board, based on the IJC’s Directive and feedback received at public meetings:

- To maintain or improve the health of coastal and riverine ecosystems;
- To reduce flooding, erosion and shore protection damages;
- To reduce the impact of low water levels on the value of coastal property;
- To reduce shipping costs;
- To maintain or increase hydropower value;
- To maintain or increase the value of recreational boating and tourism opportunities; and,
- To maintain or enhance municipal-industrial water supply withdrawal and wastewater discharge capacity.

The Study Board also recognized that climate and thus NBS in the upper Great Lakes basin could be significantly different over the coming decades and that regulation of Lake Superior outflows, while potentially having a significant effect on Lake Superior levels, was likely to have little effect on water level
changes caused by these climate shifts on lakes Michigan-Huron and Erie. Hence, the Study Board decided to develop an adaptive management plan to complement the new regulation plan. Chapter 9 addresses the Study’s analysis and recommendations with respect to the role of adaptive management in addressing future extreme water levels in the Great Lakes-St. Lawrence River system.

5.2.3 Evaluation Framework

As outlined in Chapter 2, the Study Board developed an evaluation framework in which regulation plan options were quantitatively evaluated by measuring the success in meeting stated goals and objectives. These seven steps were followed iteratively to develop a wide range of metrics that the Study Board used to assess progress towards meetings its plan objectives:

- articulation of Study planning objectives and review of existing criteria;
- identification of water level and flow metrics;
- identification of performance indicators (PIs) for each interest;
- review of functional relationships between PIs and selected hydrological attributes;
- generation of time series of PI values;
- establishment of a method for generating composite values of some basic hydrological metrics to express areal extent, frequency, severity, duration and persistence;
- establishment of a method for the summation, display and comparison of composite PI values and,
- establishment of coping zones for each water interest to help assess impacts.

To guide the evaluation of candidate regulation plans, the Study Board determined that any change to the IJC’s Orders of Approval and regulation plan for Lake Superior outflows must:

- 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 the length of shoreline of the Great Lakes relative to the budget available for assessment studies;
- address, to the extent possible, ecological, economic, and social impacts associated with the regulation of outflows from Lake Superior;
- balance the needs of the various interests, specifically by minimizing disproportionate losses to all interests and regions, including disproportionate water level changes on one lake at the expense of another; and,
- provide robustness, or flexibility in design, so that the International Lake Superior Board of Control and the IJC can respond to changing climatic conditions affecting the Great Lakes system.

The evaluation framework focused on directly relating lake level fluctuations and critical threshold levels to economic productivity. This was accomplished through the use of PIs, conventional economic information and metrics routinely used for traditional benefit-cost analysis. These PIs were then used to compare and evaluate the relative performance of each economic sector or interest (e.g., hydropower, commercial navigation, recreational boating) under the range of historical and anticipated lake level fluctuations across all sectors and lakes.

Each of the six interest-specific technical work groups (TWGs) was responsible for identifying PIs to be applied in measuring plan performance relative to its interest. Not all of the PIs were required to be quantifiable in dollar terms, but all needed to be significant to the interest they represent, measurable, and sensitive to changes in a regulation plan.

Table 5-1 lists the PIs used in the analysis, by interest.
Table 5-1
Performance Indicators (PIs), by Interest

<table>
<thead>
<tr>
<th>Key Interest</th>
<th>Primary PI</th>
<th>Other PIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic, Municipal and Industrial Water Uses</td>
<td>None used; all plans had very similar impacts in this interest, so a primary PI was not useful in plan selection</td>
<td>Frequency and duration of affected services and the population affected</td>
</tr>
<tr>
<td>Commercial Navigation</td>
<td>Net average annual change in the costs of shipping</td>
<td>Frequency and magnitude of navigation benefits by month</td>
</tr>
<tr>
<td>Hydroelectric Generation</td>
<td>Net average annual change in the value of energy at St. Marys River hydropower plants</td>
<td>Net average annual change in energy produced at the St. Marys River plants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency and magnitude of hydropower benefits by month</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Robustness of plan benefits with various price assumptions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum energy produced in a month</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum value produced in a month</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Month-to-month and annual flow stability</td>
</tr>
<tr>
<td>Ecosystems</td>
<td>See Table 5-2 for primary ecological indicators</td>
<td>Zone C occurrences for 34 ecosystem indicators</td>
</tr>
<tr>
<td>Coastal Zone</td>
<td>Net average annual change in the costs of maintaining shoreline protection</td>
<td>Flooding: high water level statistics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low water impacts: low water level statistics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Erosion: rates of erosion on lakes Superior and Michigan-Huron (but there were no significant plan differences in the erosion rates)</td>
</tr>
<tr>
<td>Recreational Boating and Tourism</td>
<td>None used; although plans could change the number of slips available on Lake Superior, there was no evidence that showed an unusable slip actually hindered boating</td>
<td>Number of slips each month that were unavailable for use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Boat ramp utility score</td>
</tr>
</tbody>
</table>

4 For more information on the PIs, see IUGLS, 2012.
5.2.4 Coping Zones: Predicting the Impacts from Extreme Water Level Conditions

The Study also applied the concept of coping zones to help evaluate regulation plan options by allowing plan formulators to predict the impacts from extreme water levels. Each TWG developed a range of coping zones for its specific interest that assessed vulnerability to water level fluctuations as well as confounding factors such as GIA, wind/waves/storm surges and precipitation patterns. Each TWG identified three levels of progressively more challenging water level conditions for the interest:

- **Zone A**: a range of water level conditions that the interest would find tolerable;
- **Zone B**: a range of water level conditions that would have unfavourable though not irreversible impacts on the interest; and,
- **Zone C**: a range of water level conditions that would have severe, long-lasting or permanent adverse impacts on the interest.

Clearly, higher and lower levels would exacerbate the problems that had been experienced before. However, it was not known whether damages would grow linearly or exponentially. The clearest example of this relates to flooding damage. The historical high water levels have a recurrence interval of approximately 100 years. Floodplain management measures have been taken in most places to discourage development that could be damaged at these levels. But property just a little higher than this level could be developed and might still have the advantages of a water view and lakefront location. If water levels shifted higher under climate change, then flood damages could increase significantly, but because it is deemed safe now, little stage-damage data have been collected for development immediately above the floodplain.

With the important exception of coping zones for ecosystem interests, the coping zone tool proved to be not as meaningful as PIs for measuring the impacts of the small water level changes produced by different regulation plans.

Instead, hydropower and navigation outcomes are better characterized by economic models, even in extreme water level conditions. These outcomes are functions of water levels in different lakes as well as flow, and the economic models capture all these inputs and use well-established functional relationships to relate them to benefits. Similarly, shoreline protection costs provide a much more sophisticated characterization of the impact of static water levels and waves on shoreline protection infrastructure. Erosion changes with different climate scenarios, but there are generally no measurable differences between regulation plans. Flooding metrics used in the evaluation of regulation plans are simple, and similar to Zone C definitions.

The usable slip count and boat level ramp usability index used as recreational boating indicators provide a continuous assessment of the availability of slips and ramps, but there are no data to indicate how losses in availability actually affect recreational opportunities. In addition, counts of how frequently a plan caused Zone B or C conditions were not thought to provide useful plan evaluation information, because the difference between levels in any of the final plans was small. For example, a difference of 2.5 cm (1 in) between the Lake Michigan-Huron water levels of two plans could mean that one plan was in Zone A and the other in Zone B.

PIs for domestic, municipal and industrial uses were based on data provided by most of the largest and some of the smaller water supply and treatment plants that define the levels at which service is impacted and the levels at which service is lost, along with the numbers of people affected. The elevations provided exceed the range of water levels modelled, so these functions are applicable to extreme climate conditions.

**Ecosystem Indicators**

Coping zones for ecosystem interests were different from ones in the other five interests in two ways. First, the high and low water levels that caused problems for coastal development, navigation, recreational boating,
hydropower and municipal water systems were generally good for ecosystems. Second, ecosystem coping zone definitions were generally complex, often combining water level, time of the year and persistence. The Study Board had to place greater reliance on the definition of the ecosystem interests’ coping Zone C because of that complexity. For any of the other interests, there were other measures that allowed the Study Board to track the onset of damages as water levels rose or fell (e.g., the number of customers without municipal water service, economic damages for navigation and hydropower, shoreline protection structure costs, and number of unusable slips in recreational boating). But the complexity of the ecosystem indicators made it difficult for the Study Board to gain an understanding of how the levels of impacts would differ. As a result, the Study Board specified the performance indicator levels that marked the transitions from one coping zone to another.

Detailed analysis of the plan results for 34 ecosystem indicators showed the differences between plans were generally insignificant. For many indicators, there were no differences between plans when simulated with the same NBS, even though there could be great differences in ecosystem indicator metrics between two different NBS sequences regardless of which plan was used. There were numerical differences between plans in the eight ecosystem indicators in Table 5-2.
## Table 5-2
### Eight Primary Ecological Performance Indicators Used in the Study

<table>
<thead>
<tr>
<th>PI Code</th>
<th>Zone C Condition</th>
<th>Performance Indicators</th>
<th>Goal is to Avoid Zone C</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUP-01</td>
<td>SUP-01 measures the degree to which natural <strong>peak water level</strong> events on Lake Superior, which occur roughly on a 30-year cycle, are lowered by regulation.</td>
<td></td>
<td>Prevent/minimize range compression for Lake Superior</td>
</tr>
<tr>
<td>SUP-02</td>
<td>SUP-02 measures the degree to which there is a <strong>drawdown</strong> of Lake Superior following a peak water level ‘event’. SUP-01 and SUP-02 scores closer to pre-project (and larger than 1977A) are better.</td>
<td></td>
<td>Prevent/minimize range compression for Lake Superior</td>
</tr>
<tr>
<td>SUP-04</td>
<td>Peak summertime water level rises above 184.0 m (about 603.7 ft) for 3 or more consecutive years</td>
<td>Wild rice abundance in Kakagon Slough, near Duluth, MN</td>
<td>Maintain viability of wild rice population</td>
</tr>
<tr>
<td>SUP-05</td>
<td>Mean spring (Apr-May) water level is more than 0.67 m (about 2.2 ft) below the mean level for the preceding 10-year period for 7 or more consecutive years</td>
<td>Northern pike habitat and population in Black Bay on the north shore of Lake Superior</td>
<td>Prevent significant decline in northern pike abundance</td>
</tr>
<tr>
<td>SMQ-01</td>
<td>Mean flow rate during June maintained below 1,700 m³/s (about 60,035 ft³/s) for 5 or more consecutive years</td>
<td>Lake sturgeon spawning habitat</td>
<td>Provide suitable spawning area for lake sturgeon</td>
</tr>
<tr>
<td>SMQ-02</td>
<td>Mean flow rate during May-June maintained below 2,000 m³/s (about 70,600 ft³/s) for 7 or more consecutive years</td>
<td>Maintenance of flushing flows in the channel into Lake George (a small lake near Sault Ste. Marie, ON between Sugar Island and the mainland)</td>
<td>Maintain substrate in Lake George channel</td>
</tr>
<tr>
<td>LMH-07</td>
<td>Mean growing season (Apr-Oct) water level is less than 176.0 m (577.4 ft) for a period of 4 or more consecutive years</td>
<td>Fish and wildlife community eastern Georgian Bay wetlands</td>
<td>Maintain fish access to eastern Georgian Bay wetlands (current conditions)</td>
</tr>
<tr>
<td>LMH-08</td>
<td>Mean growing season (Apr-Oct) water level is less than 176.12 m (577.8 ft) for a period of 4 or more consecutive years</td>
<td>Fish and wildlife community eastern Georgian Bay wetlands</td>
<td>Maintain fish access to eastern Georgian Bay wetlands (+100 yr conditions)</td>
</tr>
</tbody>
</table>
5.2.5 The Role of Shared Vision Planning

The overall approach to the Study’s strategy to address the IJC’s Directive was based on shared vision planning. Shared vision planning builds on water resources planning traditions that extend back to the beginning of the 20th century (Holmes, 1979). More recently, shared vision planning has evolved 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 rather than investment in new structures.

Overview

Shared vision planning applies advances in planning, modelling and public participation in results-oriented systems analysis (Figure 5-2). It is an iterative process built on the following 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; and,
- Use, exercise, and update the plan.

Figure 5-2
Results-oriented Shared Vision Planning

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 (SVM). SVMs are built with user-friendly, graphical simulation software, and bridge the gap between specialized computer analysis tools and the way people typically conceptualize problems and make decisions. This helps minimize disagreements about facts and shifts the debate to how to balance conflicting objectives. Given that baseline conditions are also modelled, participants in the shared vision planning exercise can better understand the implications of any regulatory decision.
Unlike traditional modelling approaches to water management planning, 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 ensure that the model will be thoroughly reviewed and that there is a level of trust in the results. The explicit connections also help researchers shape their investigations to address the identified needs of decision makers.

**The Study’s Shared Vision Model**

The Study Board used a SVM to undertake “practice” decisions and followed a process of “informed consent”

5. The process is designed to allow experts, stakeholders and decision makers a series of opportunities to weigh the decision as information develops so that the final decision will be transparent.

The SVM used in the Study was an EXCEL-based spreadsheet that calculates and displays the economic and environmental PIs based on water levels and flows from proposed regulation plans. (The plans were simulated in a hydraulic model, the Great Lakes Routing Model.) The SVM incorporated results from an ecological model (Integrated Ecologic Response Model) that calculates the ecosystem scores, and executable code that runs a version of the Upper Great Lakes Shore Protection (UGLSP) model that calculates shoreline protection costs.

The SVM was developed over the course of the Study as data were gathered and benefit algorithms were completed and refined, and as the Study Board’s decision criteria were refined in the practice discussions. Initially, the SVM presented the results of one alternative compared to stored results for plan 1977A, using only the historical NBS. Later SVM outputs included multiple NBS choices and allowed comparisons of any two alternatives to real time evaluations of plan 1977A. By the end of the Study, the SVM was able to compare all plans across all NBS sequences for the different criteria.

The SVM was designed to operate like a website using hyperlinks to move from section to section. Later, the SVM became more accessible, with users able to work with it using a web browser and Internet connection. Figure 5-3 illustrates the SVM’s homepage.

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5 The phrase is borrowed from medical practice based on the common notion that the best decisions have to be based on a shared understanding of science and what the decision means in the lives of those affected.
Figure 5-3
Homepage of the Study's Shared Vision Model

Upper Great Lakes
Shared Vision Model

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
</tr>
</tbody>
</table>

**What do you want to do?**

- Pick a plan that's good for whatever future water supplies come into the Upper Lakes
- Browse through the details of plan performance for 2 plans and one NBS
- See the mechanics of how the SVM calculates benefits
- Look at how the different plans are defined
- See what NBS sequences are used in the SVM
5.3 Application of the Hydroclimatic Analysis

5.3.1 Plausible Scenarios for Future NBS

As described in Chapter 4, there is considerable uncertainty regarding future NBS in the upper Great Lakes basin. As a result, the Study Board considered four scenarios that encompass the widest range of plausible futures. Each is based on a different hypothesis about the impact of varying climate. NBS data series from different models were selected to test plans under each scenario. For the Study Board to endorse a plan, the plan had to perform as well as any other plan for all four of the scenarios. The four scenarios are:

1. **Stationary Climate** (i.e., over the next 30 years, NBS will be similar to the historical NBS)

   The primary argument for planning for this scenario is that climate change impacts will be insignificant over the expected life of the next regulation plan (30 years) and that the Study’s statistically-estimated extreme NBS sequences provide for a sufficiently rigorous test.

2. **Climate is changing, but the direction of NBS is unclear**

   This scenario combines the concern that climate change may already be happening with acknowledgment that there are climate model results that show changes in mean NBS ranging from wetter (increase in NBS) to drier (decrease in NBS) for Lake Superior and similar ranges for the other lakes.

3. **Climate is changing and NBS is decreasing**

   This planning scenario is based on the hypothesis that recent Great Lakes NBS already demonstrate the impact of increased atmospheric concentrations of CO₂ and other greenhouse gases. Data show that CO₂ emissions have been increasing as fast as or faster than the “worst case” projections of the Intergovernmental Panel on Climate Change (IPCC, 2007). A slight decreasing trend in NBS is projected by many climate models.

4. **Great Lakes NBS will next enter a very wet phase**

   In this view, Great Lakes NBS are quasi-cyclical, and the next cycle will see above-average NBS. For example, the low lake levels that have been experienced since the mid-1990s followed high NBS conditions in the 1970s and 1980s, which in turn had followed low NBS conditions in the 1960s.

5.3.2 Rationale for Selecting the Suite of Net Basin Supply Sequences

The Study’s hydroclimatic analysis and NBS sequences, outlined in Chapter 4, served as input into the work to evaluate candidate regulation plans. Of the hundreds of future climate change scenarios or NBS sequences generated by the hydroclimatic analysis, 13 were chosen for detailed plan formulation and evaluation. These 13 are representative of the range of plausible sequences that could be used to test the limits of any new proposed regulation plan. This suite of sequences allowed the Study Board to test plans for “robustness” – the capacity to meet particular regulation objectives under a broad range of possible future water level conditions. It was determined that this would be a rigorous and prudent approach to assessing the overall robustness of a plan.

The 13 NBS sequences that were selected came from five different scientific approaches:

1. **Historical Data**: Water management measures are most often evaluated using NBS that have occurred in the past, particularly when there is a fairly long historical record. In this case, there were 109 years of
Chapter 5

estimated NBS on which to base this dataset; more importantly, the dataset included very wet and dry sequences.

2. **Stochastic**: Two stochastic supply sets, together containing more than 100,000 years of statistically-generated NBS, were generated based on the historical NBS. The stochastic datasets include much wetter and much drier supplies than any in the historical dataset. From these, seven 109 year-long sequences were used to reflect a range of future NBS conditions. To test the ability of plans to deal with extreme conditions, the seven sequences included very wet and very dry sequences that would occur only rarely. The seven stochastic sequences were selected for use by filtering with the levels produced by routing these NBS through plan 1977A. These sequences included the:

- 109-year NBS set that contained the highest and lowest monthly levels on Lake Superior;
- 109-year periods with the highest and lowest monthly levels on Lake Michigan-Huron;
- 109-year period with the highest 50-year average combined levels on lakes Superior and Michigan-Huron;
- 109-year period with the lowest 50-year average combined levels on lakes Superior and Michigan-Huron; and,
- 109-year period with the smallest range in 50-year average combined levels on lakes Superior and Michigan-Huron.

3. **Climate Change based on Regional Climate Model (RCM) Outputs**: Down-scaled RCMs produced two sequences, both reflecting the IPCC A2 climate change scenario, using two different RCM simulations. These NBS sequences produced a change in the seasonality of NBS, with increases in NBS generally occurring during winter and spring, and decreases seen in the late summer and early fall, even though the average annual values were not that much drier.

4. **Climate Change Datasets Generated with a Stochastic Model**: This enabled a shift in the mean of future NBS over time based on both direct Global Climate Model (GCM) projections and GCM-based projections of how a variety of climate parameters might change. These datasets purport to show the onset of climate change, with the greatest effects at the end of the 109 years. Two severe periods were selected from the large stochastic set.

5. **Recent Trends**: One dataset was created statistically by assuming that any trends in NBS on each lake since 1960 reflected a linear trend rather than the dry or wet portion of a cycle. This represented one view of what NBS would be if the past decade of low water levels on the upper lakes reflects climate change.

Table 5-3 summarizes the 13 NBS sequences used in the plan evaluation. The table includes the names of sequences used in the SVM as well as a brief description of the key features of the sequences.

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6 *Stochastic* – statistics involving or showing random behaviour. In a stochastic simulation, the common statistical properties of a historical series of streamflows or lake levels (e.g., mean, standard deviation, variance) may be randomly rearranged to create a new ‘synthetic’ series of plausible flows and lake levels, based on those measured properties.

7 As described in Chapter 4, Scenario A2 represents a future climate scenario characterized by high levels of greenhouse gas emissions. This scenario corresponds most closely to recent experience and International Energy Agency (IEA) projections (IEA, 2011).

8 Also known as General Circulation Model or Global Circulation Model
Table 5-3  Summary of NBS Sequences Applied in Regulation Plan Evaluation

<table>
<thead>
<tr>
<th>Climate Scenario</th>
<th>NBS Sequence</th>
<th>SVM Code</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Stationary</td>
<td>1. Historical</td>
<td>HI</td>
<td>The 109-year period 1900-2008 recorded NBS, adjusted to current demands and diversions. This sequence has as many as 7 consecutive years above, and 7 consecutive years below average NBS.</td>
</tr>
<tr>
<td></td>
<td>2. Low Range</td>
<td>LR</td>
<td>A 109-year sequence from the stochastic NBS. The standard deviation of annual NBS is only 453 m³/s (about 16,000 ft³/s), compared to 495 m³/s (about 17,480 ft³/s) (for historical NBS).</td>
</tr>
<tr>
<td></td>
<td>3. Dry</td>
<td>DS</td>
<td>A 109-year sequence from the stochastic NBS. Still representative of current climate, this is the driest stochastic sequence for Lake Superior.</td>
</tr>
<tr>
<td>2. Uncertain Change</td>
<td>4. High Michigan</td>
<td>HM</td>
<td>A 109-year sequence from the stochastic NBS. Based on current climate, but creates the highest Michigan-Huron levels from the stochastic datasets, with a great range between wettest and driest years.</td>
</tr>
<tr>
<td></td>
<td>5. Wet (shifts mean up slightly)</td>
<td>WS</td>
<td>A 109-year sequence from the stochastic NBS. Even though it is based on current climate, it happens to reflect a higher mean NBS for the entire 109-year period.</td>
</tr>
<tr>
<td></td>
<td>6. Low Michigan</td>
<td>LM</td>
<td>A 109-year sequence from the stochastic NBS. Based on current climate, but creates the lowest Michigan-Huron levels from the stochastic datasets while still producing a maximum level greater than historical. Includes 14 consecutive years of below average NBS.</td>
</tr>
<tr>
<td></td>
<td>7. CC-AET</td>
<td>AT</td>
<td>A climate change sequence. One of the sequences produced by the Canadian RCM that produces higher highs and lower lows. Plan rankings were similar to CC-AEV (Sequence 9) so there is no tab in the SVM showing the AET results.</td>
</tr>
<tr>
<td>Climate Scenario</td>
<td>NBS Sequence</td>
<td>SVM Code</td>
<td>Comments</td>
</tr>
<tr>
<td>------------------</td>
<td>--------------</td>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>3. Change to Drier</td>
<td>8. Low Superior</td>
<td>LS</td>
<td>A 109-year sequence from the stochastic NBS. Based on current climate, but produces the lowest Lake Superior level in entire stochastic simulation.</td>
</tr>
<tr>
<td></td>
<td>9. CC-AEV – 1977A Superior min lower than stochastic min</td>
<td>AV</td>
<td>Another Canadian RCM sequence; 1977A produces lower levels with this sequence than with any in the stochastic.</td>
</tr>
<tr>
<td>10. Sequence A2 174</td>
<td>T1</td>
<td>One of thousands of climate change sequences in which the climate change effect becomes more pronounced over time. Plan 1977A Superior levels drop below 182.0 m (597.1 ft) using this sequence.</td>
<td></td>
</tr>
<tr>
<td>11. Sequence A2 370</td>
<td>T2</td>
<td>Another sequence that got drier over the course of the 109 years, but even more severe than sequence A2 174.</td>
<td></td>
</tr>
<tr>
<td>12. Extended trend</td>
<td>TR</td>
<td>This sequence did not use climate models, but just reduced historical NBS assuming the mean would continue to decline as it has in the last two decades. This was the most severe dry test of all, and many plans could not keep water levels above 182.0 m (597.1 ft).</td>
<td></td>
</tr>
<tr>
<td>4. Wet cycle soon</td>
<td>13. High Superior</td>
<td>HS</td>
<td>Current climate with average NBS close to historical NBS, but with the highest Lake Superior level in the stochastic set. The wettest portion of this supply sequence comes early in the simulation, as would be expected if recent dry NBS forecast a reversal to wet conditions.</td>
</tr>
</tbody>
</table>
5.4 Decision Criteria for Evaluating Candidate Regulation Plans

5.4.1 Role of the Decision Criteria

All candidate plans were evaluated against plan 1977A performance to show the net change that would occur if the existing plan was replaced. The Study Board wanted to clearly demonstrate that whatever plan that was put forward to the IJC improved performance over the existing plan. The focus then, was on: what constitutes improved performance and how should it be reflected in the evaluation criteria?

In addition, there are some comparisons to preproject conditions that were used to determine whether regulation is imposing a significant impact compared to the impacts that would have occurred without the structures in place. Comparisons to the 1955 Modified Rule of 1949 plan were also referenced because it was the last plan that did not include balancing – it compresses Lake Superior levels and allows for a wider range of Lake Michigan-Huron levels. As noted in section 5.1.2, this plan was in place up to 1979, when the IJC issued the Supplementary Order that required that Lake Superior levels be balanced with those of Lake Michigan-Huron.

Therefore, the Study Board’s goals, objectives and principles were translated into nine decision criteria. These criteria had to be further quantified by an associated set of metrics that could be used to directly and objectively compare plan performance for each formulated plan, and against the existing plan 1977A and the preproject condition. The system of performance metrics enabled the Study Board and the plan formulators to better design plans to achieve these goals and evaluate how well these plans met the decision criteria under a variety of possible future NBS conditions as described above.

The nine decision criteria were grouped into three categories and posed as questions:

**Hydrological Decision Criteria**

1. How well does the plan perform in keeping Lake Superior water levels between 182.76 and 183.86 m (599.6 to 603.2 ft)?
2. Does the plan maintain the historical balance of Lake Superior levels with Lake Michigan-Huron levels?
3. How much does the plan lower the highest Lake Michigan-Huron levels and raise the lowest?
4. How frequently does the plan avoid extremely low Lake Superior levels?

**Ecological Decision Criteria**

5. Does the plan enhance ecological attributes and reduce negative environmental impacts?

**Economic Decision Criteria**

6. Does the plan minimize disproportionate loss to any particular water interest?
7. How much does the plan reduce net shoreline protection costs?
8. How much does the plan increase benefits to commercial navigation interests?
9. How much does the plan increase benefits to hydroelectric generation interests on the St. Marys River?

The regulation plan evaluations summarized in Chapter 6 show how these decision criteria shaped selection of a preferred plan.

The Study’s SVM generated scores or “pass/fail” evaluations for the decision criteria. Figure 5-4 presents a summary display of the decision criteria. Each of the nine decision criteria represented in the summary displays are supported by more detailed displays so that users can more fully understand the relative
performance of each plan being formulated at each stage of the planning process. This was a continuous, iterative formulation and evaluation process. New information was developed and introduced into the evaluation system, and new plans were formulated and adjusted to improve their effectiveness in meeting the evolving planning objectives and performance metrics.

**Figure 5-4**
SVM Summary Evaluations for the Nine Decision Criteria

**Tradeoffs Among Water Interests**

There were, as would be expected, competing needs among the different interests. The Study Board sought to:

- maintain or improve hydroelectric generation and commercial navigation benefits, protecting the priority given them by the Treaty;
- perform at least as well as plan 1977A had done in terms of impacts on ecosystem interests; and,
- reduce shoreline protection costs.

As it is very difficult to accommodate all these water interests equitably on all the lakes, tradeoffs were inevitable between achieving all the objectives on Lake Superior versus those on Lake Michigan-Huron. As a result, the Study Board imposed the IJC principle of “no disproportionate loss” to assure that the benefits for the majority were not produced at the expense of significant losses to any particular interest.
5.4.2 Hydrological Decision Criteria

Criterion 1:
How well does the plan perform in keeping Lake Superior water levels between 182.76 and 183.86 m (599.6 to 603.2 ft)?

Criterion (a) of Condition 1 of the IJC’s current Orders of Approval specifies these levels as desirable maximum and minimum levels for Lake Superior. These levels are close to historical records, and similar to the levels reached by plan 1977A simulated with the historical NBS. The current Orders establish an absolute requirement to stay within the levels when tested with historical NBS adjusted for diversions (at least to 1979) and Lake Superior water levels must not exceed 183.86 m (603.2 ft) more often than under the 1955 Modification of the Rule of 1949 plan. The Orders include the statement “with the supplies of the past as adjusted and in such a manner as to not interfere with navigation” within Condition 6 of the Orders.

In the SVM, a “pass” score means that for the selected plan and NBS, this criterion was fully met; in other words, the maximum Lake Superior level was less than or equal to 183.86 m (603.2 ft) and the minimum was 182.76 m (599.6 ft) or more. As described in Chapter 6, none of the candidate plans was able to keep Lake Superior levels within this range when simulated with the more extreme NBS not experienced in the historical record (1900-2008). As a result, the pass/fail scores were supplemented by comparisons of the frequency and magnitude of the potential violation.

The SVM can generate level frequency graphs for any plan and any of the 13 NBS datasets (Figure 5-5). The graphs show how often (frequencies on the horizontal axis) the lake in question is below a certain elevation (marked on the vertical axis). The graph on the left shows the Lake Superior levels of three plans (A, B, 1977A) under the T2 NBS sequence (a climate change scenario, sequence 11 listed in Table 5-3) and 1977A under historical NBS (dashed line). The left-most point on the graph is the highest Lake Superior level during the entire simulation for that plan and NBS set. To the right of “Max” on the horizontal axis, there is the frequency “0.99” and the levels on the graph above that are slightly lower than the corresponding maximum for each plan and NBS. This is a depiction of the statistic that “99 percent of all Lake Superior levels simulated with this plan and NBS will be less than the level shown above 0.99”.

In the illustration shown in Figure 5-5, the plan under the T2 NBS sequence would lower Lake Superior high levels slightly, but would greatly reduce low levels. Among the three plans illustrated, 1977A is worst at avoiding the lowest levels on Lake Superior.
Criterion 2:

Does the plan maintain the historical balance of Lake Superior levels with Lake Michigan-Huron levels?

The notion of balancing lake levels was provided as an objective in the Supplementary Order; a balancing formula is included in the current plan 1977A. In this plan, Lake Superior levels are balanced with Lake Michigan-Huron levels when each are an equal number of standard deviations above or an equal number below the long-term monthly mean for each. In 1977A, there are fixed values for 12 monthly means and 12 monthly standard deviations for each lake based on the simulated lake levels expected with the 1955 Modification of the Rule of 1949. (Given that these values were fixed decades ago, they are somewhat different from current averages and standard deviations). Figure 5-6 illustrates how this criterion was applied to compare two candidate plans.

Over time, there will be an equal number of Lake Superior levels within one standard deviation of the mean as there are Lake Michigan-Huron levels within one standard deviation of its mean. But when the distance from the mean is tested in any one month, the lakes are almost unavoidably out of balance as recognized by the existing Orders, which attempt to address this issue. For example, if Lake Superior is currently near average levels and Lake Michigan-Huron is well above average, then the existing Orders encourage a smaller release than would otherwise be made. This would raise levels on Lake Superior and lower them on Lake Michigan-Huron, bringing them closer to balance in the coming months. However, because of the huge volumes in both lakes, relative to the flow between the lakes, it would take many months to adjust the lake levels so that they were above or below their average levels by a proportional amount.

The SVM provided a pass/fail grade for this criterion. A passing grade means that the sub-criteria for assessing the degree to which the two lakes are balanced, for a particular plan and NBS, met thresholds similar to plan 1977A scores. The first sub-metric was the range of imbalance, a measure of magnitude – how far out of balance the lakes typically were. As illustrated in Figure 5-6, a plan with a smaller range of
imbalance would produce a flatter graph with all values closer to the x-axis (zero imbalance). The numerical score for the range of imbalance is proportional to the sum of the areas above and below the x-axis.

The other sub-metric is a frequency bias, which is a measure of which of lakes Superior or Michigan-Huron is more likely to be more out of balance than the other. The farther from the 50 percent mark on the x-axis that the line crosses the x-axis, the more biased a plan is with respect to one lake or the other.

Figure 5-6 Balance Display in the SVM
Criterion 3:
How much does the plan lower the highest Lake Michigan-Huron levels and raise the lowest?

Figure 5-7 shows the highest and lowest two percent of water levels on lakes Superior and Michigan-Huron comparing two plans given historical NBS. Plan 1 is better for reducing the highs on Michigan-Huron, but results in higher highs on Superior. There is little difference in low levels between the two plans.

Reducing the highest levels of Lake Michigan-Huron slows erosion and reduces flooding and shoreline protection damages. Raising the lowest levels helps provide easier access for commercial shipping and recreational boating. Homeowners also report that lower levels reduce property values of near-lake homes.

As noted previously, the ability to control Lake Michigan-Huron using Lake Superior is limited. Lake Michigan-Huron levels are driven primarily by NBS of the lake’s larger watershed area and the discharge of water into Lake St. Clair. Therefore, changes in the releases from Lake Superior tend to have a much larger effect on Lake Superior than on the receiving lakes downstream.
Criterion 4: How frequently does the plan avoid extremely low Lake Superior levels?

Plan 1977A includes a provision required by Criterion C in the 1979 Supplementary Order that when Lake Superior levels are at 183.4 m (601.7 ft) IGLD1985\(^9\) or lower, the plan release cannot be greater than what would have occurred with no structures (i.e., the preproject release). This is one way of avoiding Lake Superior levels being lower than would have occurred before the structures were built.

5.4.3 Ecological Decision Criteria

Criterion 5: Does the plan enhance ecological attributes and reduce negative environmental impacts?

Lake Superior levels under plan 1977A are not that much different from unregulated lake levels and there is no evidence that wetlands along the coast of Lake Superior have been affected by the current regulation plan. (Georgian Bay wetlands are clearly affected by GIA and the increased conveyance of the St. Clair River, but these impacts cannot be significantly reduced through regulation of Lake Superior). The concern for Lake Superior is how NBS conditions that are significantly drier or wetter than the historical record could affect the environment.

The Study Board used metrics, developed by Study investigators, to rate new plans that attempted to reflect these relatively small changes. A coping zone metric was used to rate water level conditions (see section 5.2.4). The basic criterion was that the new plan should perform at least as well as the existing plan. The criterion used the 34 environmental performance metrics assessed within an Integrated Ecologic Response Model (IERM2) (Figure 5-8). As shown in the figure, the IERM2 model calculated wetland vegetation indicators directly from water level characteristics, and generated other indicators based on water levels and wetland vegetation information.

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\(^9\) International Great Lakes Datum (IGLD 1985) is a fixed frame of reference used to measure water levels in the Great Lakes-St. Lawrence River System. The datum has its zero reference elevation at Rimouski, QC on the St. Lawrence River.
5.4.4 Economic Decision Criteria

Criterion 6:  
*Does the plan minimize disproportionate loss to any particular water interest?*

The Study Board defined disproportionate loss in terms of two interests, shoreline protection (long-term costs of maintaining existing structures) and recreational boating (changes in the availability of slips) that had potential lake-to-lake conflicts and were not addressed in other decision criteria. The Study Board flagged plan results for these two metrics if they fell outside certain bounds.
Figures 5-9 and 5-10 show the SVM displays for disproportionate loss for shoreline protection and recreational boating, respectively. In this example, Plan 1 results in slightly worse shoreline protection than 1977A in several reaches but never by more than 2 percent, while it reduces overall shore protection costs. Similarly, as Figure 5-10 shows, both Plans 1 and 2 created very slightly higher rates of unusable slips on Lake Superior in return for slightly lower rates on Lake Michigan-Huron, a tradeoff that was not considered to create a disproportionate loss to Lake Superior boaters.

If the Study Board allowed no region to suffer any disbenefits compared to 1977A, it could not have changed the plan. This stems from the fact that changing a 1977A release will change levels on Lake Superior and Lake Michigan-Huron in opposite directions. The point of this decision criterion was to limit the negative impact that any one region would receive from a plan that was better overall. The Study Board tried to minimize these regional impacts, and it flagged as disproportionate shoreline protection costs in any one region that increased by more than 8 percent. Figure 5-9 shows the SVM spelled out the summary evaluation for these two plans: that “no reach sees shore protection costs increase by more than 8 percent”.

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Figure 5-9 Check for Disproportionate Shoreline Protection Losses

Figure 5-10 Changes in Slip Availability on Different Lakes
Chapter 5   2/6/12

Criterion 7: 
How much does the plan reduce net shoreline protection costs?

The Study Board sought to reduce the total costs of maintaining shoreline protection on lakes Superior and Michigan-Huron, and as a minimum to not increase costs over the current plan 1977A. An algorithm was developed that used existing large-scale databases for structures, waves and shoreline configurations to produce the average annual costs of maintaining shoreline protection in 24 regions on the lakes (see Figure 5-9). The algorithm calculates the costs of maintaining shoreline protection for each plan in each reach in each month of the simulation, and then compares those reach-by-reach costs to the costs under 1977A. The SVM can display either the gross costs or (as selected in Figure 5-9) the net benefit (1977A costs minus candidate plan costs), by reach. Lake Erie shoreline protection costs were not calculated because regulation of Lake Superior has a negligible effect on Lake Erie levels or shoreline protection costs.

Criterion 8:
How much does the plan increase benefits to commercial navigation interests?

The Study Board preferred plans that at least preserved or even decreased shipping costs on the Great Lakes. It considered changes from plan 1977A costs, looking at average annual, worst year and best year, and frequency-magnitude distributions of annual benefits.

Figure 5-11 illustrates a sample comparison of the impacts on commercial navigation interests of two different plans. Costs are shown for 10 routes reflecting possible combinations of shipping origins and destinations. For example, Route 1 (Lake Superior) is for shipments from one Lake Superior port to another. In this case, the levels on Lake Superior were the only levels needed to calculate these costs. Route 6 (lakes Superior-Michigan-Huron-St. Clair) included shipments between Lake Superior and Lake St. Clair ports, and the levels on lakes Superior, Michigan-Huron, and St. Clair as well as the St. Clair River and three points on the St. Marys River, were needed to calculate costs.

As indicated in Figure 5-11, the Study’s SVM included “drop” menus that control basic assumptions underlying the calculations that created the values. The default assumptions were that: peaking and ponding was taking place; and, that ship operators going through the locks at Sault Ste. Marie would allow 0.6 m (2 ft) less under-keel clearance at the origin and destination than they would through the connecting channels (because they moved quickly through the channels, and because the channels have some rock-bottom areas).

The columns show the gross costs, the net improvement compared to 1977A costs, the net improvement as a percentage of 1977A costs, and the best and worst years in terms of net costs for each plan on each route.
Criterion 9: How much does the plan increase benefits to hydroelectric generation interests on the St. Marys River?

The Study Board preferred plans that at least preserved or even increased the value of hydroelectricity generated by the hydropower plants on the St. Marys River. In this analysis, the Study Board considered only the power plants on the St. Marys River. It was recognized that changes in the releases from Lake Superior will have a small effect on Lake Erie levels eventually, which would, in turn, affect the energy produced at power plants at Niagara Falls. However, any changes in the levels and flows driving hydroelectric energy at Niagara are small and beyond the ability of existing computer models to estimate in a planning study or for operators to control effectively in practice (e.g., the error in the estimate would generally be larger than the estimated change).
5.5. Summary of the Study’s Framework

Chapter 5 describes the framework and the tools that were developed to help the Study in formulating and evaluating candidate plans for Lake Superior regulation. The key building blocks for the framework were:

- The historical context for Lake Superior regulation in the form of the rationale for various types of regulation plans that led up to the development of the existing plan, 1977A, the characteristics of all the preceding plans and the conditions that led to changes in those plans;
- Objectives for a new regulation plan in the form of specific statements of water management principles;
- An evaluation framework focused on directly relating lake level fluctuations and critical threshold levels to impacts on key interests, through tools such as performance indicators and coping zones;
- Nine decision criteria that incorporated the Study Board’s objectives and water management principles;
- 13 NBS sequences representing the full range of plausible future NBS conditions to test the robustness of any plan; and,
- A shared vision planning process to support collaborative and transparent decision making.

Chapter 6 outlines how the Study Board applied this framework and these tools to evaluate and rank candidate Lake Superior regulation plans, and to identify a preferred plan to recommend to the IJC.

5.6 Key Points

With respect to the Study’s approach to formulating candidate plans for Lake Superior regulation, the following points can be made:

- The existing Lake Superior regulation plan, 1977A, in effect since 1990, represents the culmination of nearly 75 years of water management experience responding to changing economic, environmental and social conditions across the upper Great Lakes basin.
- The rationale for reviewing the existing plan is based on several important factors that have emerged over the past 20 years:
  - a recognition of the considerable uncertainty about future NBS and corresponding water levels in the Great Lakes basin as a result of natural climate variability and human-induced climate change;
  - the opportunity to apply new data, modelling and knowledge about the hydrology and hydraulics of the Great Lakes system; and,
  - a much better understanding of the needs of water-using interests that any new regulation plan must address.
- The Study Board established clear objectives for a new Lake Superior regulation plan – and for the upper Great Lakes basin as a whole – based on the IJC’s Directive and feedback received at public meetings:
  - To maintain or improve the health of coastal and riverine ecosystems;
  - To reduce flooding, erosion and shore protection damages;
  - To reduce the impact of low water levels on the value of coastal property;
• To reduce shipping costs;
• To maintain or increase hydropower value;
• To maintain or increase the value of recreational boating and tourism opportunities; and,
• To maintain or enhance municipal-industrial water supply withdrawal and wastewater discharge capacity.

➢ The overall approach to the Study’s strategy was based on shared vision planning, an iterative and collaborative process through which participants can better understand the implications of any regulatory decision. The Study Board used a SVM to undertake “practice” decisions, allowing experts, stakeholders and decision makers a series of opportunities to weigh the results as information developed, so that the final decision will be transparent. The SVM was an EXCEL-based spreadsheet that calculates and displays the economic and environmental PIs based on water levels and flows from proposed regulation plans.

➢ Four categories of climate scenarios were used to organize the wide range of views on what NBS would be like in the coming decades: similar to the past; affected in some unknown way by climate change; made drier because of climate change; and, wetter because of natural cycles of wet and dry on the Great Lakes.

➢ Of the hundreds of NBS sequences generated by the Study’s hydroclimatic analysis, 13 were chosen for detailed plan formulation and evaluation. These 13, developed through several different scientific approaches, are representative of the range of plausible sequences that could be used to test the limits of any new proposed regulation plan. This suite of NBS sequences allowed the Study Board to test plans for “robustness” – the capacity to meet particular regulation objectives under a broad range of possible future water level conditions.

➢ The Study Board’s goals, objectives and principles were translated into nine specific decision criteria. These criteria, posed as questions under hydrological, ecological and economic factors, enabled the Study Board and plan formulators to better design plans to achieve these goals and evaluate how well these plans met the criteria under a variety of possible future NBS conditions.