International
Lake Ontario - St. Lawrence River
Study Board

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March 23, 2006

Mr. Dennis L. Schornack
Chairman, United States Section
International Joint Commission
1250 23rd Street, NW, Suite 100
Washington, DC, USA 20037

Rt. Hon. Herb Gray
Chairman, Canadian Section
International Joint Commission
234 Laurier Avenue West, 22nd Floor
Ottawa, Ontario, Canada K1P 6K6

Dear Chairman Schornack and Chairman Gray:

The International Lake Ontario–St. Lawrence River Study Board is pleased to submit herewith its Final Report at the request of the International Joint Commission. The Report identifies the regulation plan options, which address new hydrologic conditions, and all interest groups that benefit from the operation and regulation of the system. All candidate regulation plans provide net economic and environmental benefits over the current Plan 1958-D with Deviations. Each of these options represents a mixture of tangible benefits and minimal costs. All achieve the goals mandated by the Commission in its Directive of December 11, 2000.

This report, its findings and recommendations represent five years of international cooperation by hundreds of Study participants, countless citizens and dozens of agencies, for which we are extremely grateful.

Respectfully submitted,

Eugene Stakhiv
U.S. Director

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ANNEXES

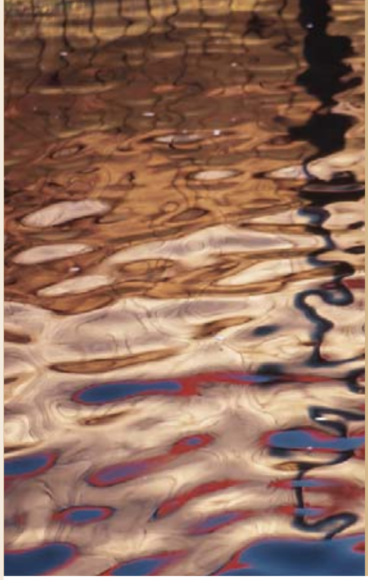
Options for Managing Lake Ontario and St. Lawrence River Water Levels and Flows

Final Report by the International Lake Ontario - St. Lawrence River Study Board

to the

International Joint Commission
March 2006

Étude internationale sur le lac Ontario et le fleuve Saint-Laurent
International Lake Ontario - St. Lawrence River Study



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Annex 1
Pertinent Documents

Introduction

Annex 1 provides three pertinent background documents for the Lake Ontario-St. Lawrence River Study. These documents are:

1. The December, 2000 International Joint Commission Directive to the International Lake Ontario - St. Lawrence River Study Board;

2. The executive summary of the September 1999 original Plan of Study for criteria review in the Orders of Approval for regulation of Lake Ontario - St. Lawrence River levels and flows; and

3. The Orders of Approval, October 29, 1952 as amended by Supplementary Orders dated July 2, 1956.

Pertinent Document 1

International Joint Commission Directive to the International Lake Ontario-St. Lawrence River Study Board, December 2000

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 a **Plan of Study for Criteria Review in the Orders of Approval for Regulation of Lake Ontario - St Lawrence River Levels and Flows** (Plan of Study), dated September 1999. The Plan of Study describes the work required to review water levels and flow regulation in the Lake Ontario - St Lawrence River system, and provides for consideration of knowledge that has been gained since the Commission's Order of Approval of the construction of certain works for development of power in the International Rapids Section of the St Lawrence River was issued on October 29, 1952 and amended on July 2, 1956, changed uses of the system, and likely future trends. The purpose of the study is i) to review the current regulation of levels and flows in the Lake Ontario-St. Lawrence River system, taking into account the impact of regulation on affected interests, ii) to develop an improved understanding of the system by all concerned, and iii) to provide all the relevant technical and other information needed for the review. In reviewing the Order and Regulation plan, and in assessing their impacts on affected interests, the Commission will be seeking to benefit both these interests and the system as a whole, consistent with the requirements of the Treaty.

2. This directive establishes the International Lake Ontario - St Lawrence River 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 Lake Ontario-St. Lawrence River 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. reviewing the operation of the structures controlling the levels and flows of the Lake Ontario-St. Lawrence River system in the light of the impacts of those operations on affected interests, including the environment;
   b. assessing 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
   c. evaluating 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 Lake Ontario-St Lawrence River regulation, to assure that all significant issues are adequately addressed.

3. The Commission will appoint an equal number of members from Canada and the United States to the Study Board, and the Commission will name a member from Canada and a member from the United States to be the co-chairs of the Study Board. The co-chairs of the Public Interest Advisory Group will be members of the Study Board. The co-chairs of the Study Board shall convene and preside at meetings of the Study Board and shall jointly take a leadership role in planning and implementing the Study Board's work.

4. The Study Board, after consultation with Commission, may establish study teams, committees, work groups and other advisory bodies to address the substantive areas identified in the Plan of Study and assist it in carrying out its responsibilities. The Study Board shall normally appoint an equal number of persons from Canada and from the United States to each of these entities. Unless other arrangements are made, members of the Study Board, study teams, committees, work groups and other advisory bodies will make their own arrangements for reimbursement of necessary expenditures.

5. The Commission, after consultation with the Study Board, will appoint a co-manager in Canada and a co-manager in the United States to assist the Study Board on a full-time basis in performing the responsibilities assigned to it in this directive. The co-managers shall work under the joint direction of the co-chairs of the Study Board and shall keep fully abreast of the work of the study teams, committees, work groups and other advisory bodies, as well as the Public Interest Advisory Group, which is established pursuant to the Public Participation terms of reference dated December 11, 2000.

6. The Study Board, study teams, committees, work groups and other advisory groups shall act as unitary bodies. The members of the Study Board, the study teams, work groups, other advisory bodies, and the co-managers shall serve the Commission in their personal and professional capacities, and not as representatives of their countries, agencies, organizations, or other affiliations.

7. The Study Board and the study teams, committees, work groups and other advisory bodies shall endeavour to conduct all their work by consensus. The Study Board shall notify the Commission of any irreconcilable differences and shall refer promptly to the Commission any lack of clarity or precision in instructions or directives received from the Commission.

8. The Study Board shall carry out its work independent of the work of the International St. Lawrence River Board of Control (Board of Control), which is responsible for overseeing the regulation of the outflows from Lake Ontario pursuant to the Commission's 1952 Orders of Approval, as amended and shall not take instructions from the Board of Control. The Study Board, however, shall maintain liaison with the Board of Control so that each Board may be aware of any activities of the other that might be useful to it in carrying out its responsibilities.

9. The Study Board shall keep the Commission fully informed of its progress and direction. The Study Board shall also maintain an awareness of basin-wide activities and conditions and shall inform the Commission about any such activities or conditions that might affect its work. In addition to regular contact with designated Commission personnel, the Study Board shall meet with the Commission at least semi-annually and shall submit written progress reports to the Commission at least three weeks in advance of those times and at other times as deemed appropriate by the Study Board or as requested by the Commission. The Study Board will also maintain such financial and other records as may be necessary to document the contributions of each country to the study effort.

10. The Commission emphasizes the importance of public outreach, consultation, and participation. In the conduct of its activities, the Study Board shall be guided by the Public Participation Guidance dated December 11, 2000. The Commission expects the Study Board to involve the public in its work to the fullest extent possible. The Study Board shall provide the text of media releases to the Secretaries of the Commission prior to their release.

11. To facilitate public outreach and consultation, the Study Board shall make information related to the study as widely available as practicable, including white papers, data, reports of the Study Board or any of its subgroups, and other materials, as appropriate. The Study Board shall develop and maintain a web-site as a means for disseminating information related to implementation of the Plan of Study, and will use the web-site to encourage public discussion of such information. To the extent practicable, the Study Board shall make available on the web-site all documents that are available for public information under the Commission's Rules of Procedure, including public comment and other information made available by decision pursuant to the Rules of Procedure.

12. The Commission will conduct formal public hearings at appropriate times during the course of this study.

13. The Study Board shall within two months of its creation submit for the Commission's approval a comprehensive work plan with an associated schedule of activities, products and budget, all based on the Plan of Study.

14. The Commission will administer, or coordinate, resource contributions from the two governments to support the activities of the Study Board, the study teams, committees, work groups, other advisory bodies, and the Public Interest Advisory Group.

Signed this the 11th day of December, 2000.

Gerald E. Galloway, Secretary United States Section	Murray Clamen, Secretary Canadian Section

Pertinent Document 2

Plan of Study for Criteria Review in the Orders of Approval for Regulation of Lake Ontario – St. Lawrence River Levels and Flows, September 1999

Executive Summary

In May 1999, a Binational Study Team was assembled by the International Joint Commission to transform the 1996 Scope of Work, which had been prepared by the International St. Lawrence Board of Control, into a detailed Plan of Study to review the operation of the structures controlling the flows and levels of the Lake Ontario – St. Lawrence system. This will require investigation of the existing criteria within the Commission's Orders of Approval for these works and a determination of what would be required to establish new criteria for improved regulation of Lake Ontario, should the Commission so desire. The 1996 Scope of Work placed emphasis on wetlands and other environmental factors, and recreational boating interests; factors not previously addressed by the original plan. The Scope of Work had also concluded that future studies should evaluate existing criteria in order to see if modifications could be made incorporating operational experience and interest preferences which have been identified since the original plan was adopted. The IJC instructed that the Scope of Work serve as the basis for this new Plan of Study. In developing this document, experts were asked to provide input on wetlands, fisheries and the environment, recreational boating, coastal processes including erosion and flood potential, commercial navigation, hydropower, industrial, municipal and domestic water intakes, public information and education, and hydrologic modeling. The Study Team then assembled these inputs and proposals into an overall Plan of Study, with costing and timelines. The following are highlights of the input provided.

Data Collection

In order to assess the various interests and criteria, extensive data collection is required. For example, information needs for environmental assessments should be centered on collection of more thorough topographic/bathymetric data at an increased number of wetland sites, concurrent collection of plant community data to reflect changes that have occurred since the Levels Reference Study data collection in 1991, and collection of data relating to fish use and accessibility to wetland habitat. The investigation of flooding, erosion and other coastal processes, requires very detailed information about the shoreline, including the shoreline geomorphology and subaqueous geology, shoreline bathymetry, shoreline elevations, bluff heights and slope, land use and property values. Understanding impacts on recreational boating requires systematic surveys of all marina operators to obtain the physical layout and operation of facilities and to obtain the current distribution of required drafts of the existing users of these facilities. Surveys are also required to determine the characteristics of water intakes and shore wells including information about those dependent upon them and changes that have occurred since 1956 to ensure that domestic and industrial water usage is catalogued.

Data collection is required at specific sites, or on a continuous shoreline basis, depending on the particular interest investigated, along both shores of Lake Ontario and the St. Lawrence River to Trois-Rivières. State-of-the-art data collection techniques are proposed, such as airborne laser-survey techniques, with geographic positioning systems (GPS), and geographic information systems (GIS).

The evaluations of impacts and effects associated with changing water levels will be based on historic recorded supply and lake level information. To the extent practical, possible future changes due to climate and demographics will be considered, and simulation techniques will also be utilized to gauge impacts and effects of possible future supply scenarios.

Evaluations

Several of the evaluations will require the development of investigative and predictive models which will assess the impact of changing levels on a particular interest. The output from each of these models will be evaluated to identify alternative approaches that meet, as nearly as possible, the needs of all interests (including the integrity of the ecosystem) while always respecting the requirements of the Boundary Waters Treaty and its Article VIII in particular.

It is proposed that new regulation plan(s) be developed and evaluated to determine to what degree they meet the new or modified criteria proposed as a result of the studies. If the regulation criteria are to be satisfied by the regulation plan for the chosen hydrologic design conditions, the criteria and regulation plan may have to be developed in concert. If the new plan does not have to fully satisfy completely each criterion, the criteria can be set prior to the plan development. If the plan cannot meet all of the criteria, a method of ranking the importance of proposed criteria, beyond that already provided for in the Treaty, must be developed to test plan changes and determine which plan best meets proposed criteria.

Since the needs and preferences of the various interests are different and at times in opposition, development of a more comprehensive set of criteria and a matching regulation plan satisfying all the interests will not be a simple task. There is a need to demonstrate what levels and flows are physically possible with the current physical regulatory works and channels, through simulation of regulation for the wide range of possible hydrologic conditions. An understanding of the reality and practicability of certain level or flow conditions could help promote better dialogue amongst the interest groups and the acceptance of the needs of others and the eventual needed compromise among the groups. It will be important that all interested parties appreciate that, within the constraints of the existing works and probable future supplies, it is highly unlikely that any new regulatory plan will be able to provide significant additional benefits to every interest group.

Project Management

It is proposed that the overall management of the multi year program of studies described herein be assigned to a Study Board created for that purpose by the Commission. The Study Board will then establish specific binational work groups which will be responsible for common data collection, as outlined in section 4.2 above, using the available expertise of the two nations and allocating resources accordingly. Study Teams will also be created for each of the “interests” identified in Part 6 of this Plan, in each case comprising a binational team from the various agencies, as a minimum, listed in Annex 1. Scheduling of their work will need to be coordinated through the Study Board. It will be the task of the overall Study Board, with input from each Study Team and the Interest Advisory Group outlined in Section 5.1, to then consider the differing outputs of each study area and bring these together in a coherent manner that allows for public discussion of the impacts and benefits of various regulation plans and criteria, always having in mind the priorities already established under Article VIII of the Boundary Waters Treaty.

The evaluation process will be iterative, beginning early on in the study process and continuing to its completion. It will involve the development and refinement of an evaluation methodology, workshops, public meetings, regulation plan development and testing. While some portions of the overall study will require data collection extending over four to five years in order to obtain an adequate baseline, others can be split into phases with data collection in the early years and scenario testing in latter years. It is expected that the last two years of this study will concentrate heavily on the development of criteria and an acceptable regulation plan. The challenge will be to develop criteria and regulation plans that recognize the interests of all groups, and which create improved benefits for some without significant negative impacts on others. A decision support methodology specific to this situation will need to be developed as a part of the proposed studies which recognizes the complexity of the impact and benefit distribution challenge inherent in regulation of the Lake Ontario - St. Lawrence River system. It is anticipated that a number of trial regulation plans will need to be developed and considered by the Study Board, so as to allow the effects of any new or revised criteria to be described in a manner which the representatives of the various interests, the general public, and the Commission can fully appreciate.

Public Involvement

Public consultation is critical to the assessment of plan criteria. It is recognized that progress in addressing water levels issues is dependent in large part on public understanding of the causes of the water level problems, and the further understanding that most proposed solutions could have consequences for others. To achieve this understanding, it is recommended that the major interests and the relevant public be involved directly in the studies, by the formation of an Interest Advisory Group, described in section 5.1. This would allow individuals with diverse interests to find common ground on many aspects of the issues. The continuous involvement of all interests throughout the criteria review process is critical to the success of the study.

Upon completion of this work, the Study Board will then report to the Commission regarding the work carried out, its recommendations on any amendments or additions to the present criteria, and the recommended regulation plan to give effect to these criteria. The Commission, in turn, may wish to hold further public consultations prior to any decision to adopt, or otherwise, the Study Board's recommendations. Additional time for consideration of the Study Board's work by the Commission, or for further public consultations, cannot be accurately estimated at this point, and is therefore not included in the overall five year project schedule.

Cost Summary

The proposed study will define the Lake Ontario-St. Lawrence River system thoroughly as an ecosystem and hydrologically in terms of its past history and potential future benefits or impacts, though at considerable cost. The full investigation of all factors will require five years to complete and is estimated to cost **$10.07 million in U.S. dollars** ($14.80 Cdn. equivalent) for work to be carried out within the United States plus **$15.79 million in Canadian dollars** ($10.74 U.S. equivalent) for work to be carried out within Canada. This converts to totals equivalent to 30.59 million Cdn. or $20.81 U.S. The study would be conducted, and these funds spent by a series of binational teams, comprising subject matter specialists serving in their personal and professional capacities from various federal, state and provincial agencies, academia and private consultants, and by the stakeholders impacted by Lake Ontario regulation, with overall coordination by the binational Study Board.

Acknowledgment

This document could not have been developed without the assistance of dozens of individuals who responded expeditiously providing input and quickly establishing teams to define required studies.

Respectfully submitted by the Study Team:

Lieutenant Colonel Mark D. Feierstein	Michael Turner
Dr. Douglas A.Wilcox	André Carpentier
Thomas E. Brown	Robert H. Clark

Pertinent Document 3

Orders of Approval, October 29, 1952 as amended by Supplementary Orders dated July 2, 1956

APPENDIX G

ORDERS OF APPROVAL FOR REGULATION OF LAKE ONTARIO

Office Consolidation

IN THE MATTER OF THE APPLICATIONS OF THE GOVERNMENT OF CANADA AND THE GOVERNMENTS OF THE UNITED STATES OF AMERICA FOR AN ORDER OF APPROVAL OF THE CONSTITUTION OF CERTAIN WORKS FOR DEVELOPMENT OF POWER IN THE INTERNATIONAL RAPIDS SECTION OF THE ST. LAWRENCE RIVER.

NOTE:
1. *The amendments of July 2, 1956 are in Light Italic type.*
2. All elevations have been converted to International Great Lakes Datum (1985) and the metric system of measurement.

ORDERS OF APPROVAL
October 29, 1952, as amended by a supplementary
Order dated July 2, 1956

WHEREAS the Government of Canada and the Government of the United States of America under date of 30 June, 1952, have submitted Applications to the International Joint Commission (hereinafter referred to as the "Commission") for its approval of the construction, jointly by entities to be designated by the respective Governments, of certain works for the development of power in the International Rapids Section of the St. Lawrence River, these being boundary waters within the meaning of the Preliminary Article of the Boundary Waters Treaty of 11 January, 1909 (hereinafter referred to as the "Treaty"), and of the construction, maintenance and operation of such works subject to and under conditions specified in the Applications, and have requested that the Applications be considered by the Commission as in the nature of a joint application; and

WHEREAS pursuant to the aforementioned request of the two Governments, the Commission is considering the two Applications as in the nature of a joint application; and

WHEREAS notices that the Applications have been filed were published in accordance with the Rules of Procedure of the Commission; and

WHEREAS Statements in Response to the Applications and Statements in Reply thereto by both Applicants were filed in accordance with the Rules of the Commission; and

WHEREAS pursuant to published notices, hearings were held by the Commission at Toronto, Ontario, on 23 July, 1952; at Ogdensburg, New York, on 24 July, 1952; at Cornwall, Ontario, on 25 July, 1952; at Albany, New York, on 3 September, 1952; at Montreal, Quebec, on 8 September 1952; and at Washington, D.C. on 20 October, 1952; and

WHEREAS by reason of the said notices of the said applications and hearings, all persons interested were afforded convenient opportunities of presenting evidence to and being heard before the Commission; and

WHEREAS pursuant to the said Applications, the hearings before, the evidence given, and material filed with the Commission is satisfied that the proposed works and use of the waters of the International Rapids Section comply with the principles by which the Commission is governed as adopted by the High Contracting Parties in Article VIII of the Treaty; and

WHEREAS the Commission has been informed that the Government of Canada has designated The Hydro-Electric Power Commission of Ontario as the entity to construct, maintain and operate the proposed works in Canada; and

WHEREAS the Commission has been informed that the President of the United States of America by Executive Order No. 10.500, dated 4 November 1953, designated the Power Authority of the State of New York as the United States entity to construct, maintain and operate the proposed works in the United States; and

WHEREAS the program of construction of the works, as proposed by the Applicants, includes the removal of Gut Dam from the International Rapids Section and the Government of Canada has informed the Commission that it is its intention to take steps for the early removal of Gut Dam as soon as the construction of the proposed works is approved and as soon as river conditions and the protection of down river and interests that will be affected during its removal will permit, thereby advancing the time of removal of Gut Dam; and

WHEREAS the Commission finds that suitable and adequate provision is made by the laws in Canada and by the Constitution and laws in the United States for the protection and indemnity of all interests on either side of the International Boundary which may be injured by reason of the construction, maintenance and operation of the works; and

WHEREAS the Commission finds that it has jurisdiction to hear and dispose of the Applications by approval thereof in the manner and subject to the conditions hereinafter set out; and

WHEREAS the Commission by Order dated 29 October 1952 (Docket 68), approved the construction, maintenance and operation of the works; and Appendix A to the said Order describes the features of the works so approved and provides the channel enlargements will be undertaken in specified areas; and

WHEREAS condition (i) of said Order provides that, upon completion of the works, the discharge of water from Lake Ontario and the flow of water through the International Rapids Section shall be regulated to meet the requirements of conditions (b), (c) and (d) thereof, and subject to possible modifications and changes to be recommended subsequently by the International St. Lawrence River Board of Control, in accordance with Method of Regulation No. 5 as prepared by the General Engineering Branch, Department of Transport, Canada, dated Ottawa, September 1940; and

WHEREAS, by the said Order of 29 October 1952, the Commission specifically retained jurisdiction to make such further Order or Orders relating to the subject matter of the Applications of the United States of America and Canada (Docket 68) as may be necessary in the judgment of the Commission; and

WHEREAS the Commission, as a result of its investigations under the Reference from the Government of Canada and the United States of America, dated 25 June 1952, regarding the levels of Lake Ontario (Docket 67), has determined that it would not be practicable to base the regulation of flows from Lake Ontario on the said Method of Regulation No. 5; *and*

WHEREAS, pursuant to published notices, hearings were held by the Commission at Detroit, Michigan, on 4 June 1953, Rochester, New York on 17 November 1953 and 12 April 1955, Hamilton, Ontario on 18 November 1953, and Toronto, Ontario, 18 November 1953, and Toronto, Ontario on 14 April 1955 at which all persons interested were afforded convenient opportunity of presenting evidence to and being heard before the Commission; and at the said hearings held at Toronto and Rochester in April 1955 all interested persons were given convenient opportunity to express their views upon the criteria and range of stage which had been tentatively proposed by the Commission; and

WHEREAS the Commission on 9 May 1955, by letters addressed to the Secretary of State for External Affairs of Canada and the Secretary of State of the United States of America, respectively, recommended adoption by the two Governments of the following:

(i) A range of mean monthly elevations for Lake Ontario of 74.15 m (243.3 feet) navigation season to 75.37 m (247.3 feet) as nearly as may be; and

(ii) Criteria for a method of regulation of outflows and levels of Lake Ontario applicable to the works in the International Rapids Section of the St. Lawrence River; and

(iii) Plan of Regulation No. 12-A-9, subject to minor adjustments that may result from further detailed study and evaluation by the Commission;

WHEREAS, by letters dated 3 December 1955, the Secretary of State for External Affairs of Canada and the Under Secretary of State of the United States of America advised the Commission that the Government of Canada and the Government of the United States of America, respectively, approved the range of mean monthly elevations for Lake Ontario and the criteria recommended in the Commission's said letters of 9 May, 1955; and also approved Plan of Regulation No. 12-A-9 for the purpose of calculating critical profiles and the design of channel excavations in the International Rapids Section of the St. Lawrence River; and

WHEREAS, in the said letters dated 3 December 1955, the two governments urged the Commission to continue its studies with a view to perfecting a plan of regulation so as best to meet the requirements of all interests both upstream and downstream, within the range of elevations and criteria therein approved; and

WHEREBY, by letter dated 3 December 1955, the Secretary of State for External Affairs, on behalf of the Government of Canada, has informed the Commission of the arrangements that have been made for the redesign of a portion of the St. Lawrence Seaway Canal in the vicinity of Montreal, between Lake St. Louis and the Laprairie Basin; and

WHEREBY condition (i) of the said Order of Approval dated 29 October 1952 makes the provision for adjustments and progressive improvements in the plan of regulation, subject to requirements and procedures specified therein:

NOW, THEREFORE, IT IS ORDERED that the construction, maintenance and operation jointly by The Hydro-Electric Power Commission of Ontario and the Power Authority of the State of New York of certain works (hereinafter called "the works) in accordance with the "Controlled Single Stage Project (238-242)", which was part of the joint report dated 3 January, 1941, of the Canadian Temporary Great Lakes-St. Lawrence Basin Committee and the United States St. Lawrence Advisory Committee, containing the features described in Appendix "A" to this Order and shown in Appendix "B" to this Order, be and the same are hereby approved subject to the conditions enumerated below, namely,

(a) All interests on either side of the International Boundary which are injured by reason of the construction, maintenance and operation of the works shall be given suitable and adequate protection and indemnity in accordance with the laws in Canada or the Constitution and laws in the United States respectively, and in accordance with the requirements of Article VII of the Treaty.

(b) The works shall be so planned, located, constructed, maintained and operated as not to conflict with or restrain uses of the waters of the St. Lawrence River for purposes given preference over uses of water for power purposes by the Treaty, namely, uses for domestic and sanitary purposes and uses for navigation, including the service of canals for the purpose of navigation, and shall be so planned, located, constructed, maintained and operated as to give effect to the provisions of this Order.

(c) The works shall be constructed, maintained and operated in such manner as to safeguard the rights and lawful interests of other engaged or to be engaged in the development of power in the St. Lawrence River below the International Rapids Section.

(d) The works shall be so designed, constructed, maintained and operated as to safeguard so far as possible the rights of all interests affected by the levels of the St. Lawrence River upstream from the Iroquois regulatory structure and by the levels of Lake Ontario and the lower Niagara River; and any change in levels resulting from the works which injuriously affects such rights shall be subject to the requirements of paragraph (a) relating to protection and indemnification.

(e) The hydro-electric plants approved by this Order shall not be subjected to operating rules and procedures more rigorous than are necessary to comply with the provisions of the foregoing paragraphs (b), (c) and (d).

(f) Before the Hydro-Electric Power Commission Ontario commences the construction of any part of the works, it shall submit to the Government of Canada, and before the *Power Authority of the State of New York* commences the construction of any part of the works, it shall submit to the Government of the United States, for approval in writing, detailed plans and specifications of that part of the works located in their respective countries and details of the program of construction thereof of such details of such plans and specifications or programs of construction relating thereto as the respective governments may require. If after any plan, specification or program has been so approved. The Hydro-Electric Power Commission of Ontario or the *Power Authority of the State of New York* wishes to make any change therein, it shall, before adopting such change, submit the changed plan, specification or program for approval in a like manner.

(g) In accordance with the Applications, the establishment by the Governments of Canada and the United States of a Joint board of Engineers to be known as the St. Lawrence River Joint board of Engineers (hereinafter referred to as the ("Joint Board of Engineers") consisting of an equal number of representatives of Canada and the United States to be designated by the respective Governments, is approved. The duties of the Joint Board of Engineers shall be to review and coordinate, and, if both Governments so authorized, approve the plans and specifications of the works and the programs of construction thereof submitted for the approval of the respective Governments as specified above, and to assure the construction of the works in accordance therewith as approved. The Joint Board of Engineers shall consult with and keep the board of Control, hereinafter referred to, currently informed on all matters pertaining to the water levels of Lake Ontario and the International Rapids Section and the regulation of the discharge of water from Lake Ontario and the flow of water through the International Rapids Section, and shall give full consideration to any advice or recommendations received from the Board of Control with respect thereto.

(h) A Board of Control to be known as the International St. Lawrence River Board of Control (hereinafter referred to as the "Board of Control) consisting of an equal number of representatives of Canada and of the United States, shall be established by this Commission. The duties of the Board of Control shall be to give effect to the instructions of the Commission as issued from time to time with respect to this Order. During construction of the works the duties of the Board of Control shall be to keep itself currently informed of the plans of the Joint Board of Engineers insofar as these plans relate to water levels and the regulation of the discharge of water from Lake Ontario and the flow of water through the International Rapids Section, and to consult with the advise the Joint Board of Engineers thereon. Upon completion of the works, the duties of the Board of Control shall be to ensure that the provisions of this order relating to water levels and the regulation of the discharge of water from Lake Ontario and the flow of water through the International Rapids Section as herein set out are complied with, and the Hydro-electric Power Commission of Ontario and the *Power Authority of the State of New York* shall duly observe any direction given them by the Board of Control for the purpose of ensuring such compliance. The Board of Control shall report to the Commission at such times as the Commission may determine. In the event of any disagreement amongst the members of the Board of Control which they are unable to resolve the matter shall be referred by them to the Commission for decision. The Board of Control may, at any time, make representations to the Commission in regard to any matter affecting or arising out of the terms of this Order with respect to water levels and the regulation of the said discharge and flow.

(i) Upon the completion of the works, the discharge of water from Lake Ontario and the flow of water through the International Rapids Section shall be regulated to meet the requirements of *conditions (b), (c) and (d) hereof; shall be regulated within a range of stage from elevation 74.15 m (243.3 feet) (navigation season) to elevation 75.37 m (247.3 feet), as nearly as may be; and shall be regulated in accordance with the criteria set forth in the Commission's letters of 17 March 1955 to the Governments of Canada and the United States of America and approved by the said governments in their letters of 3 December 1955 and qualified, by the terms of separate letters from the government of Canada and the Government of the United States of America dated 11 April 1956 and 1 may 1956, respectively, to the extent that these letters agree that the criteria are intended to establish standards which would be maintained with the minimum variation. The project works shall be operated in such a manner as to provide no less protection for navigation and riparian interests downstream than would have occurred under pre-project conditions and with supplies of the past as adjusted, as defined in criterion (a) herein. The Commission will indicate in an appropriate fashion, as the occasion may require, the inter-relationship of the criteria, the range of elevations and the other requirements.*

The criteria are as follows:

(a) The regulated outflow from Lake Ontario from 1 April to 15 December shall be such as not to reduce the minimum level of Montreal Harbour below that which would have occurred in the past with the supplies to Lake Ontario since 1860 adjusted to a condition assuming a continuous diversion out of the Great Lakes Basin of 3,100 cubic feet per second at Chicago and a continuous diversion into the Great Lakes Basin of 5,000 cubic feet per second from the Albany river Basin (hereinafter called the "supplies of the past as adjusted").

(b) The regulated winter outflows from Lake Ontario from 15 December to 31 March shall be as large as feasible and shall be maintained so that the difficulties of winter power operation are minimized.

(c) The regulated winter outflows from Lake Ontario during the annual spring break-up in Montreal Harbour and in the river downstream shall not be greater than would have occurred assuming supplies of the past as adjusted.

(d) The regulated outflow from Lake Ontario during the annual flood discharge from the Ottawa River shall not be greater than would have occurred assuming supplies of the past as adjusted.

(e) Consistent with other requirements, the minimum regulated monthly outflow from Lake Ontario shall be such as to secure the maximum dependable flow for power.

(f) Consistent with other requirements, the maximum regulated outflow from Lake Ontario shall be maintained as low as possible to reduce channel excavations to a minimum.

(g) Consistent with other requirements, the levels of Lake Ontario shall be regulated for the benefit of property owners on the shores of Lake Ontario in the United States and Canada so as to reduce the extremes of stage which have been experienced.

(h) The regulated monthly mean level of Lake Ontario shall not exceed elevation 75.37 m (247.3 feet) with the supplies of the past as adjusted.

(i) *Under regulation, the frequency of occurrences of monthly mean elevations of approximately 75.07 m (246.3 feet) and higher on Lake Ontario shall be less than would have occurred in the past with the supplies of the past as adjusted and with present channel conditions in the Galops Rapids Section of the St. Lawrence River, ("present channel conditions refers to conditions as of March 1955.)*

(j) *The regulated level of Lake Ontario on 1 April shall not be lower than elevation 74.15 m (243.3 feet). The regulated monthly mean level of the lake from 1 April to 30 November shall be maintained at or above elevation 74.15 m (243.3 feet).*

(k) *In the event of supplies in excess of the supplies of the past as adjusted, the works in the International Rapids Section shall be operated to provide all possible relief to the riparian owners upstream and downstream. In the event of supplies less than the supplies of the past as adjusted, the works in the international Rapids Section shall be operated to provide all possible relief to navigation and power interests.*

The flow of water through the International Rapids Section in any period shall equal the discharge of water from Lake Ontario as determined for that period in accordance with a *plan of regulation work which, in the judgment of the Commission, satisfies the afore-mentioned requirements, range of stage and criteria and when applied to the channels as determined in accordance with Appendix A hereto produces no more critical governing velocities than those specified in that appendix, nor more critical governing water surface profiles than those established by Plan of Regulation 12-A-9, when applied to the channels as determined in accordance with Appendix A hereto*, and shall be maintained as uniformly as possible throughout that period.

Subject to the requirements of conditions (b), (c) and (d) hereof, *and of the range of stage, and criteria, above written*, the Board of Control, after obtaining the approval of the Commission, may temporarily modify or change the restrictions as to discharge of water from Lake Ontario and the flow of water through the International Rapids Section for the purpose of determining what modifications or changes *in the plan of regulation* may be advisable. The Board of Control shall report to the Commission the results of such experiments, together with its recommendations as to any changes or modifications *in the plan of regulation. When the plan of regulation has been perfected so as best to meet the requirements of all interests, within the range of stage and criteria above defined, the Commission will recommend to the two Governments that it be made permanent* and, if the two Governments thereafter agrees, such plan of regulation shall be given effect as if contained in this order.

(j) Subject as hereinafter provided, upon completion of the works, the works shall be operated initially for a test period of ten years, or such shorter period as may be approved by the Commission with the forebay water level at the power houses held at a maximum elevation of 72.36 m (237.4 feet). Subject to the requirements of paragraphs (b), (c), and (d) hereof, the Board of Control, after obtaining the approval of the Commission, may temporarily modify or change the said forebay water level in order to carry out experiments for the purpose of determining whether it is advisable to increase the forebay water level at the power houses to a maximum elevation exceeding 72.36 m (237.4 feet).

If the Board of Control, as a result of these experiments considers that operation during this test period at the maximum elevation exceeding 72.36 m (237.4 feet). would be advisable, and so recommends, the Commission will consider authorizing operation during this test period at a maximum elevation exceeding 72.36 m (237.4 feet). At the end of this test period, the Commission will make such recommendations to the two Governments with respect to a permanent forebay water level as it deems advisable or it may recommend an extension of the test period. Such of these recommendations as the two Governments thereafter agree to adopt shall be given effect as if contained in this Order.

(k) The Hydro-Electric Power Commission of Ontario and the *Power Authority of the State of New York* shall maintain and supply for the information of the Board of Control accurate records relating to water levels and the discharge of water through the works and the regulation of the flow of water through the International Rapids Section, as the Board of Control may determine to be suitable and necessary, and shall install such gauges, carry out such measurements, and perform such other services as the Board may deem necessary for these purposes.

(l) The Board of Control shall report to the Commission as of 31 December each year on the effect, if any, of the operation of the down-stream hydro-electric power plants and related structures on the tail-water elevations at the hydro-electric power plants approved by this Order.

(m) The government of Canada shall proceed forthwith to carry out its expressed intention to remove Gut Dam.

AND IT IS FURTHER ORDERED that the allocation set out in Appendix "C" of the costs of constructing, maintaining and operating the works approved by this Order between The Hydro-Electric Power Commission of Ontario and the *Power Authority of the State of New York* be and the same is hereby approved but such approval shall not preclude the Applicants from submitting to the Commission for approval any variation in the said allocation that may be agreed upon between them as being appropriate or advisable.

AND IT IS FURTHER ORDERED that the Commission retains jurisdiction over the subject matter of these Applications, and may, after giving such notice and opportunity to all interested parties to make representations as the Commission deems appropriate, make such further Order or Orders relating thereto as may be necessary in the judgment of the Commission.

APPENDIX A

FEATURES OF THE WORKS APPROVED BY THIS ORDER:

(a) Channel Enlargements

Channel enlargements will be undertaken from above Chimney Point to below Lotus Island, designed to give a maximum mean velocity in any cross-section of the channel which will be used for navigation not exceeding four feet per second at any time, also between Lotus Island and Iroquois Point and from above Point Three Points to below Ogden Island designed to give a maximum mean velocity in any cross-section not exceeding two and one quarter feet per second with the flow and at the stage to be permitted on the first of January of any year, under regulation of outflow and levels of Lake Ontario in accordance with *Plan of Regulation No. 12-A-9, as prepared by the International Lake Ontario Board of Engineers, dated 5 May 1955*. Downstream from the power houses channel enlargements will be carried out for the purpose of reducing the tail water level at the power houses.

Final locations and cross-sections of these channel enlargements will be determined from further studies.

As approved by the Government of Canada and the Government of the United States of America in similar letters dated 3 December 1995, the said Plan of Regulation No. 12-A-9 shall be the basis for calculating critical profiles and designing channel excavations.

(b) Control Facilities

Adequate control facilities will be constructed for the regulation of the outflow from Lake Ontario.

(c) Power House Structures

The powerhouse structures will be constructed in the north channel extending from the lower end of Barnhart Island to the Canadian shore, and so located that one structure will be on each side of the International Boundary.

Each power house structure will include the main generating units to utilize economically the river flows available to it, units to utilize economically the river flows available to it, with provisions for ice handling and discharge sluices.

(d) Dams and Associated Structures

A control dam will be constructed extending from Iroquois Point on the Canadian side of the river in an easterly direction to the United States mainland above Point Rockway.

A dam will be constructed in the Long Sault Rapids at the head of Barnhart Island

Dykes and associated works will be provided as may be necessary in both the Province of Ontario and the State of New York.

All the works in the pool below the control dam will be designed to provide for full Lake Ontario level.

(e) Highway Modifications

In both the Province of Ontario and the State of New York provincial and state highways, and other roads, will be relocated in those portions subject to flooding, and reconstructed to standards at least equal to those now in existence.

(f) Railway Modifications

Such railway relocations as may be required as a result of the works herein described will be made in the Province of Ontario and the State of New York to standards at least equal to those now in existence.

(g) Navigation Facilities

Provision will be made for the continuance of 14-foot navigation throughout the International Rapids Section during the construction period.

(h) Flooded Areas

Lands and building in both the Province of Ontario and the State of New York will be acquired or rehabilitated as required. Inundated wooded areas will be cleared.

APPENDIX B

General Plan showing major works of the Great Lakes-St. Lawrence Basin Power Project are not included in the consolidation.

APPENDIX C

1. The power development works under this Application are those specified in Section 8 of the Application.

2. Total costs of the works described in Section 8 shall be based on Canadian costs and the United States costs and the total shall be equally divided between the two constructing entities.

3. The costs to be divided should be based on actually experienced and audited expenses.

4. In relation to the three principles above, the three following provisions apply:

   (a) The amount to be paid to Canada, as specified in the Agreement of December 3, 1951, between Canada and Ontario, in lieu of the construction by the power-developing entities of facilities required for the continuance of 14-foot navigation, shall be excluded from the total cost of the power project to be divided between the Canadian and the United States power-developing entities, in consideration of the fact that actual replacement of 14-foot navigational facilities will be rendered unnecessary by reason of the concurrent construction of the deep waterway in Canada.

   (b) The Authority to be established pursuant to the provisions of the St. Lawrence Seaway Authority Act, Chapter 24 of the Status of Canada, 1951 (Second Session), shall contribute an agreed sum of money towards the cost of the channel enlargement which the power-developing entities must undertake in the St. Lawrence River, as set out in paragraph 4 of the Annex to the Canada-Ontario Agreement of December 3, 1951, and in section 8 of the application to the International Joint Commission, in consideration of the benefits which will accrue to navigation from such channel enlargement.

   (c) All costs for construction, maintenance and operation of the project except machinery and equipment in the respective power houses shall be borne equally by the two entities. All costs for construction, maintenance and operation of machinery and equipment in their respective power houses shall be paid by the respective entities and shall be deemed to satisfy the principle of an equal division between the two entities.

Annex2
Technical Work Group Summaries and Contextual Narratives

Introduction

Annex 2 provides a summary of the work completed by eight of the nine technical work groups in support of the Lake Ontario–St. Lawrence River Study, including Environment, Recreational Boating and Tourism, Coastal, Commercial Navigation, Hydropower, Municipal and Industrial Water Uses, Hydrology and Hydraulics and Common Data Needs/Information Management. The work of the Plan Formulation and Evaluation Group is not included here as it is covered in the Final Report. For more information on the Plan Formulation and Evaluation Group, refer to the final report of that technical work group (Werick and Leger, 2005).

In addition to a summary of the work conducted by the Technical Work Group, the six interest-specific technical work groups prepared contextual narratives for their interest groups. These narratives were prepared to explain baseline conditions, key trends in an area of interest, how an interest adapts to changing water levels, and how an interest is affected by a management plan. The technical work groups were asked to use their best professional judgment in identifying the most likely trends, outcomes and ways of adapting to changing water levels. In addition to the six interest-specific technical work groups, an additional contextual narrative was prepared to address Aboriginal peoples.

A. Environmental Technical Work Group Summary

Objectives

The Environmental Technical Work Group (ETWG) was tasked with defining the ecological response of the Lake Ontario–St. Lawrence River (LOSL) system to different water level and flow conditions and finding criteria to guide development of a regulation plan that could benefit the environment. Like the other technical work groups, the Environmental Group used performance indicators (PIs), or more specifically, metrics of performance indicators to define the environmental response to a particular regulation plan. The indicators were designed to provide quantitative information on the behavior of various aspects of the ecosystem (e.g., wetlands, suitable habitat), including population measures for a number of faunal species, among them species at risk.

Data Collection and Evaluation Methodology

Members of the Environmental Technical Work Group developed and undertook field research programs that would permit the development of predictive relationships for how those species or guilds of species would respond to patterns of water levels and flows in the Lake Ontario–St. Lawrence River system. The Work Group conducted more than 20 research studies for the purpose of quantifying the linkage between various ecosystem components and water levels/flows in the Lake Ontario–St. Lawrence River system.

Through its work, a complete set of over 400 ecological performance indicators was developed by the Environmental Technical Work Group to represent habitat supply and/or population response in each of three regions (Lake Ontario, the upper St. Lawrence River and the lower St. Lawrence River) for six indicator groups: wetland vegetation, fish species/guilds, wetland birds, herptiles (amphibians and reptiles), mammals, and species-at-risk. A specific metric (and associated units) was identified for each performance indicator. The performance indicator metric provides a means for measuring and computing the response of that particular indicator. For example, fish habitat supply indicators were calculated as weighted suitable habitat area in hectares.

In the development of a conceptual model of the linkages between the environment and water levels and flows, wetlands were identified as a fundamental component of the process. Wetlands respond to the frequency of high and low water levels through the coverage and diversity of plant species. Changes in wetlands result in associated changes in suitable habitat for species, and, in many cases, the response of a particular species is directly tied to the response of the wetlands. However, water levels and flows can also affect faunal species directly. The species-at-risk group includes members of the other faunal groups, which are considered separately because of their special interest status (including, in most cases, protection by law). A flow chart illustrating the generalized linkages between faunal responses, wetland habitat, and water levels and flows is provided in Figure A-1.

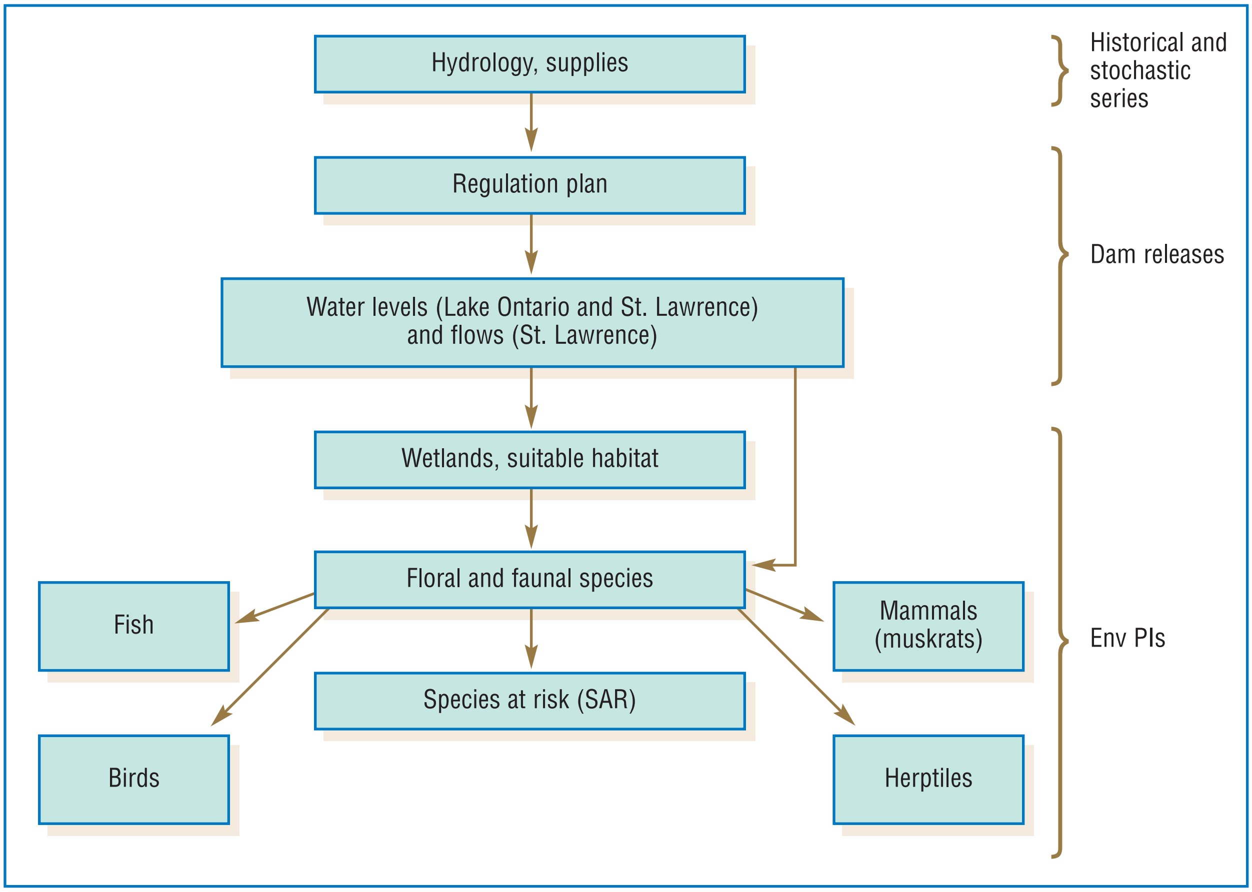

Figure A-1: Information flow in developing Environmental Performance Indicator responses

The Study Board and the Environmental Technical Work Group recognized the need for an integrating framework to permit all environmental performance indicators to be driven by the same set of forcing functions (water levels and flows, and their impact on habitat within the study domain), and to allow for simultaneous evaluation of all environmental performance indicators in the interest of ensuring that conflicts might be identified and understood. The Environmental Technical Work Group chose to use an integrated modeling framework, called the Integrated Ecological Response Model (IERM), to formulate and integrate its quantitative understanding of how the water level and flow-sensitive ecosystem components represented by the performance indicators would respond to alternative plans.

The development and application of the IERM was led by Limno-Tech Inc., in close cooperation with fellow modelers for the lower St. Lawrence River from Environment Canada-Quebec Region, and the entire Environmental Technical Work Group. Regular interaction throughout the study with other technical work groups, the Plan Formulation and Evaluation Group, and the Study Board contributed to the final product. The IERM was consistent with the Shared Vision Planning process developed for the Study and became the environmental wing of the Shared Vision Model (SVM).

In accordance with direction from the Study Board, one of the key assumptions used in formulating the IERM was that the model was not to consider the response of various performance indicators to forcing functions other than water levels and flows and temperature. Other recognized important stressors on the Lake Ontario–St. Lawrence River ecosystem—such as nutrient and sediment supplies from the watershed, toxic chemical exposure, land use changes, nuisance exotic species invasions, and, in the case of some species, stocking and harvesting practices—were assumed to be constant among the various plan-scenario conditions tested.

Context

As in the case of the economic evaluations, the environmental impacts of proposed regulation plans were measured relative to what is expected to occur if regulation continues in the same manner as it does now, under the present set of policies.

The focus of the environmental evaluation was on the effect of water levels on coastal marshes. Briefly, water level regulation has reduced the variety of plant species along the coast, which creates stresses on animal populations that thrive on plant types that suffer under regulated water levels. In general, a more diverse environment will better resist impacts from the two greatest environmental threats in the Great Lakes: toxics and invasive species (Tilman and Downing, 1987; Schindler, 1998). Lake Ontario coastal marshes provide breeding and feeding grounds for all coastal life, including several species at risk. Water level patterns have a direct physical influence on the breeding and nesting success of marsh birds and fish. More varied water levels create more variety in marsh plants, which creates a more productive and robust coastal ecology and habitat. Water levels below the Moses-Saunders Dam can strand or drown fish and bird eggs. The societal value of the environment is expressed through laws protecting habitat (i.e., wetlands) and specific faunal species (special interest or endangered).

The current estimate of coastal wetland area within Lake Ontario and the upper St. Lawrence River is approximately 26,000 hectares (64,250 acres), made up of four basic types, submerged aquatic vegetation, emergent marsh, meadow marsh, and upland vegetation (trees/shrubs) (Wilcox, et al., 2005). Over 80% of the wetland area occurs in the eastern half of the Lake Ontario basin and Thousand Islands region. Results from study-site analyses indicate a 50% reduction in meadow-marsh and emergent-floating vegetation since regulation was implemented in the late 1950s. The same period has seen a 29% increase in cattail-dominated emergent marsh area (about 1,700 hectares or 4,200 acres) (Wilcox and Ingram, 2005).

With over 12,000 ha (30,000 acres) of swamps and marshes, Lake Saint-Pierre accounts for 80% of lower St. Lawrence River wetlands. Lake Saint-Pierre supports a large population of nesting blue heron (more than 1,300 nests), a major staging area for migratory wildfowl (over 800,000 ducks and geese annually) and 167 species of nesting birds. Permanently submerged areas, wetlands and the spring floodplain are home to 13 amphibian and 79 fish species, many of which are exploited by sport and commercial fisheries alike (Centre St. Laurent, 1996). The ecological value of Lake Saint-Pierre has been recognized by its designation as a Ramsar wetland, a UNESCO Biosphere Reserve and its inclusion as a protected site under the Eastern Habitat Joint Venture. The hydrology of the lower St. Lawrence River is much more dynamic than that of the Lake and upper river throughout each period of the year. It is influenced not only by the outflows from Lake Ontario, but also by the Ottawa River flow and by the local tributaries. As a result, the lower St. Lawrence River is less sensitive to regulation.

In addition to impacts caused by regulation, the effects of changes in climate, water temperature, and water supply can influence the environmental response of habitats and the species they support. Issues such as invasive species, changes in fisheries management, pollution and population changes, and changes in the use of the resource can also impact the environment. Regardless of the regulation plan, the environment will continue to be vulnerable to various stressors such as invasive species, pollution, and land-use changes. However, the manner in which lake levels are managed can have an impact on the ecological integrity of the system and its resilience to these other stressors.

Performance Indicators

As noted earlier, the Environmental Technical Work Group initially established over 400 performance indicators for assessing impacts of levels and flows. It quickly became apparent that 400 performance indicators were far too many for the Study Board to make sense of. Through an extensive process that involved using the IERM to evaluate the response of all 400 performance indicators to alternative plan/supply scenarios, a subset of 32 key performance indicators was identified on the basis of the following criteria:

- **Significance** – the performance indicators must show some key importance to the ecosystem and region;
- **Certainty** – there must be confidence in the performance indicators' results;
- **Sensitivity** – the performance indicators must be significantly affected by the changes in levels and flows generated by the alternative regulation plans and/or supply scenarios being tested.

Performance indicators were also grouped based on similar responses to water levels and flows. In other words, each key indicator may represent a number of other indicators that behave similarly. The 32 key performance indicators selected for primary use in comparing and evaluating alternative regulation plans are presented in tables A-1 and A-2. It was these 32 key performance indicators that were used by the Study Board in the plan evaluation process. Descriptions of each of the key performance indicators, including comments on certainty, sensitivity and significance, are included in the Integrated Environmental Response Model documentation (Limno-Tech, 2005).

Even with this reduction in performance indicators, the Study Board still needed some way of comparing the different performance indicator metrics (e.g., area of wetland vs. productivity, vs. reproduction indices). It was important to adopt an approach that could be used to effectively compare the responses of many indicators to alternative regulation plans. A performance indicator "ratio" approach was developed collaboratively by Limno-Tech Inc. and the Environmental Technical Work Group to provide a means for rapidly evaluating plan responses. The response ratios are defined in such a way that it is easy to establish which plan is "better" in terms of each indicator by comparing the ratio with 1.00, where 1.00 is the environmental response under the baseline plan 1958-DD, anything greater than 1.00 represents an improvement, and anything below 1.00 a deterioration relative to 1958-DD. For example, a score of 1.44 would indicate that a performance indicator performed 44% better under the evaluated plan than under 1958-DD. The Study Board stipulated that all plans were to be measured against Plan 1958-DD as the baseline plan, but the Environmental Technical Work Group also used the Pre-project Plan in its comparisons to serve as the natural reference condition.

Table A-1: Lake Ontario/Upper St. Lawrence River Environmental Performance Indicators

Region	PI Group	PI Description	PI Metrics	Researchers	Significance	Certainty	Sensitivity
Lake Ontario	Vegetation	Wetland Meadow Marsh Community - Total surface area, supply-based (Lake Ontario)	ha	Wilcox, Ingram	5	5	5
Lake Ontario	Fish	Low Veg 18C - Spawning habitat supply (Lake Ontario)	ha-days	Minns, Doka, Chu, Bakelaar, Leisti	2	3	4
Lake Ontario	Fish	High Veg 24C - Spawning habitat supply (Lake Ontario)	ha-days	Minns, Doka, Chu, Bakelaar, Leisti	3	3	4
Lake Ontario	Fish	Low Veg 24C - Spawning habitat supply (Lake Ontario)	ha-days	Minns, Doka, Chu, Bakelaar, Leisti	2	3	4
Lake Ontario	Fish	Northern Pike – Young-of-year (YOY) recruitment index (Lake Ontario)	index	Minns, Doka	3	4	5
Lake Ontario	Fish	Largemouth Bass - YOY recruitment index (Lake Ontario)	index	Minns, Doka	3	4	4
Lake Ontario	Birds	Virginia Rail (RALI) - Median reproductive index (Lake Ontario)	index	DesGranges, Ingram, Drolet	4	4	5
Lake Ontario	Species at risk (bird)	Least Bittern (IXEX) - Median reproductive index (Lake Ontario)	index	DesGranges, Ingram, Drolet	5	2	5
Lake Ontario	Species at risk (bird)	Black Tern (CHNI) - Median reproductive index (Lake Ontario)	index	DesGranges, Ingram, Drolet	5	3	5
Lake Ontario	Species at risk (bird)	Yellow Rail (CONO) - Preferred breeding habitat coverage (Lake Ontario)	ha	Lantry, Schiavone	2	2	5
Lake Ontario	Species at risk (bird)	King Rail (RAEL) - Preferred breeding habitat coverage (Lake Ontario)	ha	Lantry, Schiavone	2	2	5
Upper SL River	Fish	Low Veg 18C - Spawning habitat supply (Upper St. Lawrence)	ha-days	Minns, Doka, Chu, Bakelaar, Leisti	2	3	4
Upper SL River	Fish	High Veg 24C - Spawning habitat supply (Upper St. Lawrence)	ha-days	Minns, Doka, Chu, Bakelaar, Leisti	3	3	4
Upper SL River	Fish	Low Veg 24C - Spawning habitat supply (Upper St. Lawrence)	ha-days	Minns, Doka, Chu, Bakelaar, Leisti	2	3	4
Upper SL River	Fish	Northern Pike - YOY recruitment index (USL)	index	Minns, Doka	3	4	5
Upper SL River	Fish	Largemouth Bass - YOY recruitment index (USL)	index	Minns, Doka	3	4	4
Upper SL River	Fish	Northern Pike - YOY net productivity (USL - Thousand Islands)	grams (wet wt.)/ha	Farrell	2	4	5
Upper SL River	Birds	Virginia Rail (RALI) - Median reproductive index (Lake St. Lawrence)	index	DesGranges, Ingram, Drolet	3	3	5
Upper SL River	Mammals	Muskrat (ONZI) - House density in drowned river-mouth wetlands (Thousand Islands area)	#/ha	Farrell, Toner	4	4	5

Table A-2: *Lower St. Lawrence River Environmental Performance Indicators*

Region	PI Group	PI Description	PI Metrics	Researchers	Significance	Certainty	Sensitivity
Lower SL River	Fish	Golden Shiner (NOCR) - Suitable feeding habitat surface area (Lac St. Louis to Trois-Rivières)	ha	Mingelbier, Morin	4	4	5
Lower SL River	Fish	Wetlands Fish - Abundance index (Lower St. Lawrence)	index	de Lafontaine, Marchand	2	4	5
Lower SL River	Fish	Northern Pike (ESLU) - Suitable reproductive habitat surface area (Lac St. Louis to Trois-Rivières)	ha	Mingelbier, Morin	3	4	5
Lower SL River	Birds	Migratory Wildfowl - Floodplain habitat surface area (Lac St. Louis to Trois-Rivières)	ha	Lehoux, Dauphin, Champoux, Morin	3	4	5
Lower SL River	Birds	Virginia Rail (RALI) - Reproductive index (Lac St. Louis to Trois-Rivières)	index	DesGranges, Ingram, Drolet	4	4	5
Lower SL River	Birds	Migratory Wildfowl - Productivity (Lac St. Louis to Trois-Rivières)	# of juveniles	Lehoux	3	4	5
Lower SL River	Birds	Black Tern (CHNI) - Reproductive index (Lac St. Louis to Trois-Rivières)	index	DesGranges, Ingram, Drolet	5	4	5
Lower SL River	Herptiles	Frog sp. - Reproductive habitat surface area (Lac St. Louis to Trois-Rivières)	ha	Armellin, Champoux, Morin, Rioux	3	2	5
Lower SL River	Mammals	Muskrat (ONZI) - Surviving houses (Lac St. Louis to Trois-Rivières)	# of houses	Ouellet, Morin	4	2	5
Lower SL River	Species at risk (bird)	Least Bittern (IXEX) - Reproductive index (Lac St. Louis to Trois-Rivières)	index	DesGranges, Ingram, Drolet	5	2	5
Lower SL River	Species at risk (bird)	Eastern Sand Darter (AMPE) - Reproductive habitat surface area (Lac St. Louis to Trois-Rivières)	ha	Giguère, Laporte, Morin	4	1	5
Lower SL River	Species at risk (herptile)	Spiny Softshell Turtle (APSP) - Reproductive habitat surface area (Lac St. Louis to Trois-Rivières)	ha	Giguère, Laporte, Morin	4	2	5
Lower SL River	Species at risk	Bridle Shiner (NOBI) - Reproductive habitat surface area (Lac St. Louis to Trois-Rivières)	ha	Giguère, Laporte, Morin	4	2	5

At the request of the Study Board, the Environmental Technical Work Group also provided error bounds around these ratios so the Study Board could clearly determine which plans were having a significant impact on a specific performance indicator. The Work Group identified a 10% error bound around performance indicators, with the exception of the fish indicators, which were assigned an error bound of 5%. The lower St. Lawrence River performance indicators were assigned a 10% error bound. For consistency, the Study Board used a standard 10% error bound on all environmental performance indicators.

The Environmental Technical Work Group further assisted the Study Board by identifying a sub-group of 13 priority performance indicators which they felt should be given greater weight in the decision process because, collectively, they provide a coherent and consistent account of the impacts of a regulation plan. The priority performance indicators are listed below.

Lake Ontario and upper St. Lawrence River
- Meadow Marsh
- Black tern reproductive index
- Virginia rail reproductive index
- Muskrat house density
- Northern pike YOY
- Large-mouth bass YOY
- High Veg 24C fish guild

Lower St. Lawrence River
- Golden shiner suitable feeding habitat area
- Virginia rail reproductive index
- Migratory wildfowl productivity
- Northern pike reproductive area
- Bridle shiner reproductive habitat surface area
- Muskrat surviving houses

A further sub-group of key performance indicators was defined for the purposes of the National Academy of Science/Royal Society of Canada independent peer review. With the exception of the wetland marsh indicator, each of the remaining performance indicators in the list is a species at risk. These indicators were chosen for review because they appeared to represent the greatest potential for conflict with indicators from other technical work groups, in terms of development of a regulation plan. The indicators chosen for the external peer review included:

- Wetland meadow marsh area (Lake Ontario)
- Least bittern (Lake Ontario) and least bittern (lower river, Lac St. Louis to Trois-Rivières) reproductive index
- King rail (Lake Ontario) preferred breeding habitat coverage
- Yellow rail (Lake Ontario) preferred breeding habitat coverage
- Black tern (Lake Ontario) reproductive index
- Spiny softshell turtle (Lac St. Louis to Trois-Rivières) reproductive habitat surface area
- Bridle shiner (Lac St. Pierre) reproductive habitat surface area
- Eastern sand darter (Lac St. Louis to Trois-Rivières) reproductive habitat surface area

Finally, the Environmental Technical Work Group was asked by the Study Board to provide an overall environmental index. While the Work Group cautioned the Study Board against using such an index for plan ranking since too much underlying information is lost, an overall environmental index was developed by Limno-Tech. This index did prove helpful to the Study Board when used in concert with the 32 key performance indicators because it gave a relative score among plans that was not always obvious when all 32 performance indicators were considered.

The overall environmental index was developed based on a weighting scheme that assigns weighting factors to 1) individual performance indicators, 2) performance indicator groups within the three regions (Lake Ontario, the upper St. Lawrence River and the lower St. Lawrence River, and 3) the three regions. Based on these weighting factors, the performance indicator ratios (relative to 1958-DD) are collapsed into group weighted average ratios, region weighted average ratios, and finally an overall index. The complete weighting scheme is provided in Table A-3.

Table A-3: Weighting Scheme for Ecological Integrity Index

LOSL Region	PI Group	Key Performance Indicator	Significance Rating	Certainty Rating	PI Weight	Group Weight	Region Weight
Lake Ontario	Vegetation	Wetland Meadow Marsh Community - Total surface area, supply-based	1.00	1.00	1.00	2.00	1.00
	Fish	Low Veg 18C - Spawning habitat supply	0.11	1.00	0.11	1.00	
		High Veg 24C - Spawning habitat supply	0.72	1.00	0.72		
		Low Veg 24C - Spawning habitat supply	0.17	1.00	0.17		
		Northern Pike - YOY recruitment	1.00	1.00	1.00		
		Largemouth Bass - YOY recruitment	1.00	1.00	1.00		
	Birds	Virginia Rail (RALI) - Reproductive index	1.00	1.00	1.00	1.00	
	Species at Risk	Least Bittern (IXEX) - Reproductive index	1.00	1.00	1.00	0.75	
		Black Tern (CHNI) - Reproductive index	1.00	1.00	1.00		
		Yellow Rail (CONO) - Preferred breeding habitat coverage	0.50	0.50	0.25		
		King Rail (RAEL) - Preferred breeding habitat coverage	0.50	0.50	0.25		
Upper St. Lawrence River	Fish	Low Veg 18C - Spawning habitat supply	0.11	1.00	0.11	1.00	0.50
		High Veg 24C - Spawning habitat supply	0.72	1.00	0.72		
		Low Veg 24C - Spawning habitat supply	0.17	1.00	0.17		
		Northern Pike - YOY recruitment	1.00	1.00	1.00		
		Largemouth Bass - YOY recruitment	1.00	1.00	1.00		
		Northern Pike - YOY net productivity (Thousand Islands)	0.50	1.00	0.50		
	Birds	Virginia Rail (RALI) - Reproductive index (Lake St. Lawrence)	1.00	1.00	1.00	0.50	
	Mammals	Muskrat (ONZI) - House density in drowned river-mouth wetlands (Thousand Islands)	1.00	1.00	1.00	1.00	
Lower St. Lawrence River	Fish	Golden Shiner (NOCR) - Suitable feeding habitat surface area	1.00	1.00	1.00	1.00	1.00
		Wetlands Fish - Abundance index	1.00	1.00	1.00		
		Northern Pike (ESLU) - Suitable reproductive habitat surface area	1.00	1.00	1.00		
	Birds	Migratory Wildfowl - Floodplain habitat surface area	1.00	1.00	1.00	1.00	
		Virginia Rail (RALI) - Reproductive index	1.00	1.00	1.00		
		Migratory Wildfowl - Productivity	1.00	1.00	1.00		
		Black Tern (CHNI) - Reproductive index	1.00	1.00	1.00		
	Herptiles	Frog sp. - Reproductive habitat surface area	1.00	0.50	0.50	1.00	
	Mammals	Muskrat (ONZI) - Surviving houses	1.00	0.50	0.50	1.00	
	Species at Risk	Least Bittern (IXEX) - Reproductive index	1.00	1.00	1.00	0.75	
		Eastern Sand Darter (AMPE) - Reproductive habitat surface area	1.00	1.00	1.00		
		Spiny Softshell Turtle (APSP) - Reproductive habitat surface area	1.00	1.00	1.00		
		Bridle Shiner (NOBI) - Reproductive habitat surface area	1.00	1.00	1.00		

It is important to note that while the overall environmental index provides an overview of the key performance indicator results, the index alone should not be considered sufficient to evaluate and rank plans; if it is used by itself, important differences between regulation plans (e.g., number and magnitude of ecological losses relative to 1958-DD) will be obscured. Therefore, it is important to always evaluate the individual key performance indicator ratios in addition to the overall environmental index.

Analysis and Findings

Water levels and flow are the major factors determining the species composition, productivity and distribution of wetlands (swamps, meadows, marsh, submerged vegetation) and other aquatic habitats (rapids, open water) in Lake Ontario and the St. Lawrence River. In Lake Ontario, reduction of the amplitude of water level variations was shown to have major effects on wetland habitats. At the upper elevations, colonization of wet meadows by shrubs was shown to result from the reduction of high level episodes. Conversely, the reduction of low-level episodes coincided with the dominance of cattails in lower marshes. These changes result in a reduction of wetland habitat diversity and surface area.

In the St. Lawrence River, the surface area of wetlands has varied widely over the past 60-year series, mostly as a result of periods of high (1970-1980) and low (1960, late 1990s) water supplies to the watershed. Invasive species propagation and dense, closed wetland cover dominated by cattail have been favoured by recent extreme low-level episodes (1995, 1999, 2001).

In Lake Ontario as well as the St. Lawrence River, wetlands provide essential habitats over the entire life cycle of aquatic animals, which use these areas for breeding, feeding and as shelters from predators. Among the wide variety of micro-organisms, semi-aquatic and aquatic animals using wetlands, the Environmental Technical Work Group identified performance indicators for several fish, wildfowl, songbirds, amphibians, reptiles and one mammal species. For all these species, the surface area of breeding and/or feeding habitat was modeled as a function of water level variations, since the availability of these habitats is positively linked to the reproductive success of and support capacity for animal populations.

Current muskrat population levels in the upper St. Lawrence River are extremely low, so any improvement tends to create large positive ratios. Muskrats constitute a very important part of both wetland structure and function and therefore represent much more than just their own species. They can influence vegetation species richness in wetlands, offer suitable substrate for seed germination, help facilitate decomposition processes, provide nesting sites for birds and turtles including some species at risk, and create microtopography in wetlands. Many bird, mammal, plant, and likely fish species (e.g., northern pike) respond favourably to the increases in open water and edge and channel effects created as a result of muskrat disturbance.

The presence/absence and annual density of active muskrat houses were used to estimate house density in order to represent the performance of muskrats. Fall and winter bring the most challenging conditions for muskrat populations, and winter flooding of muskrat houses can be very damaging.

Many of the wetland birds, such as black tern, least bittern and Virginia rail, represent an index of reproductive potential in emergent marsh during the breeding season, based on carrying capacity (an annual estimate of the number of potential breeding pairs in emergent marsh). Therefore, if the emergent marsh is doing well, these species generally also do well. These species were sensitive to water level changes on Lake Ontario brought about by regulation.

In the St. Lawrence River, high spring levels and access to the floodplain were shown to benefit wildfowl productivity, pike reproduction and managed marshes. Later in the season, short-term rises in levels resulted in losses due to flooding of shorebird nests. Successful nesting of turtles requires the availability of beaches and suitable soft, dry substrate near the water. River flow was also shown to influence the composition of river fish assemblages and the timing of fish migration between the lower river and the Estuary.

In the lower St. Lawrence River, wetland habitats and faunal species showed a strong response to the large interannual variations of water levels resulting from differences in water supply to the basin (1960-2001). However, in contrast to the situation in Lake Ontario, the sensitivity of individual performance indicators to different regulation plans in the lower river was small. The lesser sensitivity of performance indicators in the lower St. Lawrence River results from a combination of different factors:

1. Hydrological series used to simulate the effects of each regulation plan assume that the current state of infrastructures (shape and depth of the navigation channel, underwater structures, dams, river profile) and the current ice management regime do not vary over the entire time series, potentially underestimating the variance due to cumulative effects. Ecosystems are subjected to the cumulative impacts of all modifications to levels and flows, in terms of which, regulation plays a small, albeit significant, role.
2. Downstream of Montreal, the discharge from the Ottawa River and from other largely unregulated tributaries increases total discharge and induces additional variability (seasonal and event-related), which masks the signal from Lake Ontario outflow to some extent. The direct effect of Lake Ontario regulation becomes less evident as one moves downstream, as in the case of Lake Saint-Pierre, for which a number of performance indicators were developed.

Integration into the Shared Vision Model

The Environmental Technical Work Group worked closely with the Plan Formulation Technical Work Group in the development of the IERM to ensure that the IERM could be linked directly with the Shared Vision Model in its application. The hydraulic algorithms in the IERM were constructed to duplicate the hydraulic results generated by the SVM. Therefore, it was possible to verify the IERM hydraulic computations by directly comparing the results with the quarter-monthly water level and flow predictions generated by the SVM framework. When possible, verification of performance indicator results was conducted by developing detailed spreadsheet calculations that were intended to reproduce the IERM output for a given performance indicator. For some of the more complex sub-models, it was necessary to develop simplified spreadsheet calculations that could adequately reproduce the relative performance indicator response when two regulation plans were compared. Verification of the IERM sub-models was also achieved through an iterative process in which individual Environmental Technical Work Group researchers reviewed model results and provided feedback after each version of the IERM was released. Ultimately, a “stamp of approval” was obtained from each researcher with regard to implementation of their specific research in the IERM. For more information on the IERM and the validation process, refer to the Integrated Environmental Response Model documentation (Limno-Tech, 2005)

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A. Environmental Contextual Narrative

1. General Socio-economic Context

(a) Production value of the interest

Economic value is difficult to determine for environmental conditions, although social value may be evaluated in a qualitative sense. Replacement cost for loss of a resource (e.g., rebuilding a wetland), or possibly estimated impacts on ecotourism (including sport fishing) might be used to provide some idea of costs associated with ecosystem changes, but economic costs cannot account for impacts associated with loss of diversity or reduction in numbers of certain species, or other factors that might affect ecosystem health. Although difficult to quantify for the Lake Ontario–St. Lawrence system specifically, nationwide surveys have demonstrated strong support for a healthy and diverse environment, and the natural resources of the Great Lakes serve as a magnet for tourism in both the U.S. and Canada (NYSG 2004).

Coastal ecosystems offer diverse habitats that support a myriad of plant, fish, and wildlife species. The economy of many coastal areas is dependent on the recreational value of these habitats and the sport fishing, commercial fishing, hunting, bird-watching, swimming and hiking activities associated with them. Expenditures by large numbers of seasonal tourists on lodging, food, sporting goods, boat and vehicle rentals, gasoline, and personal items often represent the major source of income to coastal communities. The ecosystems that supply the fish, wildlife, and recreational facilities underlying that economy have been severely impacted by many human actions. Conversion of diverse wetland habitats to vast stands of cattails clearly represents one of the greatest impacts on the Lake Ontario coastal ecosystem and has been shown to be a direct response to water-level regulation.

Societal value is also expressed through laws protecting habitat (i.e., wetlands) and specific faunal species (special interest or endangered species). The ETWG assessment of the ecosystem response to alternative plans is built on an evaluation of key indicators of overall ecosystem diversity, productivity, and sustainability (see below).

(b) Number of stakeholders

Potential stakeholders include the over seven million people living in the Lake Ontario basin, as well as the more than four million living in the Montreal – Quebec City areas. In addition, there is a large sport fishing industry that attracts people from outside the area.

(c) Organizational characteristics

Stakeholders are relatively unevenly distributed around the shorelines of the Lake and River, with several large population centres (Toronto, Montreal, Rochester) and a number of smaller communities. For example, the majority of the Canadian population (about 60%) is concentrated in a narrow belt that represents 2.2% of the total land between Windsor, Ontario and Quebec City. The population density in 1996 along the Canadian portion of the lower St. Lawrence River ranges from 10 persons per square kilometre in the most natural areas to more than 3,800 persons square kilometre in the major cities (Toronto and Montreal). Much of the area bordering the water is low-density residential, agricultural or natural preserve. In addition to several government agencies and departments (e.g., Department of Environmental Conservation, Environmental Protection Agency, Environment Canada), a number of environmentally oriented groups are active in the area, including The Nature Conservancy, Ducks Unlimited, Trout Unlimited, Nature Conservancy of Canada, ZPI (Zones of Primary Intervention), Quebec Society for Wetland Conservation, Quebec Wildlife Federation, Save the River, the Thousand Islands Land Trust and other land trusts in the coastal zone of both countries, Federation of Ontario Naturalists, the charter boat sport fishing industry, and the Audubon Society. The Mohawk/St. Regis tribes also constitute a significant interest group on the upper St. Lawrence River.

(d) Values and perceptions of the interest

Environmental value is associated with shoreline properties, accessible and usable beaches, attractive wetlands, and the fauna they support. The economic importance of many fish, wildfowl and fur-bearing animals has long been recorded and is still important. However, the perception of 'environment' is variable depending on one's ties to the watershed (i.e., by membership in naturalist groups, as an avid angler, commercial fisher or boater, as one who reads about nature, etc.). First Nation and tribal peoples have historical or traditional values and perceptions about the environment that transcend economic value, although this is not to say that they do not benefit economically from the environment, since they fish in the St. Lawrence River, Lake St. Francis and Lake Ontario.

Attaching an economic value to the maintenance of one's values or perceptions of the watershed is, therefore, a difficult task. The concept of value holds, but obviously values vary, for both U.S. and Canadian citizens, as well as Aboriginal peoples.

(e) Significant statutory, regulatory and policy restrictions

There are 84 species of plants and animals in the Lake Ontario/upper St. Lawrence coastal zone that are sensitive to water level fluctuations and are being tracked as species of concern by the Natural Heritage Program in New York and the Natural Heritage Information Centre in Ontario. Thirty of these species are officially designated by state, provincial, or federal authority as threatened or endangered. In the U.S., the barrier beach ecosystem of eastern Lake Ontario has been designated by the U.S. Fish and Wildlife Service as critical recovery habitat for the endangered piping plover (*Charadrius melodus*). In the lower St. Lawrence River (Quebec section), there are 13 special concern, vulnerable, threatened and/or endangered species impacted by water level regulation (according to the Centre de Données sur le Patrimoine Naturel du Québec - CDPNQ) that are protected under federal or provincial laws: the *Species at Risk Act* (Bill C-5) at the federal level, and the Loi sur les espèces menacées et vulnérables and the Loi sur la conservation et la mise en valeur de la faune at the provincial level. Laws and regulations protecting special interest species are likely to change over time, and any actions that might affect these species must be evaluated within those laws. In addition, species such as the muskrat have special significance to certain segments of the population and have taken on special importance even though specific laws protecting them are limited to harvesting seasons. It should be noted that the IJC is not obligated to follow or abide by the laws and regulations that protect species; however, it is probably in the Commission's best interest to consider them and the impacts on species-at-risk when choosing a water level regulation plan.

Regulations protecting species or even simply the passage of fish (see section 35 of Canada's *Fisheries Act*) may influence watershed management, as well as court decisions relating to Aboriginal treaty rights and jurisdiction or territory.

(f) History of the interest

Much information is available on this subject, some alluded to in responses to other questions here, but it is impractical to cover such a history in this document.

(g) Trade flows and current market conditions (This is not relevant to ETWG.)

(h) Effect of last high or low water conditions

These high and low water conditions represent natural events and are important factors in maintaining wetland and biological diversity over the long term (Wilcox 1989, 1990, 1993; Wilcox et al. 1992, 1993; Wilcox and Meeker 1995).

Intensive plant community surveys within coastal wetlands representative of the Study area confirm previous conclusions that the distribution of plant communities in Lake Ontario–upper St. Lawrence River coastal wetlands is highly correlated with water-level history (Wilcox et al., 1992). The wetland plant community type observed at specific elevations was consistent among sites within and across the wetland geomorphic types. Analyses of historical aerial photographs also confirm that plant communities have responded to interannual water-level cycles, with communities shifting up- and down-slope, based upon hydrologic preferences, during high and low water-level cycles, respectively.

2. Performance Indicators

A table of "key" performance indicators (PIs), as well as their significance, uncertainty and sensitivity (to water level and flow regulation), is presented earlier in the Environment Technical Work Group Summary. This list has been distilled from an original list of over 400 proposed PIs. The process of reducing the larger list to the key PI list involved eliminating certain PIs that were determined to be either too uncertain or to be insensitive to water level variations, and grouping PIs that behaved similarly in response to water level. Thus, one key PI may in fact represent the response of many other PIs from the original list. The importance of a particular key PI in the final evaluation will depend in part on the number of other PIs it is representing. In general, the wetland vegetation PI is most closely linked to water levels and there is strong substantiation for it based on study design. Other key PIs are also directly sensitive to water levels or flows, or are linked to water levels through habitat responses correlated with the wetland PI. The high sensitivity indices in the table should be noted as an indication of the relative role played by water levels and flows in controlling these PI responses.

3. Potentially Significant Benefit Categories Not Addressed by the Current Performance Indicators (Secondary Impacts)

Secondary impacts on ecotourism, including such activities as bird-watching, fishing and hunting, are not directly incorporated in the current PIs (also see response to 1a above).

4. Key Baseline Conditions

In terms of general ecosystem response, the main baseline condition is the pre-regulation, or "natural" state, which represents the best condition for the ecosystem (see also response for #5, Key Trends). The other baseline used by ETWG for comparison purposes is the current regulation plan, which is considered a reference condition against which changes in PIs for alternative plans are to be evaluated. The main goal of the ETWG is to establish a regulation plan that improves ecosystem response, relative to the current plan, and at worst causes no degradation of environmental response. The main tool used to assess different plans within the ETWG is the Integrated Ecological Response Model (IERM), which is designed to facilitate comparisons among plans.

5. Key Trends

Possible changes in temperature and/or climate in general, and water supply specifically, would affect the environmental response. In addition, issues such as invasive species, changes in fisheries management, pollution and population changes (in numbers and/or distribution), or changes in use of the resource may also impact the environment. Thirty-year cycles in water levels, embedded within 150-year cycles, have been documented for Lake Michigan by Baedke and Thompson (2000), and 15-30 year cycles can be seen in the hydrographs for all the lakes, including Lake Ontario prior to regulation. Thus, the baseline condition is not static; rather, it is controlled by the natural cycles of variation. If "baseline" is taken to mean pre-project conditions, then it should be recognized that Plan 58-D was implemented at a time of low supplies, which then rose over the following three decades to historical highs. These natural variations in supply are difficult to predict, though they obviously have an impact on the environmental response. It might also be noted that various climate change scenarios predict generally drier conditions, with corresponding lower supplies. The IERM is not designed as a full ecosystem response model since it does not take into account the above issues, which certainly affect the ecology of the system. In keeping with the constraints of the present study, the IERM (and the PIs defined by ETWG researchers) focuses on those changes in the ecosystem that are related to water level and flow variations.

6. Expected Consequences of Changes of Regulation

The worst consequence would be the elimination of a species, particularly one that might be endangered or of special interest. In Canada there is a "no net loss" principal for wetlands (and fish habitat in general), so any deliberate change in water regulation would have to consider possible mitigation actions, such as wetland or shoreline habitat restoration. In general, changes in water regulation are expected to have an impact on distribution and abundance of different wetland types, thus affecting habitat suitability and eventually the populations of different indicator species.

Study results indicate that moderation of water-level fluctuations under water regulation has significantly restricted the long-term hydrologic environment important to the maintenance of coastal wetland meadow marsh communities. Moderation of long-term water-level fluctuations has also created hydrologic conditions that have supported the expansion of aggressive, dominant emergent and submergent plant species, resulting in a reduction of plant species richness and emergent marsh habitat quality. It is likely that the reduction in habitat quality has also been influenced and magnified in wetlands that have been impacted by increased nutrient and sediment inputs attributable to surrounding land uses. However, intensive surveys and historical aerial photo evaluations provide very similar results across all of the study sites, including sites with largely natural (forested) watersheds. The consistency in study results supports the conclusion that water-level moderation through water regulation is having a major impact on coastal wetland habitat quality.

7. Adaptive Behaviours

"Adaptive Behaviours," as defined here, are not relevant for ETWG, since it is the ecosystem that will change in response to changes in water levels and flows. Such behavior is already incorporated in PI responses in the IERM.

8. Risk Assessment/Sensitivity Analysis

Information serving as the basis for the IERM and SVM algorithms used to assess the environmental response to hydrologic change has been gathered largely through field studies and literature reviews. The field studies have a duration of two or three years at most, although several studies were designed to evaluate the response to lake-level changes dating from pre-regulation, and there is uncertainty associated with extrapolating the environmental response to a 50- or 100-year hydrologic sequence. In addition, the environmental response is sensitive to longer-term sequences in the hydrologic record (i.e., not just what is happening in one particular year or season), and those types of relationships are more difficult to incorporate in the SVM framework. As previously mentioned, the current evaluation framework does not account for factors external to the study (e.g., changes in water quality, global warming, invasive species, land use, fisheries management practices, etc.) that might impact the environment. Recognizing that uncertainty about outcomes is a constant feature of the management of complex and dynamic ecosystems such as Lake Ontario/St. Lawrence, and also that the mathematical relationships used by the IERM and SVM to predict outcomes are hypotheses based on a limited period (several years) of research, it has been proposed that a new management plan be adaptive in its implementation. Such an adaptive management approach brings a systematic process that involves learning from the outcomes of operational actions to continually improve management—for all the interests.

Extensive evaluations of sensitivity of PIs to water level and flow regulation have been carried out, and results are summarized in the key PI table above. As previously noted, one of the criteria used to determine the key PI list was sensitivity, and, although many of the initially defined PIs were not as sensitive, all the key PIs have a sensitivity ranking of 4 or 5 (on a 5 point scale). Details of these rankings may be found in the individual PI descriptions included in the IERM documentation (Limno Tech Inc., 2005).

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10. Review Process

Author: Joe Atkinson
Reviewed by: Jeff Watson
Received TWG support: Not reviewed
External review: N/A

B. Recreational Boating and Tourism Technical Work Group Summary

Objectives

The Recreational Boating and Tourism Technical Work Group was charged with developing: (1) a general assessment of the impact of recreational boating on the study area, (2) performance indicators that would show the effects of changing water levels on recreational boating and tourism interests, and (3) ideal criteria for water levels that would best meet the needs of recreational boaters and associated businesses.

Data Collection and Evaluation Methodology

A three-pronged approach was developed, with each approach involving a different group and a different method of assessing the impacts of water level changes. The members of the first group, recreational boaters, were surveyed by phone to determine their use of Lake Ontario and the St. Lawrence River, then by mail for specific information about expenditures and the impacts of high and low water levels on their use of the area. Those in the second group, marina and yacht club owners, were contacted in person and by phone to assess the impacts of fluctuating water levels and to obtain physical measurements of depths at slips and boat launching facilities. The third group, charter and tour boat operators, was surveyed by mail and phone to assess the impacts of fluctuating water levels on such businesses. All data was collected in 2002 and 2003.

For recreational boaters, a sample of 10,382 U.S. boat owners was drawn from boats registered in the eight counties bordering Lake Ontario and the St. Lawrence River, using only boats in the "pleasure boat" category with non-commercial addresses. The sample was stratified by boat length and by geographic region. Boaters were contacted by telephone to determine if they had boated on Lake Ontario or the St. Lawrence River in 2002. If they had, they were sent a mail questionnaire asking them more detailed questions about their boating experiences and expenditures.

In Canada, a list of registered boats was not available. Therefore, a telephone survey of the general population living in the study area was conducted to determine the number of boaters using study waters in 2002. However, not enough boaters could be obtained by this method to permit a more detailed mail survey. Instead, a mail survey was sent to Canadian Power Squadron members living in the study area to obtain the more detailed information about boating experiences and expenditures. The questionnaire was the same as the one used in the U.S. However, this group was considered representative not of all Canadian boaters, but of only those using marinas and yacht clubs. To estimate performance indicators for boat launch ramp users and private dock owners, ratios developed from U.S. data (e.g., days boated by marina users/days boated by launch ramp users) were applied to the Canadian power squadron data.

In the case of marina and yacht club owners, an inventory of all marinas, yacht clubs, and state/provincial or privately run boat launch ramps was conducted during the summer of 2002. In personal interviews conducted by field staff, services provided at each marina and yacht club were inventoried. Operators were asked about impacts to their business from both high and low water conditions, the cost of those actions taken to mitigate, and whether any revenue was lost. Depth measurements were taken at selected slips and launching facilities and used to determine the point at which the slip or launch ramp could not be used and thus when benefits would be lost.

In the case of charter and tour boat operators, a survey of charter boat captains was conducted in January and February of 2003 on the U.S. side, while Canada conducted a tour boat and excursion craft operator survey. The questionnaires surveyed business characteristics, economics, trips taken and educational information needs, and included specific questions about launching sites, problems with low or high water conditions and the costs associated with adaptations made in response to changing water levels.

Depth measurements taken at marinas, private docks, and boat launch ramps were standardized to the gauges within their respective reaches. For the Lake Ontario Reach, which includes the Lake itself and the portion of the St. Lawrence River up to and including Cape Vincent, the standardizing gauge was the one closest to the measurement location. The remainder of the upper St. Lawrence River was divided into three reaches associated with the water level gauge measurements at Alexandria Bay, Ogdensburg and Long Sault. The three reaches on the lower St. Lawrence River were referenced to the following water level gauges: Pointe Claire for Lac St. Louis, Sorel for Lac St. Pierre, and Varennes for Montreal-Contrecoeur.

Originally there were only two reaches for the upper St. Lawrence River. However, it was realized that the slope of the upper St. Lawrence River and the impact of releases from Moses-Saunders Dam on water levels just above the dam were too great to base levels on just two river gauges. As a result, the old Ogdensburg reach that had stretched from Chippewa Bay to the dam was split into two reaches: a New Ogdensburg reach–Chippewa Bay to Iroquois Dam and a new Lake St. Lawrence Reach–Iroquois Dam to Moses Saunders Dam. Figure B-1 shows the seven reaches in the study area.

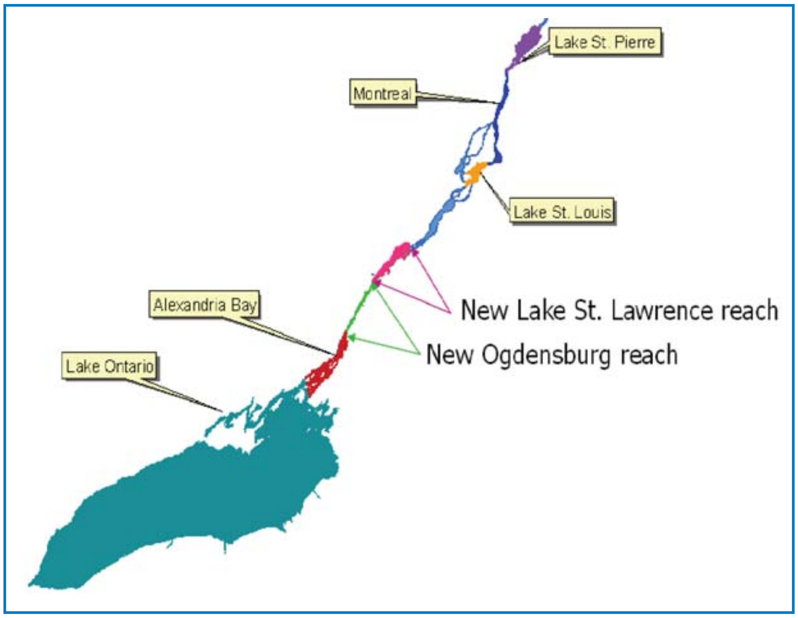

Figure B-1: ***Recreational boating reaches***

Performance Indicators

The Recreational Boating Technical Work Group focused on two performance indicators: total possible boating days lost and net economic value lost (willingness-to-pay). These measures provide an estimate of both recreational loss and economic loss as water levels change. The economic measure was chosen by the economic advisors to the Study Board to be most comparable to measures used by other technical work groups, and was used by the Study Board when comparing impacts among different interest groups. The Recreational Boating Work Group developed estimates of days boated and net economic value by water reach, country (U.S. or Canada), water access method (private dock, marina, launch ramp, charter boat), boat type (sail or power), and boat length class. Net economic value was estimated based on boat owners' willingness-to-pay for boating over and above what they are already paying. Net economic value was calculated on a per-day basis. The average value was multiplied by days boated per month unconstrained by water levels. The number of days unconstrained by water level was the sum of actual days boated in 2002 plus boaters' estimates of days that would have been boated if water levels were not a problem.

In addition to recreational boating, this technical work group was requested to examine "boating-related tourism" to further include the economic impact of boaters' expenditures on sub-regions of the Lake Ontario–St. Lawrence River study area, so that the total community and regional impacts of fluctuating water levels on boating could be estimated. To make these estimates of economic impact, a computerized input-output economic model called Impact Analysis and PLANning (IMPLAN) was used. This model estimates the technical relationships between the producing sectors of the economy (inputs) and the consuming sectors (outputs). However, the economic advisors to the study recommended that the tourism-related IMPLAN results not be used because they were not comparable with measures used by other interest groups. The results of the tourism analysis provided by IMPLAN are presented in the Recreational Boating and Tourism Contextual Narrative and the final report of the Technical Work Group (Connelly et al., 2005).

Baseline Economics

Based on the studies undertaken by the Recreational Boating Work Group, it is estimated that recreational boaters in the U.S. and Canada spent $429.7 million (in U.S. dollars, 2002 currency rate) on boating-related trips to Lake Ontario and the St. Lawrence River in 2002. These expenditures are exclusive of additional en route expenditures that occurred in areas that do not border the study region. Furthermore, U.S. and Canadian boaters received a net benefit or consumer surplus of approximately $278.5 million in 2002. This consumer surplus represents the difference between boaters' expressed valuation of their recreational experiences and their expenditures. Consumer surplus is a standard metric used in economics to measure the net value of recreational opportunities.

The economic baseline provides the context against which damages can be assessed. It gives an indication of the relevance of the damages to a particular interest. In essence, the economic baseline provides the denominator of the equation, allowing percent damages to be reported. The economic advisors suggested the baseline for recreational boating was net economic value as measured in 2002 (the most recent year available with plan 1958-DD in operation). The total baseline number covering Lake Ontario and the St. Lawrence River was **$278.5 million** (in 2002 U.S. dollars). Per reach, the following baselines apply:

Table B-1: Economic Baselines for Recreational Boating

	($US 2002)
Recreational Boating	**$278,450,000**
Above Dam	**$239,200,000**
Lake Ontario	$174,070,000
Alex Bay	$46,130,000
Ogdensburg	$10,450,000
Lake St. Lawrence	$8,550,000
Below Dam	**$39,250,000**
Lac St. Louis	$17,830,000
Montreal/Contrecoeur	$12,060,000
Lac St. Pierre	$9,360,000

Analysis

As discussed in the final report of the Technical Work Group, performance indicators (total possible days boated and net economic value) were linked to depth measurements at marinas and yacht clubs, boat launch ramps, and private docks to create water level–impact relationships (Connelly et al., 2005). A water level at which a boat would touch bottom (i.e., become grounded) or a depth of less than 2 ft at the end of a launch ramp was considered unusable, and all values associated with boats at such water levels were assumed lost until the water level rose again. At marinas and yacht clubs, the water level at which non-floating docks became inundated with water was also a point at which days or economic value would be considered lost until the water level dropped. We were unable to measure inundation at boat launch ramps or private docks.

U.S. and Canadian performance indicators were aggregated by reach for Lake Ontario and the upper St. Lawrence River. The lower St. Lawrence River is wholly within Canada and thus, no aggregation was required. Water level-impact relationships were developed for seven reaches. Economic indicators measured in dollars were all converted to 2002 U.S. dollar equivalents.

Figures B-2 to B-8 depict the net economic value lost (willingness-to-pay) by month on the seven reaches. Corresponding figures showing total possible boating days lost are provided in the Recreational Boating Technical Work Group Final Report (Connelly et al., 2005); Lake St. Lawrence and Ogdensburg, which had not been divided at the time the Report was finalized, are omitted. Essentially, the graphs represent a stage-damage curve for the recreational boating interest. Each line represents net economic value lost during a different month of the boating season. The graphs show that impacts of lower water levels are greater in the summer months of July and August than the early spring or fall months. Lake Ontario Reach users (Fig. B2) start to experience losses when water levels drop below 75.28 m (247 ft). Losses increase as water levels drop and the increase becomes dramatic below 74.62 m (244.8 ft). As water levels drop, economic losses increase because boats cannot launch or become grounded at their slips. Approximately $7.5 million in economic benefits would be lost if the water level were 74.37 m (244.0 ft) for the entire month of August.

Low water levels that cause significant losses of benefits affect the three boating segments somewhat differently (marina users, launch ramp users, and private dock owners). The larger boats tend to be located at marinas. Low water levels during the boating season may keep the owners of these boats from boating. If low water levels are predicted for fall, this may require marinas to haul boats out of the water early, thus shortening the boating season. Launch ramp users have more flexibility. If low water levels are a very localized problem for a given launch ramp, boaters may be able to shift to another ramp. In the case of more pervasive low water levels, launch ramp users may shift to other waters (e.g., Lake Champlain, Finger Lakes in New York). In the short term, private dock users lose boating benefits, as their boats are associated with primary residences or second home properties, and they have less flexibility to seek alternative places to boat.

For the upper St. Lawrence River - Alexandria Bay Reach, there appear to be no water levels without any impacts for boaters (Fig. B3). A few boaters experience problems with low water at the same time as other boaters are experiencing problems with high water. The least amount of impact appears to occur between 74.68 m (245 ft) and 75.35 m (247.2 ft).

The Ogdensburg and Lake St. Lawrence reaches of the upper St. Lawrence River have fewer boaters than the other sections and consequently, estimated impacts are smaller. Impacts on the Ogdensburg Reach (Fig. B4) appear to be minimal above 74.19 m (243.4 ft). Impacts due to high water levels are quite small compared with low water impacts below 73.91 m (242.5 ft). On the Lake St. Lawrence Reach (Fig. B5), sharp thresholds appear to occur at 72.76 m (238.7 ft) on the low end, due to the loss of boat launch ramps, and 74.22 m (243.5 ft) on the high end, with a fairly broad tolerance range of about 1.5 m (5 ft) in between.

The range of acceptable water levels appears to be quite large for all lower St. Lawrence River boaters (figs. B6 through B8). A possible acceptable range for the Lac St. Louis Reach is 21 m (68.9 ft) to 22.5 m (73.8 ft) (Fig. B6). For the Montreal-Contrecoeur Reach, a rather large range exists from 6 m (19.69 ft) to almost 10 m (32.81 ft) (Fig. B7). The range for Lac St. Pierre is the narrowest, at approximately 4.25 m (13.9 ft) to 5.25 m (17.2 ft) (Fig. B8).

Integration into the Shared Vision Model

The water level-impact relationship curves for the seven reaches were translated into impact tables using increasing water depths, at increments of one centimetre, and those impact columns were pasted into graphical converters in the STELLA portion of the Shared Vision Model and used in evaluating the historical economic benefits of alternative regulation plans relative to plan 1958-DD. The STELLA impact curves were also copied into Excel spreadsheets as stage-damage curves which could be used with stage frequency tables from the stochastic modeling results to calculate average annual impacts over 49,995 years. Completing the circle, these same “stochastic” tables were compared line by line with the original impact tables provided by the Recreational Boating Technical Work Group to earn the “stamp of approval” signifying that the Shared Vision Model had faithfully captured the research results.

Summary of Key Findings

Based on its work, the Technical Work Group estimated that recreational boaters in the U.S. and Canada spent $429.7 million on boating-related trips taken on Lake Ontario and the St. Lawrence River in 2002. These expenditures are exclusive of additional en route expenditures that occurred in areas that do not border the study region. U.S. and Canadian boaters received a net benefit or consumer surplus of approximately $278.5 million in 2002.

Based on comparisons with a 2003 New York Sea Grant-funded state-wide survey of boating in New York, U.S. study estimates of boating use and net benefits on the Lake and River are likely underestimated by as much as 36% (Connelly et al., 2004).

On the Canadian side, researchers were unable to obtain good depth measurements at boat launch ramps on Lake Ontario or the upper St. Lawrence River. Therefore, losses in net economic value for boaters in those areas are not included in the stage damage curves calculated for those reaches. Thus, the curves presented are conservative estimates.

Stage damage curves for low water levels may be conservative for two reasons: (1) some boaters will not want to risk damage to their boat or propeller without some safety margin (no safety margin was assumed), and (2) many marinas are located on inlets in situations where siltation occurs in the channel leading to the marina slips, and in some cases the depth at the slip is not the most shallow depth the boater faces in getting out to open water.

Of the $178 million in total expenditures on the U.S. side, US$68 million resulted from tourist-related spending (from boaters residing outside four groupings of counties along the New York border of these waters). After consideration of indirect effects, this tourist-related spending resulted in a total output of $96 million and 1,380 full-time equivalent jobs (Connelly et al., 2005). Based on a Canadian national survey, each dollar spent (direct expenses, net import) added another $1.50 through indirect and induced expenditures. Tourism activity was not measured in Canada, but the Toronto and Montreal areas generate substantial economic activity linked with commercial boating (e.g. tour boats). Based on the regional economic impact analysis completed on the U.S. side using IMPLAN, about two-thirds of the combination of indirect and induced employment impacts occurred in the Jefferson-St. Lawrence County region (northeastern Lake Ontario–St. Lawrence River). This sub-region is more dependent on boating-related tourism than other U.S. sub-regions and would likely be most strongly impacted if a significant number of boater days were lost due to high or low water levels.

The Technical Work Group reviewed the performance indicators depicted in figures B2-B8 and established a range of water levels which its members thought would be acceptable for the boating constituency overall and which is logically consistent between the Lake and upper river reaches. Consideration was given to developing a range of levels that not only minimized adverse impacts to boaters but that also provided a reasonable spread in consideration of regulation plan formulation. Table B-2 shows the ideal target level by reach along with the acceptable lower and upper bounds. It should be noted that these criteria were established before the Ogdensburg reach was divided into two reaches. New criteria were not established for the new reaches, because the work group had been disbanded by that time. Thus, the Ogdensburg criteria should be ignored in Table B-2.

During the boating season, the critical period for unacceptable water levels has historically occurred from late August through mid-October. Thus, the greatest incremental gains to recreational boating would be achieved if higher water levels could be attained during the fall.

Recreational boaters can tolerate certain water level variation without major damages, but they asked to be informed whenever rapid flows or levels change.

Table B-2: Ideal Criteria for Water Levels by Reach for Recreational Boating Interests for the Boating Season 15 April through 15 October. (Chart datum is shown for reference.)*

Study Reach	Chart Datum		Ideal Level		Minimum Level		Maximum Level	
	(ft)	*(m)*	*(ft)*	*(m)*	*(ft)*	*(m)*	*(ft)*	*(m)*
Lake Ontario	243.3	74.3	246.2	75.04	244.8	74.61	247.6	75.46
Alex Bay	243.0	74.1	245.8	74.92	244.4	74.48	247.2	75.34
Ogdensburg	242.5	73.9	245.1	74.70	243.7	74.27	246.5	75.13
Lac St. Louis	66.9	20.4	70.5	21.5	68.6	20.9	74.8	22.8
Lac St. Pierre	12.5	3.8	14.8	4.5	13.9	4.25	17.1	5.2
Montreal - Contrecoeur	15.7	4.8	21.3	6.5	18.0	5.5	32.8	10.0

* It should be noted that these criteria were established before the Ogdensburg reach was divided into two reaches. New criteria were not established for the new reaches, because the work group had been disbanded by that time. Thus, the Ogdensburg criteria should be ignored in Table B-2.

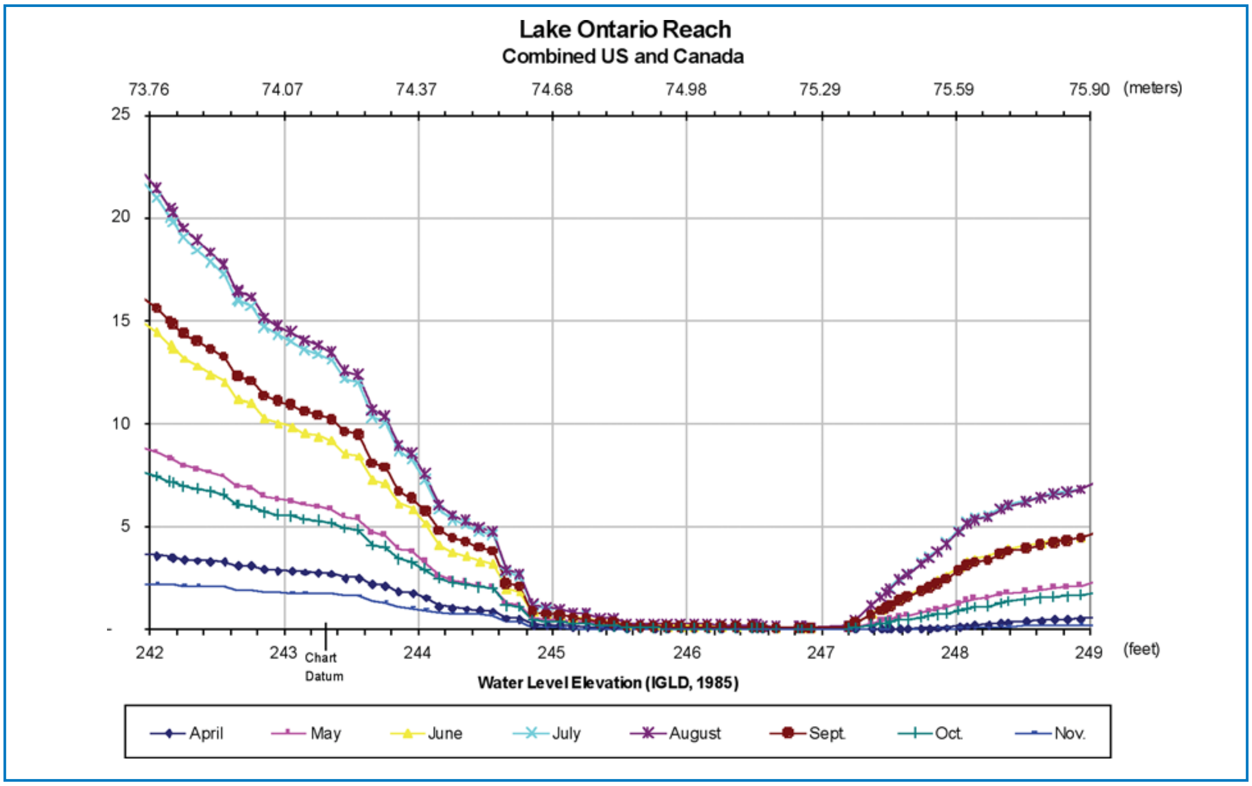

Figure B-2: Lake Ontario Reach

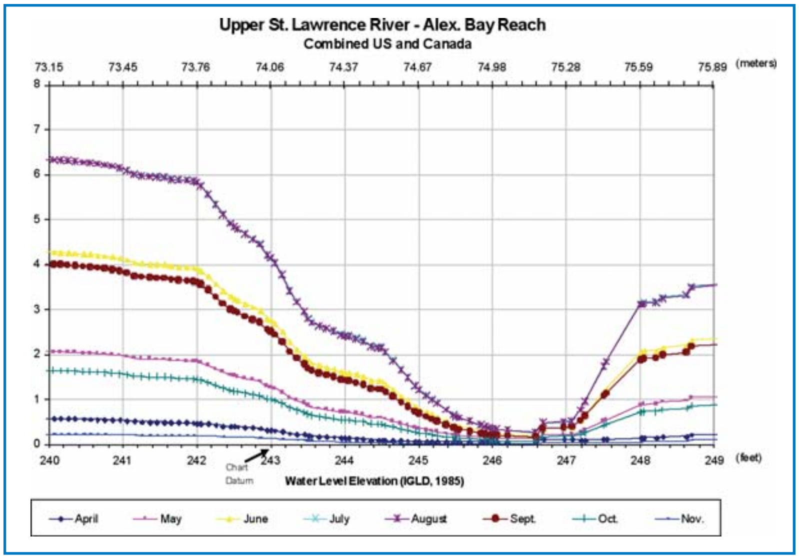

Figure B-3: Alexandria Bay Reach - Upper St. Lawrence River

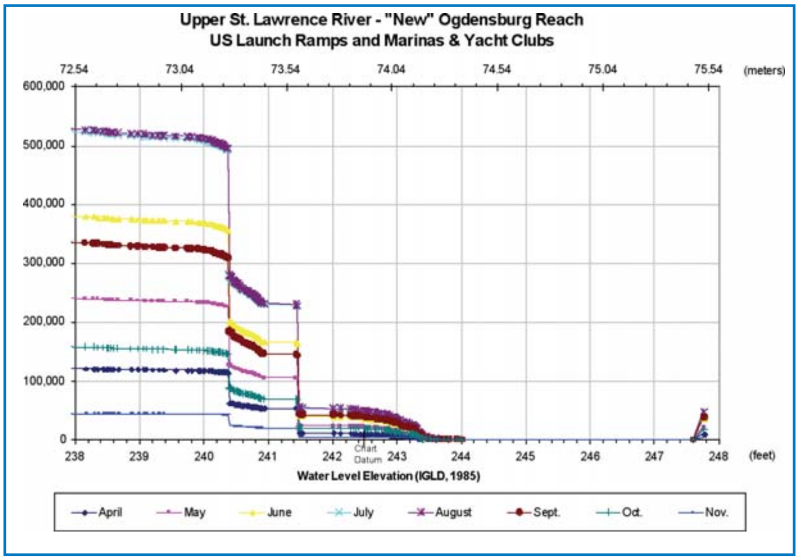

Figure B-4: Ogdensburg Reach - Upper St. Lawrence River

(Only U.S. shown here, but both countries included in SVM calculations)

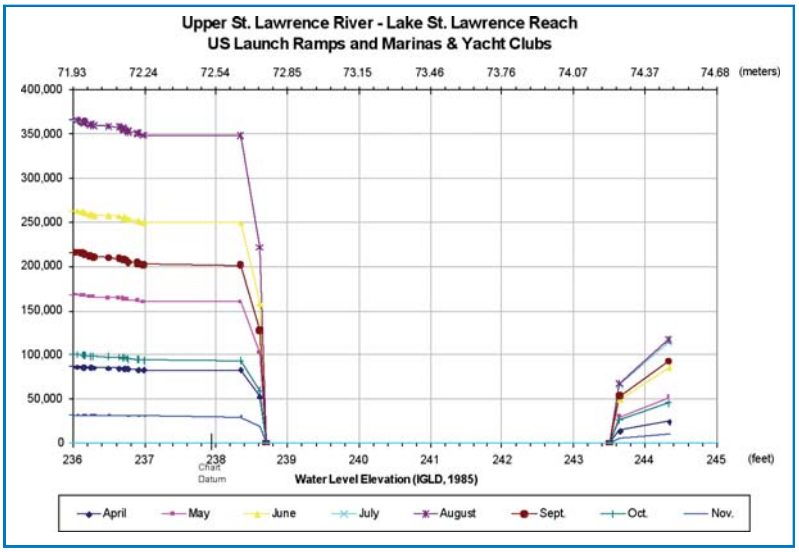

Figure B-5: Lake St. Lawrence Reach - Upper St. Lawrence River

(Only U.S. shown here, but both countries included in SVM calculations)

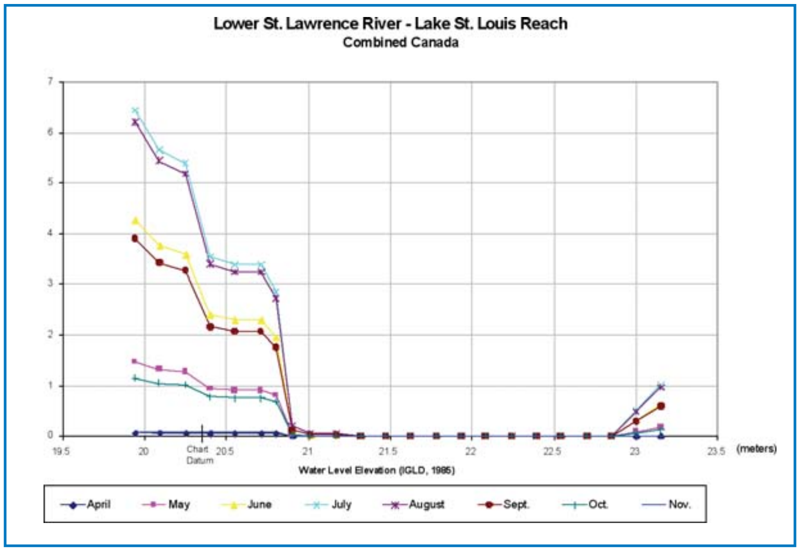

***Figure B-6:* Lac St. Louis Reach - Lower St. Lawrence River**

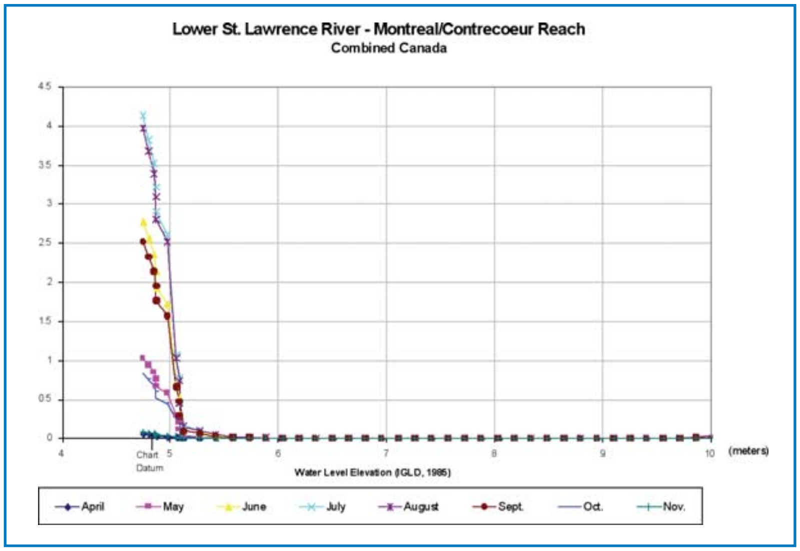

***Figure B-7:* Montreal/Contrecoeur Reach - Lower St. Lawrence River**

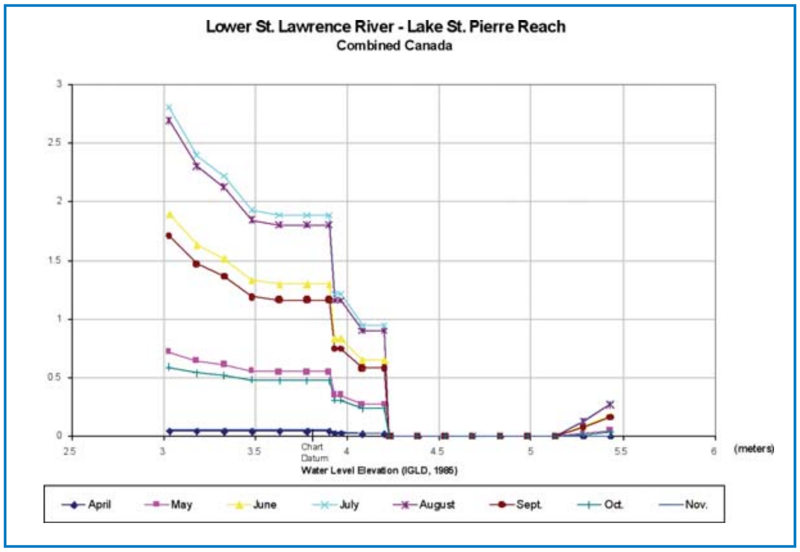

***Figure B-8:* Lake St. Pierre Reach - Lower St. Lawrence River**

Participants

Recreational Boating and Tourism Technical Work Group

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B. Recreational Boating and Tourism Contextual Narrative

1. General Socio-economic Context

(a) Production value of the interest

As a conservative estimate, recreational boaters in the U.S. and Canada spent $429.7 million on boating-related trips to Lake Ontario and the St. Lawrence River in 2002 (Connelly et al., 2005; Gardner Pinfold Consulting, 2003). These expenditures are exclusive of additional en route expenditures that occurred in areas that do not border the study region. They are also exclusive of other annual, but not trip-related expenditures made in the area ($133 million for Canadian boaters; not measured for US). U.S. and Canadian boaters received a net benefit or consumer surplus of approximately US$278.5 million in 2002.

(b) Numbers of stakeholders

Stakeholders include approximately 310,000 boaters (133,000 U.S., 177,000 CDN) and approximately 103,000 boat owners (44,000 U.S., 59,000 CDN) (Connelly et al., in review; Gardner Pinfold Consulting, 2003). Boating is very popular throughout the entire study area. Buffalo is within a few miles of western Lake Ontario and marinas located at the mouth of the Niagara River. Rochester and Toronto have large populations of boaters, some of whom boat locally, but many of whom travel east to more scenic areas along eastern Lake Ontario and the Thousand Islands where they may have summer homes, or where they can enjoy a different type of fishing (bass, muskellunge) than the salmonid fishing offered in Lake Ontario. In the lower river, a recent survey has also indicated a very large number of boat users all along the River (Duchesne et al., 2004). Additional stakeholders along the U.S. side alone include the owners of 166 marinas and yacht clubs (Connelly et al., 2002), 226 charter boat operators (Lichtkoppler and Kuehn, 2003), and a small number of tour boat operators. Also, the eight counties that border these waters have over 4,500 retail businesses (bait and sporting goods stores, gasoline service stations, restaurants and bars, lodging places, and other recreation and entertainment places) where boaters spend money (U.S. Bureau of the Census retail trade and services data). After consideration of indirect effects, tourist-related spending by boaters on the U.S. side resulted in a total output of 1,380 full-time equivalent jobs, as derived by IMPLAN analysis (Connelly et al., in review). Although comparable Canadian data are only available at the provincial level (see Goss Gilroy Inc., 2003), they are probably also very significant, considering that the riparian cities of Toronto and Montreal are the biggest cities in each province, together totalling more than eight million inhabitants.

(c) Organizational characteristics

Boaters in both the U.S. and Canada tend to be “empty nesters” (68% in the U.S.), with a mean age of about 55 and about 20 years of boating experience. They have above-average incomes as a group ($65,000 in the case of upstate New York boaters, compared with about $45,000 median household income state-wide) (Connelly et al., 2005). Average incomes of boaters in Canada are probably slightly lower (Gardner Pinfold Consulting, 2003). Although the mean income of boaters is above average, many middle income people participate in boating. Boaters on the lower St. Lawrence River often take trips of more than one day, going from the Lake to the River and vice-versa.

Marinas tend to be small businesses with low profit margins. This is in part because many marinas started as “mom-and-pop” businesses, whose owners typically do not have business degrees. Most marinas in the study area are several decades old, and at the time of construction, their owners may not have realized the extent of fluctuations in water levels over a broad time scale. Moreover, marinas can only operate in warm-weather months, and they face numerous risks peculiar to the industry (e.g., weather, quality of fishing from year to year, water levels), as well as economic conditions that affect all businesses (White, 1991; Noden and Brown, 1975). Profitable marinas tend to be larger, and in the lower river, the larger marinas are publicly owned and offer different services than the private sector (e.g., operations, maintenance) (Zins Beauchesne and Associates, 2002). Similar climatic and economic factors affect marinas and yacht clubs on both sides of the border.

Communities along New York waters vary from very rural areas (the case for the vast majority of the shoreline) to small cities (Oswego, Ogdensburg, and Massena), and finally to the metropolitan centre of Rochester. The Canadian shoreline of the St. Lawrence includes Montreal, Cornwall, and a number of villages; the Lake Ontario portion is largely rural except for Kingston and the western portion from Toronto to Hamilton. Rural communities along the shoreline are much less diversified economically and tend to have higher unemployment rates (7% to 9%, compared with 5% in Rochester based on New York state employment data), and they are much more dependent on tourism than larger urban areas. Rural portions of Lake Ontario and the Thousand Islands and Lac St. Pierre areas are heavily dependent on tourism, with harbours and locks along the River providing additional local attractions (Goss Gilroy Inc., 2003). Tourism is an important part of the economy in Toronto and Montreal as well.

(d) Values and perceptions of the interest

The primary interest and concern is in keeping water levels sufficiently high to allow boating. This is true for both marinas located in embayments along the Lake, and for marinas located on the upper and lower river. Extreme high or low water levels impact boating most strongly in July and August because that is when most boating occurs. However, assuming "normal conditions," water levels are usually only a minor problem in a few localities in the summer. Thus, the greatest incremental gains to recreational boating would occur if higher water levels could be achieved during the fall (especially during September and October). This would significantly lengthen the boating season. In Canada, the boating season is generally about a month longer on the Lake than in the lower river (Zins Beauchesne, 2002; McCullough Associates and Diane Mackie and Associates, 2002).

(e) Significant statutory, regulatory, and policy restrictions

Because of topography, lack of road access, or sensitive environmental areas (e.g., wetlands), there are few places along the shoreline of the Lake and upper river where additional marinas could be constructed. Thus, in large part, any increase in the supply of marina slips has to be accomplished through more efficient use of space at existing marinas. This has been the case for perhaps 20 years; thus, it likely would be very difficult to increase the supply of slips significantly beyond the current number. In the lower river, substantial marina expansion occurred in the 1990s and again in 2002 with the re-opening of Lachine canal (Parks Canada, 2004). Water quality has improved in the lower river with the establishment of major sewage treatment plants. If funds were available, it would be possible to enhance the recreational boating network by improving the channel connection from Lac St. Louis to Lake St. Francis. Boaters must use commercial navigation locks, and frequently encounter waits of several hours, as priority is given to commercial shipping. Lock management could be an issue in this regard, however.

(f) History of the interest

Recreational boating has been popular in this area for most of the past century, and some older marinas were established in the 19th century (e.g., St. Lawrence Yacht Club and *Club nautique de Longueuil*). Early statistics are not available but by 1971, 395,000 boats were registered in New York (Noden and Brown, 1975), compared with 504,000 today. Boating in the study area has grown by a similar rate. Marina expansion has been limited, as noted above. However, with the introduction of salmon and trout into Lake Ontario in the 1970s, thousands of people from all over the Northeast trailered their boats to the Lake. Several new boat ramps were constructed and the entryway to the Salmon River at Pulaski was improved. In the 1970s and 1980s, major dredging occurred on the Lake and at upper river marinas. Though this was not the case at lower river marinas, major connections have been reopened (e.g., the Lachine Canal) making links between the fluvial section (Varennes-Contrecoeur), Lac St. Pierre and Lac St. Louis. The St. Lawrence River, especially in the Thousand Islands area, is the location of thousands of second homes and cottages, many of which are undergoing conversion to year-round residences. Boating in conjunction with other summer activities has been a long tradition there. In addition, several state parks that provide boating access are located in the Thousand Islands area. In the lower river, the Lac St. Pierre area was recently recognized as a UNESCO Biosphere Reserve, and the Sorel-Berthier Islands area is one of the oldest rural settlements in Canada (De Koninck, 1996). The Thousand Islands area has also recently been granted Biosphere status by UNESCO.

(g) Trade flows and current market conditions

Most of the recreational boating in western and central Lake Ontario is local, although there are significant numbers of boaters from other counties (Connelly et al., 1998). In the eastern Lake Ontario Basin and the St. Lawrence River counties, most boaters are tourists. Most boating tourists come from other regions of New York State, but many salmon anglers, especially in Oswego County, come from other northeastern states (Connelly et al., 1990). Current market conditions are generally steady, but are probably not increasing significantly. Except for climate conditions, gas price is probably the main factor that could change market conditions for boaters in the short run. For Canadian tourism, the dollar exchange rate (CDN-US$) can also have a huge impact. Terrorism and safety measures at borders are an inconvenience for boaters, but have not imposed a significant constraint on tourism. At the larger urban centres, most boaters are local, while in the Thousand Islands area, boating-related tourism is much more important (e.g., more than doubling the number of boaters in summer in the Gananoque area) (Thousand Islands International Tourism Council, 2002).

(h) Effect of last high or low water conditions

We have good data from marinas concerning only very recent high and low water periods. During those periods, a few marinas incurred significant losses, but the industry-wide impact was not large. Over the years, most of the marinas on Lake Ontario have installed floating docks, which ease problems in high-water situations. In the lower river, floating docks are the norm for marinas and yacht clubs, with very few exceptions. According to Canadian Coast Guard data, in low water years such as 1999, the number of accidents in the lower river increased, while accidents in other sectors (not having water level problems) were reduced (though water is not the only factor involved) (Canadian Coast Guard, 2001). Low water accidents are usually caused by rocks which, in high water, are deep enough to pass over safely. Low water often brings new boating hazards, undiscovered by neophytes until contact is made.

2. Performance Indicators

a1. Key performance indicator: Net economic value lost by recreational boaters and charter boat patrons as water level varies from ideal levels for boating.

a2. Key assumptions: On the U.S. side, we assumed that the population of boaters from which we drew our survey sample (those whose county of principal use as listed on their boating registration bordered the study area) included all boaters who used Lake Ontario and the St. Lawrence River. This was the only population from which a cost-efficient sample could be drawn. In 2003, New York Sea Grant funded a state-wide survey of boating in New York State that allowed us to estimate the magnitude of this conservative assumption. The results of the Sea Grant study showed that 36% of Lake Ontario or St. Lawrence River boaters listed a county away from the Lake or River as their county of principal use. The Sea Grant study did not ask willingness to pay, but at-site expenditures for boaters whose county of principal use borders the study area were similar to those of other boaters. This suggests that willingness to pay would be similar for the two groups. Thus, our U.S. estimates of boating use and net benefits on the Lake and River are likely underestimated by as much as 36% (Connelly et al., 2004). It is also possible that boats registered outside New York State were launched on the Lake or River. We inquired about non-NYS registered boats in our survey of marina operators (the most likely place where out-of-state boats would be berthed) and found them to be a very small percentage [<2%] of all boats.

On the Canadian side, a telephone survey of the general population living near the Lake and River was conducted to estimate the number of boaters. The survey area extended approximately 50 miles north of the Lake and River (Gardner Pinfold Consulting, 2003). We believe the number of boaters who come from outside the area surveyed is very small because the population outside the survey area is small and many other boating sites exist outside the survey area. We were unable to get good depth measurements at boat launch ramps on Lake Ontario or the upper St. Lawrence River. Therefore, net economic value lost for these boaters is not included in the stage damage curves calculated for those reaches. The curves presented are therefore conservative estimates.

The other major assumption is that boaters in fact behave in a manner consistent with the stage damage curves shown in our results. We do not have independent data from a year of high or low water to test this assumption (although other factors also affect participation). Thus, we have to examine the assumption deductively. Regarding boater behavior during low water levels, we took depth measurements at marinas and boat launch ramps and asked private dock owners for an estimated water depth on a particular day (Labor Day of 2002). These measurements, when merged with the depth requirements of boats of various sizes, incorporated no safety margin. Stage damage curves for low water levels may therefore be conservative for two reasons: (1) some boaters will not want to risk damage to their boat or propeller without some safety margin, and (2) many marinas are located on inlets in situations where siltation occurs in the channel leading to the marina slips, and in some cases the depth at the slip is not the most shallow depth the boater faces in reaching open water. Regarding high water levels, we assumed boater days were lost when fixed docks at marinas were inundated. Although no further measurements were taken, at many marinas, boats must pass under a bridge to reach open water, and at levels where docks are inundated, larger boats cannot fit under these bridges. We assumed boaters at launch ramps and private docks could boat at any high water level—a conservative assumption, because of the cost and logistics of obtaining such data.

Related to the above is the assumption that boaters do not move to another area during times of water level problems, and thus, once water levels hit certain low or high thresholds, all boating benefits are lost. We believe this is a safe assumption for private dock owners, whose boats are in the water at their sites and are thus closely tied to those sites. We also believe it is a safe assumption for boaters who use marinas on a year-to-year basis. We are aware of some cases in which boaters using marinas were forced to find substitute sites only for hauling out their boats (Boudier and Bibeault, 2001). Most marinas and yacht clubs charge an annual slip rental, which is paid in advance, making it unlikely that boaters will have their boats hauled out and moved other marinas (which may have no slip vacancies) mid-season. Boaters who trailer their boats and use launch ramps have more flexibility and may be able to move other facilities in low-water situations. However, they may lose the boating day when they assumed they would launch their boat, and water levels may affect nearby ramp facilities similarly.

Total possible days boated used to calculate the performance indicator was the sum of days boated in 2002 plus boaters' estimates of the number of additional days they would have boated by month if water levels had been sufficient. The hypothetical nature of the estimate of additional days raises the possibility that boaters would not have gone boating on all of those days. Since they were being asked after the fact what they would have done, we can be more certain that days were constrained by water level and that the estimate of additional days is approximately accurate. The trend in boaters' estimates of additional days follows the typical water level pattern, giving further credence to their estimates, with a few days lost in spring due to high water, no days lost in summer, and more days lost in fall due to low water. The estimate of total possible days boated used in calculating the performance indicator is therefore unconstrained by water levels.

Boaters were asked in the late fall of 2002 to recall the number of days they boated Lake Ontario or the St. Lawrence River by month for 2002 to date. Two types of bias could have affected their answers. One was response bias: respondents to the survey could have been more active boaters (boating more days) than non-respondents. We found this to be the case when we compared respondents and non-respondents' answers to a screening interview question regarding days boated thus far in 2002. We accounted for this bias by reducing the estimate of total days boated by 4.7%. A second type of bias is memory recall bias. Respondents could have trouble recalling exactly how many days they had boated each month in 2002 by the fall of that year. Past research has shown a general trend toward overestimation of participation (Connelly et al., 2000). Although we tried to minimize this bias by sending out the questionnaires as soon as possible after the end of the boating season, we believe there is likely some overestimation.

We assumed no temporal substitution of boating days, i.e., that boaters facing water level problems would simply boat later in the year after these problems were alleviated. In times of frequent high water levels, this could occur to some extent in the case of resident boaters such as private dock owners. Much of the boating is tourism-related, however, and these boaters are not likely to realize until they reach their destination that water level problems exist. Thus, these trips and boater days are lost. In the case of low water conditions, the problems are exacerbated in late summer and fall, when water levels continue to decline gradually. Boating days lost at a particular time in late summer and fall have little opportunity for substitution later in the year.

There may be some exaggeration of data (e.g., boater days, expenses) for strategic reasons. Boaters were told that the information they provide would help the IJC manage water levels. However, the wording of the message in the cover letter and inside cover of the questionnaire was composed with care. Respondents were told the general purpose of the study and they were encouraged to participate, but we avoided language that suggests that recreational boating is competing against other interests or that high use and expenditure data would help recreational boating. We believe the effect of this potential bias is minimal.

b. Data limitations; fungibility of the performance indicators: Primary data limitations are covered above. Some assumptions or potential biasing elements likely cause slightly inflated estimates, while other assumptions and limitations, especially related to sampling, understate boating participation and therefore benefits. If anything, we believe that on balance, our estimates are slightly conservative. However, we do not believe the estimates seriously understate lost benefits.

The performance indicator of net benefits lost is based on willingness-to-pay data asked of boaters. This is the conceptually correct measure for comparing net benefits lost from recreational boating with net benefits lost from other sectors. Because of its hypothetical nature, this method is sometimes criticized. However, we used methods generally approved by resource economists and survey researchers to arrive at the most valid estimates possible. First, we defined and eliminated outlier estimates. Second, we asked if boaters provided an inflated estimate of willingness to pay in order to enhance the value (consumer surplus) of recreational boating. Those who responded affirmatively were assigned the mean value provided by other boaters (which was, on average, a reduced value) rather than the value they gave.

Considering various water level plans and possible ranking of those plans, we believe it is unlikely that changes in any of these assumptions would affect plan ranking for recreational boating. Changes in assumptions might affect the proportional loss for recreational boating as compared with other interests.

3. Potentially Significant Benefit Categories Not Addressed by the Current Performance Indicators (Secondary Impacts)

Of the $178 million in total expenditures on the U.S. side, $68 million resulted from tourist-related spending (by boaters residing outside four groupings of counties along the New York border of these waters). After consideration of indirect effects, this tourist-related spending resulted in a total output of $96 million and 1,380 full-time equivalent jobs (Connelly et al., in review). Based on a Canadian national survey, each dollar spent (direct expenses, net import) added another $1.50 through indirect and induced expenditures. Tourism activity was not measured in Canada, but the Toronto and Montreal areas generate substantial economic activity linked with commercial boating activities (e.g. tour boats). As an example, for 14 of 27 tour boat operators contacted, water-level-related loss of income between 1998 and 2002 was estimated at $727,000 (Gardner Pinfold Consulting, 2003).

Regional economic impact analysis was performed using IMPLAN to examine economic impacts attributable to boating in sub-regions of New York that result from new expenditures from boaters who were not residents of each sub-region. The four sub-regions, from west to east, were Niagara County (which is classified as part of the Buffalo Metropolitan Statistical Area [MSA]), Orleans-Monroe-Wayne Counties (much of the Rochester MSA), Cayuga-Oswego Counties (Oswego County is part of the Syracuse MSA), and Jefferson-St. Lawrence Counties, which are not part of an MSA.

The sales or output impacts and the employment impacts resulting from boater spending are shown in Table B-3. Over half of all tourist-related spending throughout the entire study area occurred in the Jefferson-St. Lawrence County region (northeastern Lake Ontario–St. Lawrence River), and about two-thirds of the combination of indirect and induced employment impacts occurred here. Within the U.S., this sub-region is most dependent on boating-related tourism and would likely be most strongly impacted if a significant number of boater days were lost due to high or low water levels.

The sales impact per boat day was calculated to facilitate construction of an additional water level–impact relationships and regional economic impact performance indicator. Because of (1) how the boater sample was drawn, (2) the various reaches of Lake Ontario and the St. Lawrence River, and (3) the similarity in economic impact data for central and western Lake Ontario, the three western sub-regions were merged to arrive at these estimates. As in the case of direct expenditures, aggregate sales impacts per boat day are highest (over $119 per day) in the eastern Lake Ontario–St. Lawrence River area.

Some notable points that can be derived from Table B-3, with further explanatory notes, are as follows:

1. The majority of the total economic impact (65% of sales and 59% of jobs) created from boater spending occurs in the Eastern Lake Ontario–St. Lawrence River sub-region. This region has a wealth of scenic and recreational resources, and tourism has historically been very important in this area (Connelly and Brown, 1988).
2. The overall output multipliers (Totals/Direct) are quite consistent across the four sub-regions and are only moderate in size, ranging from 1.37 for Cayuga-Oswego to 1.49 for Orleans-Monroe-Wayne.

Table B-3: Output and Employment Estimates from Spending by Recreational Boaters on the New York Portion of Lake Ontario and the St. Lawrence River in 2002, by Coastal Region

Coastal Impact Area	*Direct*	*Indirect*	*Induced*	*Totals*
Aggregate Sales Impacts (000s of U.S. dollars)				
Niagara	$2,048	$438	$432	$2,919
Orleans-Monroe-Wayne	1,537	347	402	2,286
Cayuga-Oswego	20,496	3,172	4,503	28,171
Jefferson-St. Lawrence	43,464	11,841	7,749	63,055
Totals	67,545	15,798	13,087	96,431
Sales Impacts per Boat Day				
Region-wide	$51.95	$12.15	$10.06	$74.16
Niagara to Oswego	31.24	5.13	6.92	43.30
Jefferson-St. Lawrence	82.33	22.43	14.68	119.44
Aggregate Employment Impacts (Full-time equivalent jobs)[1]				
Niagara	$35.3	$4.1	$5.4	$48.7
Orleans-Monroe-Wayne	25.2	2.9	4.2	32.3
Cayuga-Oswego	392.2	30.5	58.0	480.7
Jefferson-St. Lawrence	597.1	124.9	97.0	819.0
Totals	1,049.8	162.4	164.6	1,380.7

1 IMPLAN-defined jobs have been converted to full-time equivalents (40 hours per week) using Bureau of Labor Statistics data. These data indicate that the typical retail and hospitality job is approximately 30.8 hours per week. Thus IMPLAN data were weighted by a factor of 0.77 to arrive at estimates in full-time equivalents.

4. Key Baseline Conditions

Boating is sensitive to economic conditions, but this probably applies more to the purchase of new boats and perhaps the type of boat purchased than to actual boating participation. A prolonged economic downturn or substantially higher fuel prices could dampen the growing demand for larger motorized boats and new boats, but these conditions likely would not have a great impact on boating participation. This is based on prior experience dating back to the 1970s; boating demand has not been estimated in the light of recent oil and gas price increases. During the energy crisis of the 1970s, people conserved fuel and took fewer long trips, but continued to boat.

5. Key Trends

Because of the price of new boats, boating has short-term fluctuations that mirror the general economy. We are currently seeing this, with sales on the increase since the fall of 2003, after a period of stagnation. Over a broader period, however, boating has increased in numbers, and boats have grown larger. Surveys show a growth of about 10% in the number of boaters between 1994 and 2002, and the U.S. Forest Service, which does long-term forecasting for a number of recreation activities, predicts a 21% increase in boating from 1995 to 2006. In the Quebec region, the number of boats (of all types) increased by 22% from 1995 to 2000, with the highest increases seen in motor boats under 20 feet (26%) and rowboats (22%) (Fisheries and Oceans Canada, 2004). Sailboats of more than 20 feet have also increased by 12%. On the St. Lawrence River (lower section), between 1995 and 2002, use of power boats and rowboats has increased, but use of sailboats has decreased (Duchesne *et al.*, 2004). Although difficult to forecast precisely, it is likely that the number of boats will increase on the St. Lawrence River (lower river, at least) in the coming years.

The average horsepower of motor boats increased from 65 hp in 1985 to 86 hp in 2002 in the U.S., and this trend is probably similar in Canada. Also, the 1990s brought the emergence of "cigarette" boats that travel at more than 60 mph on the lower river. We expect continued slow growth in boating, with also a trend toward slightly larger boats where we find higher water levels conditions. These larger boats will have slightly deeper depths, on average, which means low water levels will pose an increasing problem, although at a gradual rate. Jet skis and personal watercraft have appeared within the past 15 years and the number of users has grown substantially. This segment of boating is less affected by water levels, however.

6. Expected Consequences of Changes of Regulation

Based on previous experience, boaters are loyal to boating. In times of economic difficulties nationally, or at times of higher fuel prices, they make adjustments within the activity of boating; they do not change from boating to some other outdoor activity. Thus, it is difficult to imagine a scenario in the future where there would be fewer boaters. As a result, water levels would remain a critical concern to boaters. Adaptation measures could also be adopted (in part) by marina operators, but safety considerations and boater education/training will remain an issue (i.e. development of better ability to navigate when facing adverse conditions linked with climate and water levels).

7. Adaptive Behaviours

Many marinas have adapted to upward fluctuating water levels through the construction of floating docks. For this reason, high water levels are less of a problem for recreational boating than low water levels. Some smaller marinas still have not gone to the expense of installing floating docks, however. Low water levels are more difficult for marinas to adapt to because, for generalized low water, there is no obvious solution, and for specific situations, dredging may be required; this may take a year or two because of both costs and the difficulty of obtaining the necessary permits. Small boat owners who are fishing or water-skiing may be able to adjust over time by going to an inland lake or river. However, many boaters have specific interests in Lake Ontario or the St. Lawrence River because of waterfront properties or other interests.

Over a period of several years, boaters might adapt to low water conditions by buying smaller boats with shallower drafts. In the short term, they would probably simply boat less, going only in late spring and early summer when water levels are highest. Marina owners are less flexible. We believe that in a three-year period of low water levels, perhaps one-quarter to one-third of marinas would go out of business (based on limited in-depth survey information from Boudier and Bibeault, 2001).

8. Risk Assessment/Sensitivity Analysis

(See also adaptive behaviours above.) The primary risk we would identify is associated with water levels that are below the critical levels of the stage damage curves. Low water levels at which significant losses of benefits occur affect three boating segments somewhat differently—marina users, launch ramp users, and private dock owners. The larger boats tend to be located at marinas. Low water levels during the boating season may keep boaters from boating. If low water levels are predicted for fall, this may require marinas to haul boats out of the water early, thus shortening the boating season and threatening the economic viability of the marinas. Launch ramp users have more flexibility. If low water levels are a very localized problem for a given launch ramp, boaters may be able to shift to another ramp or launch at a marina. For more pervasive low water levels, launch ramp users may shift to other waters (e.g., Lake Champlain, Finger Lakes in New York, regulated St. Francis in Quebec). In the short term, private dock users would probably lose boating benefits, as their boats are associated with primary residences or second home properties, and they have less flexibility to seek alternative places to boat. In times of high or low waters, media reports often overstate the actual situation, or fail to give adequate coverage when water levels return to a generally safe range for boating. This situation keeps many boaters at home and adds to the negative economic impact estimate that would be obtained solely from estimating boater days lost when waters are at unsafe levels.

Most uncertainties in our estimates affect the magnitude of dollar amounts on damage curves, but not the seasonal patterns and general shapes. These issues may affect judgments of disproportionate loss, but are unlikely to affect plan rankings. Thus, any additional sensitivity analyses should focus on factors that change the seasonal pattern of the curves, e.g., the extent to which boaters would take more trips in late summer and fall if water levels were not a problem.

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10. Review Process

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Received TWG Support: 1/18/05
External Review: Frank Lupi

C. Coastal Processes Technical Work Group Summary

Objectives

The Coastal Technical Work Group evaluated the impacts that changes in water levels on Lake Ontario and the St. Lawrence River would have on human presence along the coasts. Factors other than calm water levels have a significant influence on the impacts experienced by coastal areas, and these factors vary greatly from area to area. Along Lake Ontario, wind-driven waves and wind-induced water level changes (surge) are key factors influencing damages to coastal areas. These factors are of much less importance along the St. Lawrence River, although wind-driven waves are significant in some areas such as Lake St. Lawrence. In portions of the St. Lawrence River downstream of Montreal, waves generated by passing ships have a major influence on coastal processes.

Data Collection and Evaluation Methodology

It became evident at an early stage of the study that it would be advantageous to use more than one evaluation methodology. Differences in physical features, coastal processes and data availability led to a decision to develop one approach for Lake Ontario and the St. Lawrence River upstream of the control dam at Cornwall-Massena, and a second approach for the St. Lawrence River between Cornwall-Massena and the downstream study limit of Trois Rivières.

Lake Ontario and the Upper St. Lawrence River

The Work Group reviewed modeling approaches that have been used for similar purposes in previous studies. The Flood and Erosion Prediction System (FEPS) computer model, developed by W.F. Baird and Associates, Ltd. in 1997 under contract to the United States Army Corps of Engineers (USACE) for the Lake Michigan Potential Damages Study (USACE, 1999), was selected to form the basis of the evaluation procedure on Lake Ontario and the upper St. Lawrence River. This model has been adapted and further upgraded for the specific needs of the Study.

Existing spatial and temporal data was gathered together for the Study. Several significant data gaps were filled through the collection and development of new data. A dedicated computer, known as the Coastal Data Server, was set up to store these volumes of data. Lake bottom depths (bathymetry), land surface elevations (topography) and ortho-photographs of the current shoreline conditions were provided through the Common Data Needs Work Group (refer to that section for more information). Property parcel data was gathered from U.S. counties and Canadian regional municipalities, where available. Shoreline classification data was gathered by the Coastal Work Group on a 1-km-reach basis along the Lake Ontario and upper St. Lawrence River shoreline and included details on the geomorphic shoreline type, nearshore geology and type and quality of shoreline protection that is present along the shoreline. Historical aerial photographs documented the shoreline and river conditions from approximately the 1930s to the present. Historical recession rate data was compiled by the Coastal Technical Work Group based on existing information as was information on previous flooding events. Hourly water level data at gauges on the Lake and River were compiled in the Shared Vision Model. Hindcast time series wind speed and direction based on the past 40 years of data was used to develop a wave energy database. Historical ice cover data for Lake Ontario was compiled from the Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration. The Coastal Data Server consists of 120 gigabytes of digital information that is actively part of the decision making process.

The Lower St. Lawrence River

In comparison to the upper portion of the study area, the waters downstream of the control dam are differentiated by the influences of river flows, ship wakes and the response of shorelines composed, for the most part, of marine clays.

An extensive digital data collection of bathymetry, topography, flow conditions, aerial photography and databases relating the land-use and erosion processes was compiled in a data warehouse based in the Ste-Foy, Quebec offices of Environment Canada. This dataset formed the backbone of the performance indicator analysis for the lower St. Lawrence.

Application of regional-scale computer modeling to the shorelines of the lower St. Lawrence River from Cornwall, Ontario to Trois-Rivières, Quebec was developed by Pacific International Engineering to create a new and clear understanding of the relative importance of river currents, wind waves and ship-generated waves and how they interact with water levels (*Pacific International Engineering, March 2004*). This enabled the development of simplified predictive tools for erosion and an assessment of economic impacts.

Flooding stage-damage relationships were developed for 42 municipalities on the lower St. Lawrence River from Cornwall to Trois Rivières by Environment Canada-Quebec Region based on parcel and assessment data of the affected properties and a fine-resolution digital elevation model developed for the Coastal Technical Work Group by the Common Data Needs Technical Work Group (refer to that section).

Performance Indicators

Lake Ontario–Upper St. Lawrence River

The impacts of water level fluctuations on Lake Ontario and upper St. Lawrence River shoreline communities were categorized by three primary performance indicators, specifically: flooding, shoreline erosion of developed properties, and existing shoreline protection maintenance. The Coastal Technical Work Group also examined sediment budgets, beach access, and barrier beaches and dunes as possible performance indicators.

Flooding

Over 3,000 shoreline property parcels are located below elevation 76.2 m (250 ft) and could be at risk of flooding on Lake Ontario and the upper St. Lawrence River. Flood damages to these properties generally occur during periods of high lake levels and severe storms. The flooding performance indicator on Lake Ontario quantifies the impacts of flooding due to inundation of structures and the force of waves striking buildings. Economic damage calculations are made for individual property parcels at risk of flooding. The flooding performance indicator algorithm was developed, tested, calibrated and verified in the Flood and Erosion Prediction System (FEPS). The flooding performance indicator algorithm is applied to the entire parcel database for the duration of a simulation in the Shared Vision Model, commonly 101 years. However, the wave database was based on 40 years of data statistically hindcast to represent the 101-year simulation period. An analysis determined that this could significantly affect plan results as the happenstance nature of waves meant that a plan that shifted levels might avoid or enhance damage depending on the wave sequence. To address this, a number of statistically generated wave sequences were derived based on the quarter month maximum of the maximum, the average of the maximums and the 1st and 2nd standard deviation from the maximum. The results could be tested for all of these sequences. Using this method, it was determined that the 1st standard deviation was probably the best wave-sequence representation for ensuring that the numbers were not being underestimated. The 40-year hindcast wave data was used in the 50,000 stochastic analyses since the shear number of combinations of levels and waves would dismiss any bias in the data. For more information on the flooding performance indicator refer to the report *Flooding Performance Indicator: Methodology and Shared Vision Model Application* (Baird, 2004a).

Erosion of Developed, Unprotected Properties

Shoreline erosion and the associated economic impacts were calculated for individual property parcels around the perimeter of the Lake and on the upper river. The erosion performance indicator algorithm is based primarily on average recession rates and wave energy. The erosion function is applied to all of the 1-km shoreline reaches on Lake Ontario and the upper St. Lawrence River that feature a long-term recession rate. If the shoreline does not erode or has a long-term accretion trend, the function is not applied.

Once shoreline recession is predicted for a given reach and regulation plan, the second component of the erosion performance indicator, the economic calculation, is applied. This calculation is applied to developed, unprotected properties only and is based on the timing and cost of building shore protection to safeguard the value of a building. This approach was reviewed and supported by the economic advisors, who agreed that damages should be capped at the cost of building shore protection since this is the realistic response rather than allowing erosion to continue to the point where the value of the building would be lost. For the evaluation, it was assumed that the riparian owner would let erosion occur until the minimum distance from the home to eroding shoreline is 10 m (32.8 ft). Figure C-1 provides visual interpretation of how the erosion performance indicator is applied.

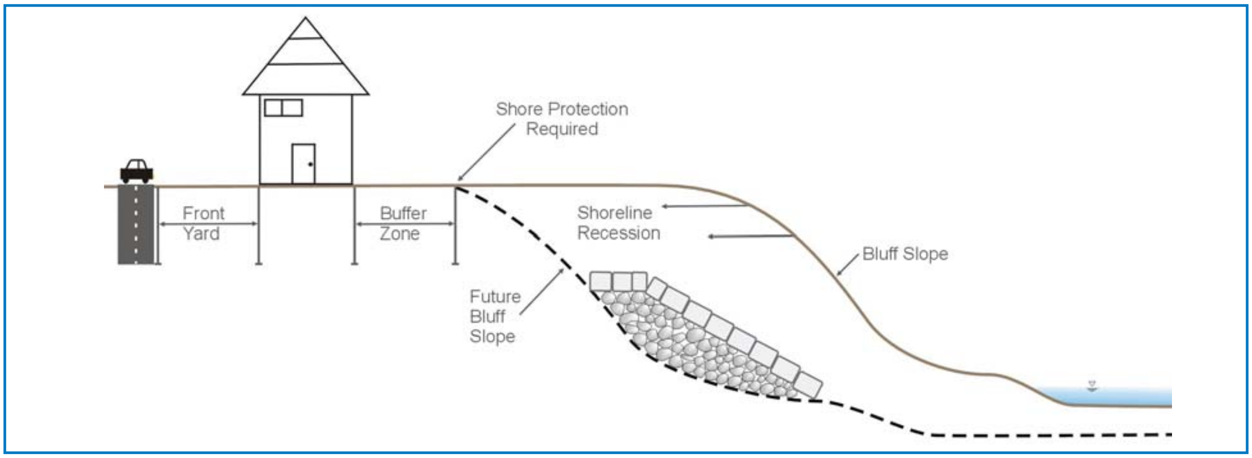

Figure C-1: Conceptualization of erosion performance indicator

The difference among plans is the timing of when a riparian owner would have to build shore protection under Plan 1958-DD versus an alternate plan and is captured in economic terms by discounting future damages so that the later the damage, the less important it is. For more information on the erosion performance indicator, refer to the report Erosion Performance Indicator: Methodology and Shared Vision Model Application (Baird, 2004b).

The unit costs for the construction of new shore protection under the erosion performance indicator are listed in Table C-1.

Table C-1: Unit Costs for the Construction of New Shoreline Protection

ShoreUnit	Shore Protection Cost ($/m)	Shore Protection Cost ($ft)
CayugaCo	2,168	661
DurhamRM	2,012	613
Frontenac	2,432	741
HaltonRM	2,432	741
HamiltonRM	2,432	741
Hastings	2,012	613
JeffersonCo	2,488	759
Leeds	2,134	651
Lennox	2,432	741
MonroeCo	1,933	589
NiagaraCo	1,889	576
NiagaraRM	2,070	631
NorthumberlandRM	2,012	613
OrleansCo	1,889	576
OswegoCo	2,168	661
PeelRM	2,048	624
PrinceEdward	2,012	613
StLawrenceCo	2,134	651
Stormont	2,134	651
Toronto	2,048	624
WayneCo	1,933	589

Shoreline Protection Maintenance

Shoreline protection structures are already present for a large percentage of riparian properties exposed to flooding and erosion hazards around the perimeter of Lake Ontario. Based on the parcel database, approximately half of the shoreline length has been armoured with good quality seawalls and revetments. For the evaluation of new regulation plans, it is assumed that these structures are stable, will be maintained, and will continue to provide effective erosion protection. However, if a regulation plan results in more extreme high water levels, there will be negative impacts on the existing structures that were designed for the range of lake levels since 1960. The existing shoreline protection indicator quantifies the impacts of the alternative regulation plans on the structures currently providing effective erosion control around the perimeter of Lake Ontario and the St. Lawrence River.

The three principal modes of failure that require significant maintenance or complete replacement and that are considered in the shoreline protection maintenance performance indicator are as follows:

- Age failures – degradation of materials, such as concrete or quarried stone;
- Overtopping failures – wave overtopping during storms (event driven);
- Downcutting failures – cumulative process at the toe of the structure.

Age failures are independent of lake levels. However, the volume of water overtopping a structure during a storm is very sensitive to lake levels. In Figure C-2, the crest of the concrete wall is a product of the design lake level and design wave height. If these levels are exceeded during a storm, the wall may fail or require significant maintenance. The existing shore protection performance indicator evaluates a regulation plan by cycling through the hydrograph and looking for storm events that would cause failure or require maintenance of existing structures.

Lake bed downcutting is another common mode of failure for existing shoreline protection structures and it is sensitive to water levels. For example, if lake levels are low and the waterline is offshore of the structure toe, downcutting will not occur. Conversely, if water levels are very high, the majority of the wave energy will be dissipated on the structure face or will overtop the structure. Therefore, the amount of downcutting is very sensitive to lake levels. Figure C-3 shows a shore protection structure where increased downcutting may lead to structure failure.

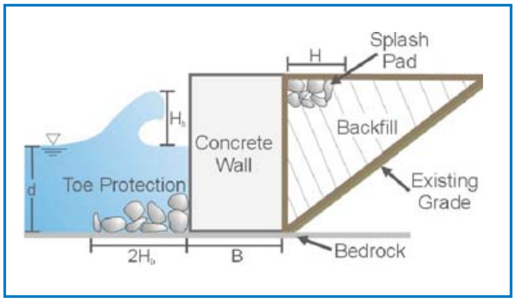

Figure C-2: Conceptual schematic of shore protection design

Figure C-3: Example of existing shore protection at risk of undercutting during low water periods

Downcutting also influences the future replacement cost of either an age or overtopping failure. If significant downcutting has taken place over the simulation time, the expense to replace the structure will be increased since a larger structure will have to be built given the deeper toe. For more information on the shore protection performance indicators refer to *Shore Protection Maintenance Performance Indicator: Methodology and Shared Vision Model Application* (Baird, 2004c).

Sediment Budget

The sediment budget indicator was developed to categorize the relationship between shoreline recession and barrier beaches and dune environments. The bluff shorelines of Lake Ontario have been eroding for thousands of years. This process provides new sand and gravel for the nearshore zone and thus is the source of new material for beach and dune environments around the Lake. Without a "background" erosion rate, there would be no new sand and gravel to nourish the beaches and dunes along the shore. Originally, the Coastal Technical Work Group thought this should be assessed; however the economic advisors determined that sediment budgets should not be included in the economic analysis noting that the processes of erosion, transport, and deposition are dynamic and change over time. Beach accretion may be a final step in the transport process or it may be an intermediate one that is subject to further erosion and further transport. Beach accretion is only one of the economic consequences of sediment transport and while it appears to have positive net benefits, other sediment impacts, such as the initial loss of eroded material and sediment deposition in channels and harbours, seem to be negative. With these negative impacts left unmeasured, accounting for beach accretion alone would put a favourable light on sedimentation when the overall impact may be negative. The discussions indicated that the net benefits of beach accretion were not large, relative to other net benefit measures.

Beach Access

The beach access performance indicator was developed to quantify water level impacts on beaches, such as those located in provincial and state parks. During high lake levels, beach width decreases as more sand is submerged, thus reducing the width of the beach for recreation. A field survey was completed at two large provincial and state parks (Sandbanks and Hamlin, respectively) to collect data from beach users. This information, along with existing published data on beach visitation and economic behavior was to be used to quantify the impact of water levels on beach visitation. An economic function was developed to determine the impacts of high and low lake levels. However, the economic advisors did not believe that this performance indicator had the proper rigor to be compared with the other economic performance indicators. They advised that it not be included in the analysis, but rather be reported in the contextual narrative.

Beach and Dune Performance Indicator

The beach and dune performance indicator was developed to quantify water level impacts on natural beach and dune systems, such as barrier beach complexes protecting wetlands. The sandy barrier systems, such as the beaches of eastern Lake Ontario, are sensitive to high lake levels and storms. However, given the dynamic nature of the littoral system it was too difficult to quantify sand transport and would have taken considerable resources to build such a model. As a result, based on existing knowledge and literature reviews, a hydrologic criteria metric was developed that basically mimicked the erosion criteria developed by the Coastal Technical Work Group.

Lower St. Lawrence River

Local flood depth-damage curves were developed for buildings in the floodplain of the St. Lawrence River, as shown in Figure C-4. These were used to calculate the primary economic flooding performance indicator, dollar damage to buildings and contents of buildings as a result of a flood event.

Regional numerical models and functions relating this damage data were developed on a municipal basis. The Sorel Islands as well as the municipalities around Lac St. Pierre are by far the most flood-damage prone. In the Lac St. Louis area, the municipalities at greatest risk are Beauharnois, Léry and Notre-Dame-de-l'Île-Perrot (Doyon et al., 2004).

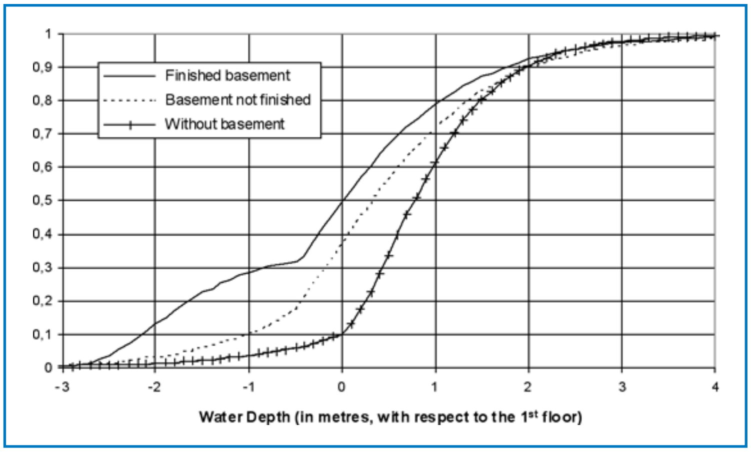

Figure C-4: Depth-damage curves applicable to one-story buildings within the St. Lawrence floodplain

The Coastal Technical Work Group decided that the economic performance indicator would not fully describe the impacts of a flood on communities on the lower river and therefore they also established some societal indicators to complement and provide context for the economic performance indicator, accounting for societal aspects of damage. However, they all reflect direct damage.

The societal performance indicators include the following:
- Number of flooded residential buildings;
- Number of expropriated properties;
- Total area (in hectares) of flooded lands quantified by land-use type; and
- Total length (in kilometres) of flooded roads quantified by road type.

Erosion of Unprotected Properties

Erosion along the lower St. Lawrence was calculated for unprotected properties. On the lower river there are very few developed, unprotected eroding properties. The land that is eroding is primarily located on undeveloped islands. On the Lake, no value was given to this land lost because a gain was assumed elsewhere in the system. This is not necessarily the case on the River, where sediments are carried downstream towards the ocean. However, two important findings played into the analysis. First, the economic value of the property lost was so small that it simply did not factor into the plan-evaluation decision process. Second, based on field observations and modeling studies, it was determined that in many areas along the lower river, erosion is primarily ship-wake driven. While water levels play a significant role in erosion processes along the River, regulation of Lake Ontario outflow is seen to have an influence on erosion rates that is secondary to the large seasonal fluctuations in River levels (Davies and MacDonald, 2004a).

Shoreline Protection Maintenance

About half of the total frontage on the lower St. Lawrence River has shore protection. Economic analysis shows that the cost of shore protection far outweighs the economic value of land lost due to erosion. Shoreline protection maintenance is calculated in a St. Lawrence River Model (SRM) developed by Pacific International Ltd. The scour at a structure is determined from a set of polynomial equations with coefficients that vary according to water level. Required structure crest elevation is computed from the higher statistics of the maximum quarter-monthly water levels using a moving 10-year window. These are combined with data on structure locations and type in order to compute the change in the annual equivalent cost of shore protection. A detailed survey was undertaken to document the individual shore protection structures along the lower river. Scour modeling was validated by comparison of the rate of bed downcutting to that at unprotected eroding sites in the vicinity. The water level fluctuation statistics used for determination of structure crest elevation were compared with those from more detailed models (Davies and MacDonald, 2004a).

Baseline Economics

An estimated 25,000 privately owned riparian properties are located on Lake Ontario and the St. Lawrence River upstream of the Moses Saunders Dam. There are three components of baseline economics in the case of shoreline properties: (i) developed properties without shoreline protection, (ii) properties with existing shoreline protection, and (iii) properties at risk of flooding.

With respect to erosion, there are close to 2,700 developed properties in the coastal database (i.e., properties with residential or commercial buildings) that do not currently have shore protection, which places them at risk of erosion damages. The assessed building value for these properties is close to US$300 million (not including land value). There are approximately 5,000 developed properties that already have good quality (level 1 or 2) shore protection. The shore protection structure value itself is close to US$500 million and the assessed building value is roughly US$1 billion. (Baird, 2005b). The difficulty lies in the fact that these are the values of the housing and property stock. They are not appropriate as baseline measures because what is needed is an estimate of the scale of the annual flow of economic activity.

To provide the right context for annualized damages, a value for a building needs to be put in annualized terms. A standard way to develop a context measure, suggested by the economic advisors, was to use the depreciation of the shoreline building. Depreciation is an estimate of the amount of expenditure needed to keep the value of the housing stock unchanged. As a result, it provides an estimate of annual loss of investment irrespective of regulation plan. Based on a depreciation rate of 3.6%, as suggested by the economic advisors, the annual depreciation of the US$300 million building value at risk of erosion is roughly US$10.8 million. This represents the denominator to be used in assessing the percent benefit gained or lost by any given plan relative to plan 1958-DD for the erosion performance indicator. In the case of erosion to undeveloped, protected properties on Lake Ontario, Plan B^+ has a net benefit of -US$0.17 million relative to Plan 1958-DD. The percent damage for this performance indicator then, would be -US$0.17 million divided by US$10.8 million for a loss of 2%.

Since the value of shore protection will increase over time as new shore protection is built as part of the erosion performance indicator, it is difficult to separate the baseline economics for the shoreline protection maintenance indicator and the erosion performance indicator. However if only the properties with existing shoreline protection are used, a conservative estimate results. Combining shore protection value with building value provides a total investment value of US$1.5 billion. A 3.6% depreciation rate yields an annual depreciation of roughly US$54 million to be used as the baseline economic value for Lake Ontario shore protection maintenance. In other words, regardless of the regulation plan in place, it is estimated that property owners would spend approximately $54 million annually to maintain their property values. Thus, gains and losses associated with a specific regulation plan can be measured relative to this amount.

With respect to flooding on Lake Ontario, there are approximately 2,400 developed properties that are within 2.0 m of chart datum and considered at risk from flooding. The building and contents value for the 2,400 properties is estimated at $500 million. Based on the 3.6% rate the depreciation measure is US$18 million. Among the counties assessed on the upper St. Lawrence River (Jefferson and St. Lawrence Counties), there were approximately 600 properties at risk of flooding, representing a US$75 million building and contents value. The resulting baseline economic value, based on 3.6% depreciation, would be US$2.7 million.

On the St. Lawrence River downstream of the Moses Saunders dam, there are an estimated 5,770 single-family dwellings within the 100-year floodplain, with an estimated value of US$380 million, with a depreciation value of $13.7 million to be considered the baseline for downstream flooding damages. Thus, the sum of these flooding-related depreciation costs is US$18.0 million + US$2.7 million + US$13.7 million = US$34.4 million. As pointed out above, gains and losses associated with a specific regulation plan can be measured relative to this amount.

Downstream shore protection maintenance damages should be relative to the depreciation of the $200 million in shore protection infrastructure for a baseline of $7.2 million.

Table C-2 shows the baseline economics for the coastal performance indicators, in millions of U.S. dollars annually.

Table C-2: Economic Baselines for the Coastal Performance Indicators ($US million)

COASTAL	Economic Baseline
Lake Ontario	*$82.8*
Shore Protection Maintenance	$54.0
Erosion of Unprotected Developed Parcels	$10.8
Flooding	$18.0
Upper St. Lawrence River	*$2.7*
Flooding	$2.7
St. Lawrence	$20.9
Flooding	$13.7
Shore Protection Maintenance	$7.2

Importance of the Stochastic Analysis

The 50,000-year stochastic supply sequence was used to generate reliable estimates of average annual damages for the Lake Ontario and lower St. Lawrence River flooding performance indicators. As part of the analysis, each flooding event was considered to be independent, and the long supply sequence gives a good representation of the possible range of water levels for the various plans. For the Lake Ontario erosion and shore protection maintenance performance indicators, there is a serially dependent component to the economic calculation due to the need to measure the amount of erosion or undercutting that occurs along a section of the shoreline over time. On the advice of the economic advisors, the ability of a plan to delay erosion or shore protection maintenance damages was required to be evident in the evaluation. As a result, the 50,000-year stochastic supply sequence was broken up into 495 sequences of 101 years, and each plan evaluated using all the sequences. The average damage was determined for each quarter-month using the 495 supply sequences, and the results were discounted to a present value to represent the impact of postponing the damages. As recommended by the economic advisors, a discount rate of 4% over a thirty-year period was used.

Analysis

Riparian interests around Lake Ontario are most sensitive to high water levels associated with particular regulation plans. The estimated impacts are further influenced by wave energy and wave height conditions, which tend to vary around the Lake and throughout the year but are generally greatest during the spring and fall (see Figure C-5). Thus, the timing of high water levels during the spring and fall can have a considerable impact on plan results. Plans that tend to keep lake levels lower in the late fall and early spring will result in conditions more favourable for the riparian interest. In addition, regulation plans in which the annual peak water level consistently occurs in the June, July, and August period will generally minimize coastal impacts.

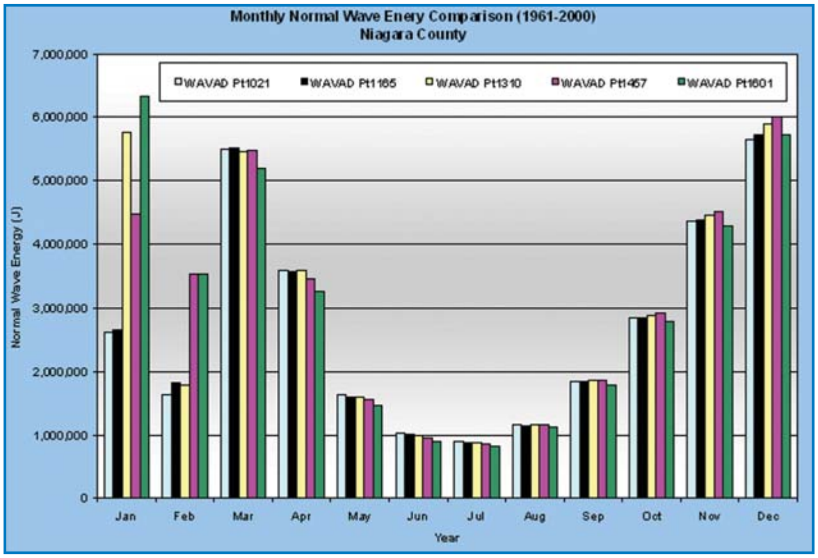

Figure C-5: Monthly normal wave energy comparisons (1961-2000) for Niagara County

Analysis revealed that the shore protection maintenance performance indicator was the most sensitive to changes in a regulation plan on Lake Ontario. There are two particular factors contributing to the increased sensitivity. First, existing shore protection represents a large investment around the perimeter of the Lake (estimated value of $497 million) and postponing the maintenance of that shore protection can be economically beneficial. Second, shore protection maintenance is very sensitive to the impact of waves and is therefore affected by changes in the timing of levels as discussed above. In particular, high water levels occurring during periods of high waves will cause overtopping failures in a very short period of time, and the shore protection module of FEPS allows shore protection to fail multiple times during a simulation period (generally 101 years).

Absolute average annual damages for the shore protection maintenance performance indicator occur predominantly in counties along the south shore of Lake Ontario. Figure C-6 shows the distribution of plan damages (%) for Plan 1958-DD based on the stochastic supplies. The relative distribution of damages among counties is consistent among the various plans evaluated.

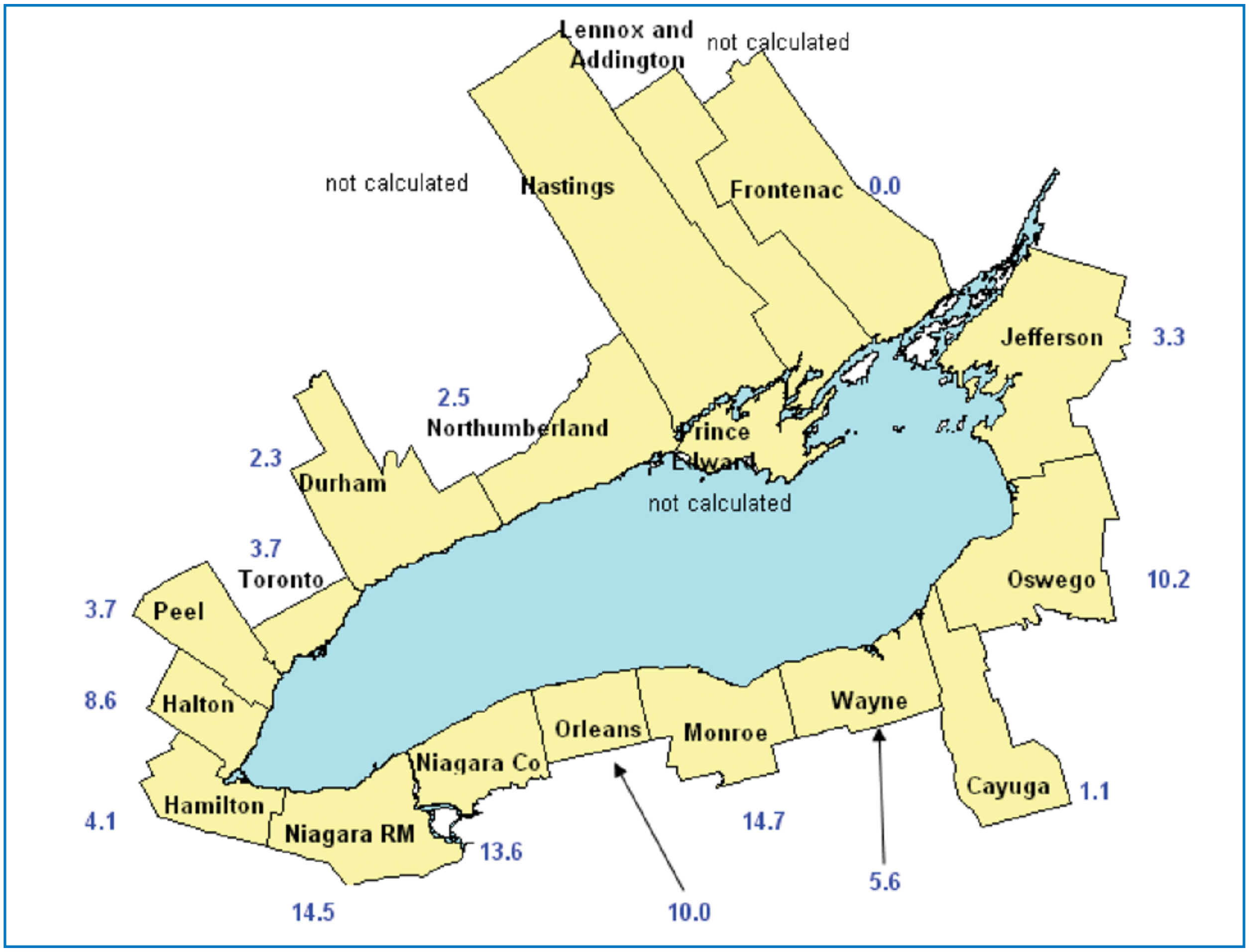

Figure C-6: Map of percent damages for 1958-DD, by county, on Lake Ontario

The susceptibility of shore protection to overtopping damages is partly influenced by the estimate of the design water level used in the calculation. In the FEPS model, the design water levels are attributed on a county basis and are estimated based on risk determined from a statistical analysis of the historical wave and surge conditions for a particular county (standard coastal engineering practice). It is recognized that not all structures built within a county will meet the estimated design water levels (some may be higher and some lower). However, determining actual design water levels for individual parcels around the Lake is very difficult, and, based on its evaluation of damages using both estimated design water levels and actual design water levels found in Halton Region, the Coastal Technical Work Group feels that the county estimation is appropriate. A sensitivity analysis revealed that the choice of design water levels for a county can influence susceptibility to overtopping failures under a particular plan. The use of higher design water level estimates for areas along the south shore of Lake Ontario where shore protection costs are greatest tends to decrease overtopping failure. Applying higher design water levels can significantly reduce the differences among plans with respect to the shore protection maintenance performance indicator. If most existing shore protection structures in fact exceed the Coastal Technical Work Group estimates of height requirements for surge in U.S. counties, then differences among plans are less than FEPS estimates. However, experience suggests that U.S. shore protection structures are sometimes under-designed and that many if not most of the structures have lower top elevations than estimated in the FEPS modeling; hence the differences among plans are at least what FEPS estimates and possibly more.

The erosion of unprotected properties performance indicator for Lake Ontario is less sensitive to differences among regulation plans than the shore protection maintenance performance indicator. While existing shore protection can fail multiple times during a simulation, the erosion module of FEPS only estimates the initial cost of building shore protection on unprotected parcels, while any ongoing maintenance is measured as part of the shore protection maintenance performance indicator. Estimating the economic damage of erosion in terms of the timing of having to build shore protection is an appropriate way to put a dollar value on expected damages. However, it was found that regulation plans with marginally different average annual economic damages for the erosion performance indicator could have quite different observed recession rates. Therefore, the economics may not always identify differences in plans in terms of erosion processes around the Lake because of the capped value of shore protection. As a result, both the economic value and the erosion rates were provided to the Study Board in their analysis.

Average annual flooding damages on Lake Ontario are generally the smallest damages of the coastal performance indicators. This is partly because most plans work very hard to keep lake levels below approximately 75.6 m (248 ft). In general, flooding damages are not well distributed throughout a 101-year sequence (see figure C-7). Instead, damages are largely event driven and all the damages may occur in only a few years. As a result, care must be taken when interpreting the average annual results, especially for the 101-year sequences. The full 50,000-year stochastic provides the most reliable results in terms of expected average annual damages.

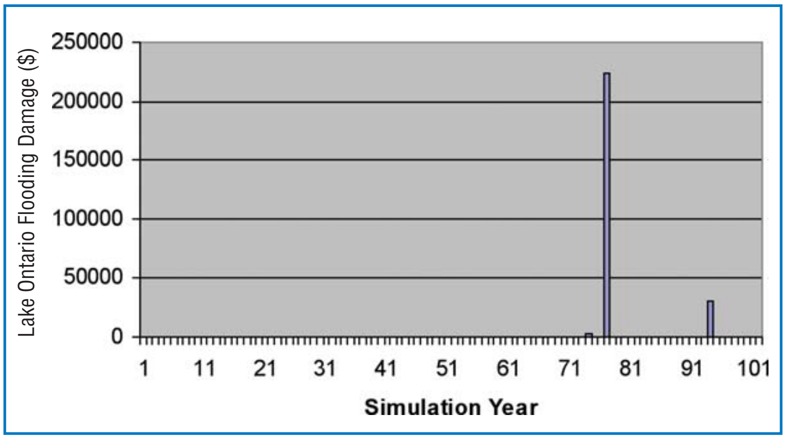

Figure C-7: Absolute flooding damages over 101 years under Plan 1958-DD

On the lower St. Lawrence River, shore protection maintenance is not very sensitive to changes in a regulation plan because much of the damage is a result of ship wake, which is not influenced by regulation. In contrast to the open Lake, wind generated waves do not play as great a role on the River, and the natural fluctuation of the lower river as a result of the Ottawa River freshet and local tributary inflows has a greater impact than regulation. Therefore, large differences among plans are generally not observed. On the lower St. Lawrence River, the flooding damage performance indicator is most influenced by regulation. Figure C-8 presents estimates of average annual damages for regional county municipalities (RCMs) based on the Plan 1958-DD stochastic supplies. The distribution of damages among the various RCMs is representative of all the regulation plans. In general, flooding damages are greatest in the RCMs closest to Lac St. Pierre. Although the potential exists for considerable flooding damage in the RCMs closer to the city of Montreal, regulation is quite effective in maintaining desired water levels in these reaches due to the proximity to the Moses-Saunders Dam. Further downstream, within-week variability due to tributary inflow can cause higher levels then anticipated and lead to increased flooding damages.

Integration into the Shared Vision Model

The detailed computer modeling used to determine performance indicator impacts for both shoreline processes and flooding in the lower river has been condensed into representative algorithms within the Shared Vision Model. This now allows the evaluation of performance indicators, thereby facilitating the integration of the findings of this work into the overall decision-making process.

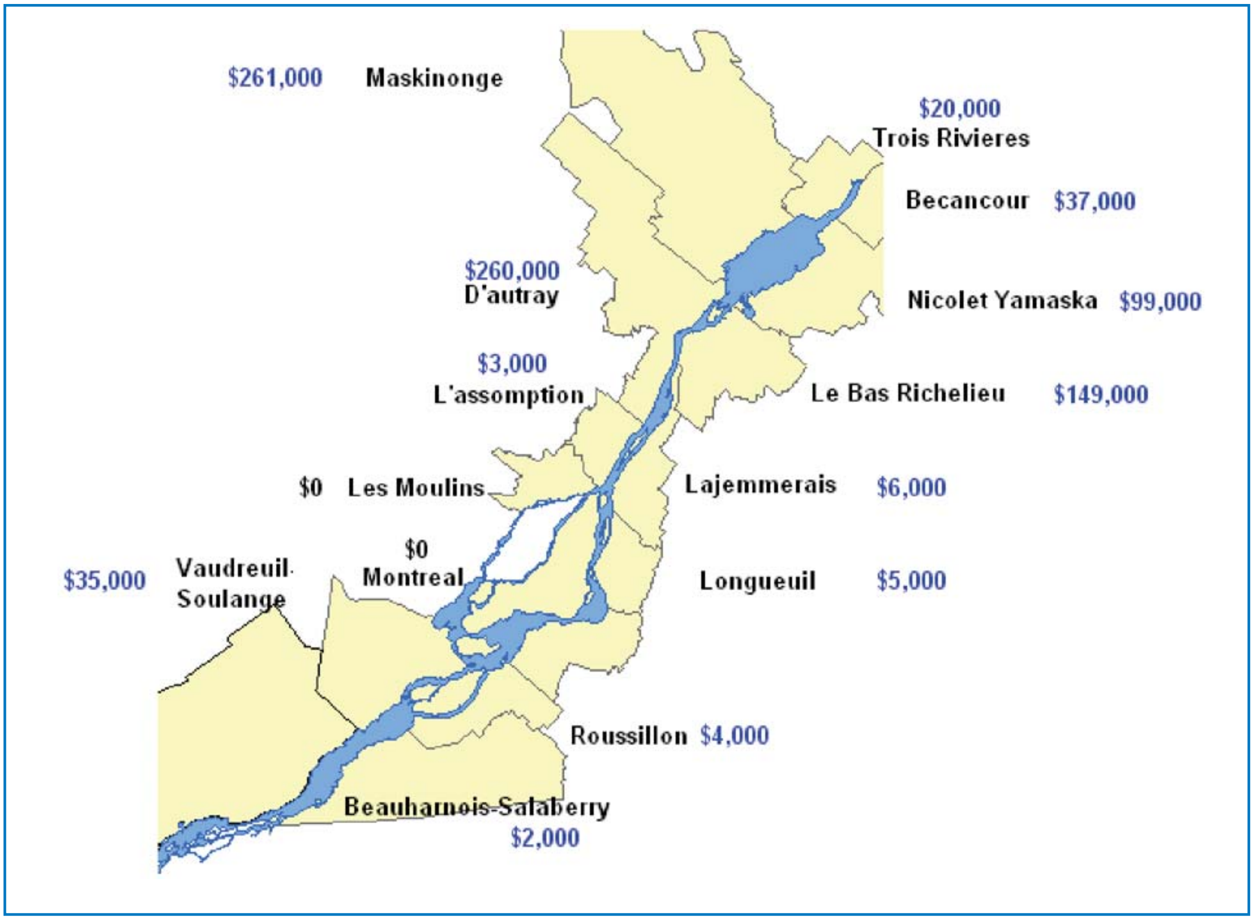

Figure C-8: Map of downstream coastal damages (average annual 1958-DD stochastic by regional county municipality) $US

The FEPS and SRM run as separate components of the Shared Vision Model. An executable version of the FEPS was developed to allow for quick analysis of alternative plans and was later modified to allow for the running of the full 50,000-year stochastic supply sequence. Results from the historical SRM evaluations showed little difference among plans. Evaluations for four stochastic and four climate change scenarios confirmed this, so the SRM was not modified to run through the 50,000-year simulation. Instead, the final values for downstream shore protection costs are an average of the historical and four extreme 101 stochastic series results.

Summary of Key Findings

- The timing of high water levels during the spring and fall can have a considerable impact on plan results. Plans that tend to keep Lake levels lower in the late fall and early spring will result in conditions more favourable to the riparian interest.

- Regulation plans in which the annual peak water level consistently occurs in the June, July, and August period will generally minimize coastal impacts.

- The shore protection maintenance performance indicator was the most sensitive to changes in a regulation plan on Lake Ontario because shore protection maintenance is very sensitive to the impact of waves, and postponing the maintenance of existing shore protection can be economically beneficial, especially to south shore residents.

- The susceptibility of shore protection to overtopping damages is partly influenced by the estimate of the design water level used in the calculation. Higher design water levels can significantly reduce and even eliminate differences among plans in terms of this performance indicator.

- Erosion on Lake Ontario will occur regardless of the regulation plan. The difference among plans lies in how quickly it will happen. While the estimated dollar impact of regulation may be relatively small, the impact on recession rates can be significant.

- The probability of flood damage along Lake Ontario can be estimated based on a combination of water level and time of year; damage is least likely when storms are least likely (in the summer). Average annual flooding damages on Lake Ontario are generally the smallest damages among those associated with the various coastal performance indicators. Damages are largely event driven, and all the damages may occur in only a few years.

- Low water levels can exacerbate erosion and shore protection damage because the "toe" of the bank is eroded, leading to collapse of unprotected banks and the undermining of existing shore protection.

- On the lower St. Lawrence River, shore protection maintenance is not very sensitive to changes in a regulation plan because much of the damage there is the result of ship wake, which is not influenced by regulation.

- The flooding damage performance indicator is most influenced by regulation on the lower St. Lawrence River, especially in lower portions downstream of Montreal around the Sorel/Lac St. Pierre area.

- Erosion on the lower river is not a major economic issue since most of the developed properties are already protected.

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C. Coastal Processes Contextual Narrative for Lake Ontario and the Upper St. Lawrence River

This contextual narrative has been prepared for six Coastal Performance Indictors (PIs) on Lake Ontario and the upper St. Lawrence River: Erosion, Existing Shore Protection, Sediment Budgets, Flooding, Beach Access and Barrier Beaches and Dunes. A separate contextual narrative prepared for the lower St. Lawrence River follows.

1. General Socio-economic Context

The Coastal Technical Work Group (CTWG) has developed an extensive database to complete the impact evaluation for the six performance indicators (Coastal Data Server, active). In addition to spatial datasets, such as 3D topographic grids and temporal information, such as hourly wave data along the shoreline, a comprehensive property parcel database has been developed for a 100- to 200-m buffer zone along the shoreline, depending on local hazards and site conditions. The parcel database includes over 20,500 property parcels. This dataset, extensive field work, and the four-year technical investigation were used to provide background data for this contextual narrative. Information on the general socio-economic context is given below:

(a) Production value of the interest

Several tracts of shoreline are not covered in the parcel database due to a lack of digital parcel data; these include the City of Toronto, County of Prince Edward, Bay of Quinte and much of the Canadian shoreline of the upper St. Lawrence River. Therefore, based on a general knowledge of these areas and the existing 20,570 parcels in the database, we estimate that there are over 25,000 privately owned riparian properties on Lake Ontario and the upper river that are exposed to coastal hazards. The assessed value of this property is approximately $5 billion. This dollar estimate is based on actual data plus projections for areas with missing information. It does not include county or municipal holdings, such as water treatment plants, or state/federal operations such as nuclear plants. If the tax contribution by these riparian properties to local, state/provincial and federal governments were added to the assessed value of the land/buildings, the overall production value would likely increase by 30-50%, for a total production value of $6.5-7.5 billion.

The production value of beach recreation can be measured in terms of annual expenditures. For the beaches with visitation statistics (generally state and provincial parks), the annual expenditures associated with beach use exceed $100 million. Considering that many beaches are not included because of a lack of visitation statistics (e.g., municipal beaches), the actual expenditures or productive value of beaches on Lake Ontario and the upper St. Lawrence River is likely 50-100% higher.

Barrier beaches and dunes are an integral physical component of the sheltered embayments and drowned river valleys along the shores of Lake Ontario, which in turn support wetlands and estuaries that provide critical environmental habitat. Refer to the barrier beaches and dunes performance indicator summary for additional information. Since a productive value is not placed on the environmental habitat and the species it supports, it is not possible to assign a productive value to barrier beaches or dunes. However, it is critical to note that they play a valuable role in maintaining estuaries and wetlands; hence, by extension, water level impacts on these physical features should be considered.

In summary, the overall productive value of the coastal performance indicators is $6.7-7.7 billion, which excludes the benefits of barrier beaches in terms of the natural environment.

(b) Number of stakeholders

With over 25,000 riparian properties affected by water level fluctuations, over 50,000 people in Ontario and New York State are directly concerned by erosion, flooding and shore protection impacts. Since state and provincial beaches are owned by the residents of New York State and Ontario, the entire population of these two political units are stakeholders. Further, when the environmental benefits of barrier beaches and dunes on ecosystem health and biodiversity are considered, the stakeholder group extends to at least everyone living within the watersheds that supply Lake Ontario and the upper St. Lawrence River.

(c) Organizational characteristics

There are no organizational characteristics of these stakeholders that are relevant to this contextual narrative.

(d) Values and perceptions of stakeholders

Riparian property is held around the entire perimeter of the Lake and the River. It is not possible to list all the values and perceptions of these stakeholders, however, some very general observations are provided: i) low to average lake levels are desired; ii) high lake levels are not desired because they will increase flood risk, accelerate erosion, and result in damage to existing shoreline protection; and iii) more could and should be done to regulate the Lake for the benefit of riparian interests. Further, many riparian land owners feel that, since regulation, lake levels are higher than they would have been without the dam, when, in reality, they are lower than under a no-project scenario.

(e) Significant statutory, regulatory and policy restrictions

Land use zoning and shoreline regulations influence development patterns and growth rates within the coastal hazard zone of Lake Ontario and the St. Lawrence River. Under the status quo, conversion of agricultural lands to residential parcels will continue, and the number of property parcels at risk from coastal hazards will increase in the future. Thus, the estimate of 25,000 riparian parcels will increase in the future.

The Province of Ontario recently introduced greenbelt legislation for the western end of Lake Ontario; the legislation will stop the conversion of agricultural lands to residential land use in this region. The impacts of this legislation on future growth rates of coastal riparian property will be relatively small, however, as much of the shoreline is already zoned residential in this region. In summary, future land use zoning is not expected to change, and the number of riparian properties is expected to increase on the Lake and the River.

A second regulatory consideration is the construction of shoreline protection to reduce or eliminate erosion and flooding hazards along the shoreline. Although state, provincial and federal agencies do not necessary condone the construction of engineering structures to protect residential properties, permits can be obtained. For example, on the open coast of Lake Ontario, approximately half of the riparian parcels are already armoured. If changes were made to the policies governing the construction of new shoreline protection or the maintenance of existing structures, the impacts on the riparian land owners within the study area would be significant.

(f) History of the interest

At the turn of the 20th century, residential waterfront properties were generally located in urban centres. Between the urban centres, the shoreline lands were used for agriculture or natural open spaces, such as parks. In the past 100 years, the population in the Great Lakes Basin has increased significantly, and so has the wealth in the economy. Combined, these two forces have resulted in a steady conversion of rural agricultural lands to riparian property. Initially, the focus of these converted lands along the waters edge was cottage or seasonal properties. However, in the last several decades, many of the seasonal properties have been converted to full-time residences. In addition, vast tracts of agricultural land have been converted to residential estate lots.

Given the current land use policies in Canada and the United States, pressure to convert agricultural or rural lands to residential properties will likely continue until the entire shoreline is developed into urban communities. This is referred to as the "build-out date," which corresponds to the time in the future when the entire shoreline features either residential development, commercial-industrial lands or designated park lands. This topic is discussed further in Section 5 below.

(g) Market conditions

Market demand for additional residential property will continue, as mentioned above, until no undeveloped land remains along the shoreline. Therefore, the economic impact calculations computed with the Flood and Erosion Prediction System (FEPS) and the Shared Vision Model (SVM) will underestimate the actual damages in the future. In other words, our database of shoreline development is current as of 2003/2004. In 50 years, there will be more development, but our database will not reflect this additional growth. The vulnerability of future development to damage will be strongly influenced by the enactment and enforcement (or lack thereof) of shoreline management policies.

(h) Impacts of last high or low water conditions

One of the most frequently mentioned high water years, when discussions were held with riparian land owners in the field, is 1973. During high water conditions since regulation (e.g., in 1973 and 1992), the riparian community suffered significant economic damages. The impacts included accelerated shore erosion, increased frequency of flooding, and storm damage to existing shoreline protection structures. A report published by the Ministry of Natural Resources (Water Network, 1991) documents historical river and lake flooding in the Province of Ontario and supports the findings of our algorithms: i.e., the months of March and April are the most damaging in terms of lake flooding. Also, relatively good agreement was seen between historical accounts of flood damages reported for Lake Ontario based on newspaper articles and the results generated with the FEPS.

Many long-term riparian land owners remember the low lake levels of the mid 1960's. This is often viewed as the utopian condition, with wide beaches in front of eroding bluffs and seawalls, and no threat of flooding. Natural beaches were wide and aeolian transport was able to build new sand dune systems. These low levels are desired by the members of the riparian community, and in general, make them the happiest.

2. Performance Indicators

The coastal performance indicators for Lake Ontario and the upper St. Lawrence River are listed below, along with important assumptions and data limitations.

a. Erosion performance indicator: This performance indicator quantifies the impacts of shore erosion on riparian property and public infrastructure (e.g., industrial buildings) located along the shoreline, in embayments and on the River. The algorithm assumes the owner will build shoreline protection prior to erosion actually threatening the home. The economic cost of building the shoreline protection is a liability to the land owner. The major assumption of the economic methodology is that government agencies will continue to issue permits for construction of shoreline protection.

b. Shore Protection performance indicator: Water level impacts on existing shoreline protection structures are quantified with this performance indicator. During periods of high lake levels and storms, the algorithm predicts structure failures due to wave overtopping, undermining and degradation (age). The economic impacts are measured in terms of the cost to upgrade/replace the damaged structure. If agencies stopped issuing shoreline protection permits, the economic function would overestimate structure replacement costs. However, the damage would ultimately be transferred to the building(s) in the form of destruction due to erosion (i.e., home falls over the bank) and this process is not quantified in our algorithm.

c. Sediment Budget performance indicator: This performance indicator was developed for educational purposes, and no economic function was developed to quantify water level impacts on sediment budgets.

d. Flooding performance indicator: The impacts of water levels and storm waves on flood levels and the associated economic damages are quantified by means of the flooding performance indicator. The computer algorithm can be run in two different modes: i) with mitigation, which assumes the land owner will eventually mitigate flood risks if they are repetitive, and ii) without mitigation, which assumes the owner will sustain flood damage and continuously repair damages and replace contents to full value. The Plan Formulation and Evaluation Group and the Economic Advisory Group determined the 101-year simulation should not be performed as one century-long experiment, but rather as a series of 101 one-year experiments. Therefore, the second option was applied. Using the first option, a home that might be flooded five times a century would only be flooded once, after which mitigation would remove it from the pool of vulnerable homes, thus greatly underestimating damages.

e. Beach access performance indicator: The beach access PI quantifies the impacts of water levels on the physical conditions of recreational beaches, namely beach width, and the associated impacts on beach visitation at state and provincial parks. The field data collected indicated that beach width would affect visitation and ultimately economic expenditures. Of course, other factors not related to water level regulation, such as weather, will affect visitation. The algorithm only considers the impacts of water levels on visitation, as it is the only factor affected by regulation. This indicator was not used in the analysis because it was not deemed to have the proper rigor for comparison with the other performance indicators. A short summary on beaches follows in the next section.

f. Barrier beaches and dunes performance indicator: The principal component of the beach and dune PI is to highlight the important relationship between water levels and erosion/sedimentation cycles. For example, during high lake levels, barriers and dunes will be susceptible to erosion and migration inland. Conversely, during periods of low lake levels, beaches, dunes and barrier systems can recover naturally due to onshore sediment transport and aeolian processes (wind blown sand). There is no algorithm or economic calculation for this PI.

For the erosion, shore protection and flooding PIs, the scale for the assessment was the individual property parcel, while the economic results are reported on a county, country or system-wide scale. Since digital property parcels were not available for a number of the geographic regions of Lake Ontario and the upper St. Lawrence River, the total economic benefits or costs will be an underestimate of the actual impacts. Therefore, when comparing the dollar impacts, the results from the Coastal PIs should be considered conservative.

The computer algorithms developed for the erosion, flooding and shore protection performance indicators were based on four years of detailed study and data collection, peer reviewed throughout the development process and extensively documented in the three Baird reports listed in the sources below (2004a to 2004c). The reader is referred to these documents for additional information on modeling assumptions.

3. Potentially Significant Benefit Categories Not Addressed by the Current Performance Indicators (Secondary Impacts)

Several benefits and impacts of water levels not addressed by the current performance indicator algorithms in the SVM are summarized below.

a. For the erosion PI, in addition to the cost of constructing shoreline protection to mitigate erosion, a regulation plan that accelerates erosion reduces the actual footprint of a land parcel and thus the available land area. This reduction in parcel size is not quantified by an economic calculation, nor is it reflected in assessed property values. However, it does represent a secondary impact to riparian property owners.

b. In the case of the shore protection performance indicator, structure maintenance and replacement following a failure results in larger and higher structures. Not only are these structures more expensive to construct, but in some locations the ever increasing crest elevation may also impair the visual amenities of a property. In other words, if you cannot see the lake from your family room, there is no incentive to pay extra for a waterfront parcel.

c. Following a flood event, there are many additional secondary impacts such as temporary loss of residence, required leave from work to repair/restore the home and other negative economic spin-offs. These secondary impacts are not quantified under the current methodology.

d. As mentioned previously, there are no economic calculations associated with the barrier beaches and dunes PI, only recommendations for new criteria. The benefits of increasing the frequency and duration of low lake levels will not be summarized in any economic tables; however there will be significant benefits to beach-dune systems and the environmental habitat they provide and protect.

   Beaches grow when sand moving through the water along the shore drops out of suspension. This is a very dynamic process that depends on sand supply, longshore drift, wind and wave action and water levels. Modeling the deposition process would require the ability to model the composition of soil being eroded along the entire coast, its transport along the coast and into deep water, and then the time and place of its deposition—an imposing task and one that was not deemed possible at this time.

   Compounding this difficulty is the fact that the candidate plans are fairly similar. The plan lows and highs are constrained by concerns about flooding, boating, navigation and water supply and so are more similar than different, and the distinctions between them in terms of beach deposition are almost certainly slight and beyond the precision and accuracy of any predictive model.

   Nevertheless, beach and dune systems are important for the critical role they play in sheltering the embayments and drowned river valleys located around the perimeter of Lake Ontario. Since half of the developed shoreline has been permanently altered by the construction of shoreline protection, an equivalent reduction in the production of new sand and gravel from natural erosion can also be assumed. This reduction in sediment supply will likely impact the shoreline immediately adjacent to the protection structure, plus the beaches that historically relied on the updrift supply of new sand and gravel from erosion. Collectively this process has resulted in sediment-starved shorelines throughout Lake Ontario and many of the other developed coastlines in the Great Lakes Basin. The reduction in sand supply could leave beaches even more vulnerable to water level changes. Beaches may not be able to recover from high water the way they once did. As a result, experts suspect that the small differences between candidate plans could be important to sustaining beaches. Candidate Plans such as A^+ and B^+, which include higher summer and winter lake levels that can accelerate long-term erosion rates, may lead to negative morphological changes, including breaches of new inlets during storm conditions, erosion of the protective dune systems and, possibly, the long-term degradation of the features.

4. Key Baseline Conditions

There are two key baseline conditions related to riparian property around the perimeter of Lake Ontario and the St. Lawrence River, as defined by the digital property parcel database. First, development permits will continue to be granted for privately held land. In other words, land owners will be able to develop waterfront parcels for residential and commercial endeavours. This trend will likely continue, and therefore, because development controls are weak or inadequate in some jurisdictions, future homes will be constructed too close to the waters' edge and be subject to coastal hazards. In short, the number of parcels at risk will increase in the future.

The second key baseline condition relates to the current approach for addressing water level hazards for two of the Coastal PIs: erosion and existing shoreline protection structures. The economic methods for these two PIs include adaptive behaviour in the form of engineering solutions. In other words, in the evaluation of a new potential regulation plan in simulation time (hypothetical time in the future for the computer models), if erosion is threatening homes because a plan features high lake levels, our economic methods assume the owners will mitigate the hazard by building new shoreline protection. They will not allow their investments (i.e. homes) to fall into the lake because this loss is significantly greater than the cost associated with building new shoreline protection or upgrading existing protection. It is assumed that new, upgraded, or replacement shore protection will be well-engineered, with a design life of 25 years.

As mentioned above, securing a permit to build shoreline protection along the waterfront is a complicated, lengthy and expensive proposition. However, if the riparian perseveres, often with the assistance of a professional engineer, a permit can be successfully obtained.

If the regulatory process is altered or changed in such a way that riparian land owners can no longer protect their properties from coastal hazards with engineered structures, the predicted economic damages for high lake levels will increase dramatically. Rather than incurring the cost of building a $20,000 to $40,000 seawall to protect a riparian dwelling, the owner may lose a $200,000 building because of erosion and flooding damages. Therefore, the current economic methods developed in the FEPS and linked to the SVM would significantly underestimate the impacts of high lake levels under this scenario.

In summary, there are two key baseline conditions or assumptions for the Coastal PIs. First, riparian land owners now live in coastal hazard areas, and future development of new parcels for residential or commercial uses will likely increase the number of properties at risk. Second, the riparian land owners will be permitted to mitigate coastal hazards with engineered protection. In other words, a shoreline protection structure is less costly than losing the entire home, and this is generally the desired approach for the riparian land owner.

5. Key Trends

The Coastal Technical Work Group has prepared a comprehensive report on existing and future land use trends entitled *A Summary of Existing Land Use, Land Use Trends and Land Use Management Policies Along the Lake Ontario – St. Lawrence River Shoreline: Implications for Future Water Level Management*, (CJSC, 2004). Some key findings of this report are summarized in the bullets below:

a. Approximately 60% of the Lake Ontario and upper St. Lawrence River shoreline is devoted to residential land use. In some of the developed counties, such as Monroe on the southeast shore, the percentage of developed property is much higher, at almost 90%.

b. The increase in shoreline development along the Lake Ontario shoreline for the decade from 1990 to 2000 was approximately 6%. There is every indication that this decadal growth rate will continue in the future until no undeveloped land is available.

c. On the south shore of Lake Ontario, the detailed US parcel data indicated the average new house size has almost doubled in the last 10 years, compared with all previous development. It is not surprising that the assessed values of the homes constructed in the last ten years have also doubled. Although detailed data were not available to complete a similar analysis in Ontario, the observed trends are very similar. Collectively, this land use trend is referred to as "mansionization." New estate homes are being constructed among smaller cottage settlements, or smaller homes are torn down and replaced by an estate home.

d. With this rapid pace of development, some counties will reach their maximum development potential in the next 30 years (e.g., Niagara, Orleans and Monroe in New York State). Others, such as Halton, Peel and Toronto in Ontario, have already reached their development maximum (or, are very close). In other words, there are no open tracts of land to be converted to residential communities. In some of the more rural locations, growth can be facilitated for the next 100 years, and these will be the areas experiencing the most development pressure.

e. With the ever increasing urban densities and sprawl around the Lake and River, the value of public open space and recreational opportunities along the coast will increase. This urban pressure will intensify the use of beaches for recreational opportunities, and these facts highlight the importance of the beach access and barrier beaches and dunes PIs.

In summary, the trend for riparian land and residential development is continued rapid growth and increases in the size and value of new home construction. One implication for the IJC water levels study is the impact of the static property parcel database, which will underestimate future economic impacts as development densities increase and the value of existing real estate escalates. However, regardless of these limitations, the database of existing development will be sufficient to identify the plans that generate the greatest benefits and costs, based on the current conditions. During the design of our study, the Coastal TWG determined it was more important to accurately record and catalogue the existing development patterns than to forecast future growth. The anticipated growth, in turn, will make the recreational experiences associated with beaches even more valuable in the future.

6. Expected Consequences of Changes of Regulation

The erosion, flooding and shore protection PIs collectively quantify water level impacts on the built environment. In other words, the natural shoreline conditions have been altered or heavily modified by riparian land owners for their enjoyment and often to protect themselves from coastal hazards, such as erosion and flooding. The protection in most cases is in the form of structural solutions, such as engineered seawalls and rock revetments. In some cases, these structures have been carefully designed to account for the historical range of lake levels since regulation (i.e., 1960 to present). In other instances, a design professional was not consulted and the solution was based on local knowledge and experience. Regardless of whether the protection was well engineered or poorly designed, it was meant to address the driving forces (i.e. storm waves) and the historical range of lake levels since regulation (in most cases).

If significant changes are made to the operating range of Lake Ontario, such as increasing the upper limit or the frequency of high levels during the spring storm season, the level of protection provided by the existing physical infrastructure will be reduced. In other words, a seawall designed to protect a property from flooding during a storm event in the current operating range will be less effective at water levels of 76.0 m (249.3 ft), for example.

In short, there is significant development in coastal hazard areas on Lake Ontario and the upper St. Lawrence River. Many of the riparian land owners attempt to mitigate or reduce the hazards with structural protection based on lake level trends since regulation. An increase in the frequency, duration or magnitude of high lake levels in the future under a new regulation plan will magnify the many challenges front row developments already face by being located on the edge of the Lake and River. Conversely, the existing shoreline protection would provide increased benefits if the current upper threshold for the operating range was lowered.

With respect to beaches and dunes, the current regulation plan (1958-D) and adopted deviations has reduced the natural range of fluctuations on Lake Ontario. While the reduction of high lake levels has reduced erosion rates for sandy shorelines, this stability also negatively impacts dune grass communities, which require occasional disruption. Attempts to eliminate periods of low lake levels benefit commercial navigation and recreational boating; however, they deprive these natural sandy shorelines of their period of rejuvenation through enhanced aeolian activity and beach recovery. The following bullets provide some insight into the expected consequences of changes in the regulation of Lake Ontario water levels:

- Increasing the upper limit of the operating range of Lake Ontario will accelerate beach and dune erosion and threaten the stability of barrier beaches. These are dynamic sandy systems, and hard structural engineering will not mitigate the effects of higher lake levels.
- Decreasing the lower limit of the operating range or increasing the frequency of low lake levels would provide benefits for beaches, dunes and barrier complexes. However, it is not possible to quantify these benefits in terms of dollars in the Shared Vision Model.
- Utilizing the existing regulation plan and further suppressing the natural range of Lake Ontario will reduce the potential of the beaches for natural recovery. Some of these impacts could be mitigated with large scale beach nourishments, but these projects are costly and not common on Lake Ontario.

7. Adaptive Behaviours

The following bullets describe adaptive behaviour for the six coastal performance indicators (where applicable):

a. Erosion performance indicator: The entire economic methodology for this PI is predicated on adaptive behaviour. Riparian land owners don't let their homes fall into the water—they build shoreline protection. The prevalence of shore protection (approximately 50% of lake parcels armoured) justifies the selection of this methodology.

b. Shore protection performance indicator: Again, the entire algorithm for existing shore protection is based on adaptive behaviour. When a structure fails or no longer provides adequate flood and erosion protection, the riparian adapts by upgrading the structure.

c. Sediment budget performance indicator: There is no economic methodology for this PI and thus no adaptive behaviour.

d. Flooding performance indicator: Property owners who suffer flooding or wave damage might adapt by raising their building, bringing in fill to raise the lot, and/or incorporating shore protection. While it is highly likely that property owners experiencing erosion will construct shore protection prior to their homes falling in the water, a property owner who is occasionally subject to flooding and waves may experience damages several times before adapting. For purposes of this analysis, it was assumed that property owners do not adapt to flooding and wave damage.

e. Beach access performance indicator: When water levels result in an undesirable beach condition, such as a very narrow zone for recreational activities, the most common adaptive behaviour is substitution. In other words, alternative recreational options are selected, such as interior camping.

f. Barrier beaches and dunes performance indicator: The principal users of the barrier beach and dune ecosystems are flora and fauna (animals and plants). They do not necessary adapt to changing physical conditions, such as an eroding dune system or degraded marsh, but rather respond to the altered environment. For example, the piping plover no longer nests in sand dune environments along the shores of Lake Ontario because this type of habitat has virtually disappeared. The population has responded by decreasing in size and has altered its natural range, which no longer includes Lake Ontario.

8. Risk Assessment/Sensitivity Analysis

The following bullet points provide some quantitative information on the number of homes at risk from erosion, flooding and damage to existing shore protection structures. The statistics are based on an analysis of the property parcel database, which includes over 20,500 riparian land holdings. In addition, some qualitative comments are provided on water level impacts on beaches and dunes.

a. A total of 578 homes are less than 20 m (65.6 ft) from the shoreline of Lake Ontario. Of these 578 homes, over 200 are less than 10 m (32.8 ft) from the shoreline and 91 are within 5 m (16.4 ft) of the Lake Ontario waterline. Many of these homes are at imminent risk of losses from continued shoreline erosion and flood damages.

b. A total of 7,661 homes were identified with land elevations at or below the 77.2 m (253.3 ft) contour, which was an upper threshold for potential flood damages established by the Study. Of this total, 790 have elevations at the base of buildings equal to or less than 75.37 m (247.3 ft), which is the current upper limit of the operating range for Lake Ontario. When lake levels reach or exceed this upper threshold of the existing operating range, as they did in 1973 and 1993, the risk of economic damage to these low lying properties accelerates.

c. The property parcel database identified 5,559 existing shoreline protection structures, such as seawalls and revetments, on Lake Ontario for front row buildings. Of this total, only 5% were Level 1 structures (well engineered and well maintained with a design life of greater than 50 years). Of this 5%, many of the parcels were associated with institutional buildings, such as water treatment facilities, power plants, and marinas. Very few Level 1 structures protect privately owned riparian property and buildings. Therefore, changes to the current operating range in the future, such an increase in the occurrence of high lake levels, will increase the frequency of maintenance events for the vast majority of these structures protecting riparian property (Level 2 and 3 shoreline protection structures) and decrease their life expectancy. Conversely, low lake levels will extend the life cycle of these existing shoreline protection structures and will be more effective at minimizing hazards, such as flooding.

d. There is considerable risk associated with adopting a new regulation plan that does not consider the specific needs of beaches and barrier complexes. First, human interaction with the waters edge may be negatively impacted in the future. Second, since many of the Environmental TWG performance indicators rely on the habitat created by barrier beaches, these PIs will also be negatively impacted. And finally, these physical-biological interactions are not quantified in the Shared Vision Model, which makes it imperative that the findings summarized in the contextual narratives and PI summaries be considered when evaluating new potential regulation plans.

Much of the existing coastal community along the shores of Lake Ontario and the upper St. Lawrence River is located within the coastal hazard zone. Since regulation began in 1960, the historical range of lake levels has resulted in economic costs due to erosion, flooding, construction of new structural protection, and maintenance of existing shore protection. Since development pressures are anticipated to increase the number of properties located in the coastal hazard area in the future, higher lake levels will increase economic damages. Lower lake levels, such as the new upper operating range recommended by the Coastal TWG for Lake Ontario, will decrease economic losses and provide benefit to beaches and dunes.

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Received TWG Support: Yes

C. Coastal Processes Contextual Narrative for the Lower St. Lawrence River

1. General Socio-economic Context

(a) Production value of the interest

The shorelines of the St. Lawrence River between Cornwall and Lake St-Pierre are a vital cultural, recreational, ecological and residential resource. Currently, there are about 5,770 single-family dwellings within the 100-year return floodplain of the lower St. Lawrence River between Cornwall and Trois-Rivières. There are also about 620 other buildings, either commercial, industrial, farming, etc., present in the floodplain (Doyon et al., 2004). In 2003, the existing residential buildings had an approximate total value of US$380 million (C$460 million).

There are 388 km of eroding shoreline in this section of the St. Lawrence River, of which 27 km are heavily eroding (average recession rate of 1.1 m/yr). There are over 400 km of shore protection along the St. Lawrence River downstream of Cornwall, representing an infrastructure investment of over US$200 million. Erosion and shore protection design is influenced by the combined effects of waves, ship wakes and water levels. In most residential areas, waterfront property is the most desirable and therefore most valuable property.

(b) Number of stakeholders

There are approximately 42,000 individual land parcels and 20,000 residents living along the River's banks or within the 100-year return floodplain of the lower St. Lawrence River between Cornwall and Trois-Rivières. These shorelines constitute a major natural feature of dozens of communities, including small towns and villages, First Nation communities and the city of Montreal (regional population of 3.3 million). Furthermore, the river shoreline serves as a key cultural and historical focal point for the origins of the communities.

(c) Organizational characteristics

Urban land uses occupy 3% of the territory along the shores and within the floodplain of the St. Lawrence River [Côté et al., 2003]. Agricultural activities, natural environments and wetlands constitute the dominant land uses for this sector. Certain areas of the river reach between Cornwall and Trois-Rivières are heavily urbanized, with residential land occupancy of up to 90% (Montreal, Longueuil, Trois-Rivières, Repentigny and Sorel). Other areas are moderately urbanized and urban land uses account for approximately 50% of land use (St. Lawrence River banks between Montreal and Sorel, Lac St. Louis and Bécancour). Finally, in the less urbanized areas (Lake St. Francis, Lac St. Pierre and the Sorel Islands), a low percentage of the land (generally less than 20%) is characterized by urban land uses. Some of these areas, such as the Sorel Islands, have experienced extensive seasonal residential development.

In general, densities and property values are higher in and near urban centres, such as Montreal, Longueuil and Trois-Rivières, with both density and property values decreasing in the rural communities. The average value of residences is $213K in the heavily urbanized areas, while the value in the moderately and less urbanized areas is $80K and $43K, respectively. In most heavily residential areas, waterfront property is the most desirable and therefore most valuable property.

(d) Values and perceptions of the interest

Ecologically, these shorelines are made up of a complex mixture of wetlands, wooded and grassed areas, comprising valuable habitat for a vast number of migratory waterfowl. Culturally, the River has been the source of food and transportation and it provides an important connection to historical origins for both Aboriginal and European peoples. The values and perceptions of the riparian owners are as wide and diversified as the study area itself.

(e) Significant statutory, regulatory and policy restrictions

Prior to about 1980, there were no laws or regulations controlling construction within the floodplain in Quebec. Since then, several laws and regulations have been progressively implemented for the management of construction within the floodplain. These laws address land use, shore and floodplain protection, and environmental protection. In 1976, the Canada–Quebec convention concerning the mapping of floodplains was adopted. In 1987, the Shore, Coast and Floodplain Protection Policy was adopted, the main elements of which were integrated into the development plans of Quebec's regional county municipalities (RCMs).

However, these laws and regulations seem to have failed to stop construction within the floodplain. Several authors have shown that residential development in the floodplain has continued, and in certain cases even increased, since the beginning of the 1980s, with urban expansion seemingly unaffected by the designation of floodplains [Forget et al., 1999; Bouillon et. al., 1999; Roy et al., 1997]. In the last 30 years, floodplain occupancy and its consequent economic value have generally increased in Quebec.

Since 1998, the Government of Quebec has implemented exception mechanisms to the prohibition to build within the floodplain. These mechanisms allow building within the floodplain under certain conditions (defence work, uplifted buildings, etc.). Despite the implementation of these derogation mechanisms, the laws and regulations applying to construction within the floodplain have become increasingly restrictive over the years. It is therefore likely that this general trend to restrict building in the floodplain will continue in coming years. However, it is difficult to assess the long-term impact of the overall regulations, as the regulations are applied in different manners in different areas, and certain municipalities are more permissive regarding construction within the floodplain.

Erosion processes (and related shore protection works) are driven by the combined influences of ship traffic, wind waves, river currents and water levels. Recent trends toward larger container ships downstream of Montreal have been shown to increase shoreline erosion. This places an increased pressure on the riverine system and heightens the need for careful management of the combined effects of river flows, water levels and ship traffic.

As a waterway, the River provides an essential link for one of the most safe and fuel-efficient transportation modes available. The Port of Montreal and the St. Lawrence Seaway system are important socio-economically in their own rights (see contextual narrative for navigation). Concerns about climate change and fuel cost and availability are increasing the economic imperative to use ships rather than rail or trucking to transport goods. In light of this, the Canadian and U.S. governments are examining the feasibility of expanding the draft and vessel length capabilities of the present Seaway system to accommodate much larger vessels as well as container vessel traffic upstream of Montreal.

Over the next ten years, public concerns about the environmental degradation of the shorelines of the St. Lawrence due to the combined effects of water levels and ship traffic are going to increase—because of both increased pressures on the system (in particular due to navigation issues) and increasing public concern over man's impact on the natural environment (climate change, urbanization, environmental degradation, etc.).

(f) History of the interest

For several centuries, the shores of the St. Lawrence have been privileged for human occupancy. The first houses were built mostly outside of the floodplain, residential development within the floodplain being a relatively recent phenomenon. Between 1930 and 1945, the socio-economic context (economic crisis, war) resulted in very few single-family dwellings being built in Quebec and consequently within the floodplain. From 1945 to 1964, in the context of an economic boom and rather loose regulations, a number of houses were built within the floodplain in Quebec. Between 1964 and 1983, construction within the floodplain was also fairly significant, as was also the case during the period from 1983 to 1997 despite the implementation of regulatory mechanisms to control this type of development.

This interest suffered badly during the high water levels of the 1970s. Extensive flooding occurred in 1974 and 1976, while heavy erosion triggered strong public outcry and resulted in the construction of many kilometres of shore protection. The media often portray high water levels and downstream erosion as a consequence of dam operations designed to protect Lake Ontario riparians at the cost of those downstream.

(g) Trade flows and current market conditions

The market for waterfront properties is still very active, even more so for houses located near major cities or in seasonal residence areas. At the same time, certain areas located within the floodplain, especially between Sorel and Trois-Rivières, are under pressure for development.

(h) Effect of last high or low water conditions

Residents around Lac St. Louis and the Sorel Islands suffered severe flood damages in 1974 and again in 1976. The most recent major flood event, which occurred in 1998, forced the evacuation of 1,000 residents in the Sorel Islands area. At the other extreme, when the River's water levels are low, flooding is not an issue for riparian property owners.

Similarly, high water conditions in the past have increased shoreline erosion and triggered increased shore protection costs, while lower water levels have reduced erosion and diminished public concerns regarding shore protection. There is no established program to reimburse property owners for land lost due to erosion, or for costs associated with construction or maintenance of shore protection structures. There is, however, a historical precedent for the Canadian federal government paying to build shore protection structures and maintain those erected within 300 m (1,000 ft) of the navigation channel in recognition of the impact of ship wakes and drawdown on bank erosion.

2. Performance Indicators

a. The performance indicators (PI) selected for the analysis are (Doyon et al., 2005):
   - Cost ($) of residential damages (structure and content);
   - Number of flooded homes;
   - Number of properties that could be expropriated (based on provincial regulations);
   - Total area (in hectares) of flooded lands quantified by land-use type;
   - Total length (in km) of flooded roads quantified by road type;
   - Total area and value of land lost due to erosion;
   - Total cost for modification and maintenance of shore protection; and
   - Total volume of fine sediment in river.

   Because we believe that economic performance indicators are not sufficient to fully describe the impacts of a flood and erosion on communities, we have established societal PIs to form the basis of the socio-economic impact assessment tools for flooding and erosion. As a result, some PIs translate the damage in terms of dollars while others account for societal aspects of the damage.

b. The estimated cost of possible flooding damages is based on fully comparable data that were provided by a survey of owners of riparian property in the study area. The survey asked different questions related to the cost and nature of the damages from the last major flood event that hit the region of the Sorel Islands in the spring of 1998. Flood-depth damage curves applicable to residential buildings in the study area were built for the purpose of the study.

   Also, it should be noted that, in some cases and for different reasons, the cost of damage is fully assumed by property owners who have been affected by a flood but who do not automatically ask for a government indemnity. In other words, the cost of the flooding damage is not fully assumed by the community.

3. Potentially Significant Benefit Categories Not Addressed by the Current Performance Indicators (Secondary Impacts)

The performance indicators listed above reflect direct damages without regard to the metric involved. The key PI is the cost of the residential damages (structure and content) as 89% of the buildings within the 100-year floodplain limits of the lower river are residential (Doyon et. al., 2004). However, it should be stressed that damages are not limited to the residential sector. Significant damages also occur to businesses and public infrastructure, particularly in larger floods. Infrastructure damages include damages to telephone, electricity services, roads, railways, flood structures and other public utilities.

At the same time, significant flood damages may arise from disruptions to physical and economic activities such as the loss of sales, reduced productivity and the cost of alternative travel if road and rail links are broken. These are indirect damages that have not been included in the monetary assessment of flood damages. The costs for relocation of evacuated people as well as for deployment of the contingency measures are other examples of indirect damages.

Intangible damages represent another category of damages. They arise from adverse social and environmental effects caused by flooding. There are a number of intangible costs of flooding to the community, including factors such as loss of life and limb, preparedness (cost of flood warning, planning, and community education), inconvenience, isolation/evacuation, stress and anxiety, disruption as well as other health issues. These intangible damages are not easily quantifiable and have not been included in the economic PIs.

Also, some secondary impacts can prove to be very subtle and yet, significant. For example, the properties at high risk generally have a reduced tax list value and, for this reason, they constitute a significant fiscal shortfall, in terms of municipal and school taxes, for local authorities.

Finally, we developed PIs that would allow ranking of the plans based on the assessment of specific, possible flood damages (e.g. residential damages). It should be emphasized at this point that the key PI does not allow assessment of all possible flood damages whether they are direct, indirect or intangible. Thus, the ranking of the plans will be predicated upon absolute damages, but not exhaustive ones.

4. Key Baseline Conditions

The performance indicators used to estimate flood damages rest on two working hypothesis: the first one considers only the existing residences in the assessment of possible flood damages. In other words, the residential occupancy comprises 5,770 single-family dwellings recorded within the floodplain, and the model considers that no new construction will be added to the housing inventory during the simulation. Also, the real estate values always remain constant, i.e. they are not indexed to the cost of living and do not follow the fluctuations of the real estate market. The economic damages are assessed in 2003 U.S. dollars.

The second hypothesis assumes that no mitigation measure is given to houses affected by flood damages during the simulation. Upon request by the PFEG, the model allows that a house having suffered damages (structure or content) could suffer further damages during the next flood event, whether or not the owner has taken steps to mitigate the risks of future flooding.

The analysis has assumed that ship traffic and wind-wave conditions in the River are the same as those observed over the last decade; any large-scale changes to ship traffic, such as deepening and expansion of the Seaway beyond its current dimensions, have not been considered in this analysis. Trends in increasing ship size downstream of the Port of Montreal have not been considered in this analysis.

5. Key Trends

Construction along river banks and within the floodplain will be more and more controlled given the increasing efforts of governments and municipal authorities to limit this type of development. As a case in point, the construction rate within the floodplain has greatly decreased in the Lac St. Louis area and between Montreal and Sorel, and this trend is likely to continue. However, the regulatory mechanisms have a much more moderate impact in the Sorel Islands area, where the density of houses within the floodplain is increasing. On the other hand, the newly built houses in the floodplain are better protected against flood damages.

In the coming years, it is expected that residential development will occur mostly within areas, determined by the development plans, that are known as residential development priority zones. These zones are adjacent to existing urban perimeters, generally away from river banks and the floodplain. However, the potential development of some sectors of the floodplain of the St. Lawrence River is not completely excluded, due to the existence of mechanisms that permit construction in floodplains under certain conditions.

Areas of moderate urban density are experiencing growth through new residential construction, and it is likely that a small amount of this growth will be in the floodplain. Also, construction of cottages on vacant land is continuing to occur in areas with existing cottages, and it is expected that this trend will continue, especially in the Sorel–Trois-Rivières reach. Also, over the past thirty years, there has been a trend towards conversion of seasonal cottages to permanent residential dwellings. Many cottages still remain in some areas, and it is likely that this trend will also continue.

In heavily urbanized areas such as Montreal and Longueuil, most of the available land along the River has been developed and there is very limited potential for additional development in these areas. Although this cannot be qualified as a significant trend, it is not uncommon for a modest cottage (or 2 or 3 cottages) to be torn down and replaced with a large house worth several times the value of the original cottage(s).

Generally, the properties at high risk of being regularly flooded have a reduced tax list value and constitute a significant fiscal shortfall for local authorities (cf. Section 3). Although they are devalued, the market value of these properties has historically followed overall real estate market fluctuations, some properties having seen their value grow five-fold over the past decade (Radio-Canada, 2004).

Areas of the natural environment that are protected by virtue of their legal status (protected sites) are not at risk of being affected by development in the future. There is a trend in some areas to an increase in the amount of protected natural areas.

Increasing ship traffic effects due to size of vessels (downstream of Montreal) and the effects of possible ship channel deepening could have a major effect on erosion processes and associated shore protection costs on the River. The intensity and extent of erosion and shore protection impacts are directly linked to the size, speed and number of ships using the waterway—changes in the waterway and the ships that use it can have direct impacts on the shorelines. Speed controls such as those presently in place downstream of Montreal are one of the key elements in reducing erosion due to ship traffic. The effects of ship wakes on erosion are inexorably linked to the water levels in the River: river banks are generally more susceptible to erosion during periods of high water levels.

6. Expected Consequences of Changes of Regulation

It is unlikely that there will be any significant movement of residences out of the floodplain. Also, residential construction within the 20-year return floodplain will be almost nil, considering the control applied by government authorities. In the 100-year return floodplain, residential development is likely to continue although it will remain a rather limited phenomenon. Nevertheless, we estimate at 375 the number of new houses that could be built within the 100-year return floodplain in the next 15 years. However, these houses will be better protected against flood damages. Also, the existing houses are likely to become better protected over the years.

Obviously, all these phenomena will induce an increase in the economic value of the dwelling stock within the floodplain. The number of single-family homes within the floodplain is likely to grow above 6,000 units over the next 10 years.

The combination of increased erosional pressures (due to shipping) and increased public concern over environmental degradation could result in a change in the manner in which this waterway is used. Navigation management will likely have to consider shoreline responses as a key component of channel design and traffic control. Mitigation measures related to any navigational changes will probably have the effect of increasing the amount of protected natural shoreline and wetland habitat. This may necessitate the construction of shore protection works to protect sensitive areas.

7. Adaptive Behaviours

In general, the major benefit of the construction of flood modification measures is a decreased cost of flood damage to properties protected by the measure. In spite of the fact that mitigation measures also decrease the emotional, social and psychological trauma experienced by residents in times of flooding, this Study has shown that riparian owners on the lower river do not automatically apply mitigation measures to their property after a flood event, regardless of the severity of the damages (Doyon et al., 2004).

As an example, significant damages have been reported after much less noteworthy floods than the two major flood events of 1974 (recurrence at the Sorel hydrometric station: 1 in 18 years) and 1976 (1 in 300 years). In order of importance, the following is a list of the dates of other minor floods for which damages have been recognized (but mostly in the Sorel Islands and around Lac St. Pierre):

- March 31, 1998 (1 in 5.5 years),
- February 23, 1981 (1 in 2.5 years),
- May 10, 1983 (1 in 1.9 years).

The previous example illustrates that mitigation measures are not automatically applied by property owners. If mitigation measures had been applied by all property owners who suffered severe flood damages during the flood of 1976, the following minor floods would have caused only minor damages, if any. However, we recognize that some property owners will want to eliminate all future hazards after a major flood event. Other property may consider the indemnity paid by government authorities as a type of insurance policy, which would explain why mitigation takes place gradually.

That being said, none of the selected performance indicators described above involves adaptive behaviour on the part of the riparian owners. Again, this does not mean that adaptive behaviours or application of mitigation measures by shoreline property owners does not happen.

Finally, from a computational standpoint, it must be said that the application of a mitigation factor is quite straightforward when the building-to-building approach of the detailed models is used. However, a progressively applied mitigation factor might not be as simple to implement when in the form of an SVM equation that expresses the damages for a whole municipality.

8. Risk Assessment/Sensitivity Analysis

Some environmentally significant wetlands and habitats exist in the lower St. Lawrence that are sheltered by small islands close to the ship channel (e.g. the Contrecoeurs region). These small islands are presently eroding. Should these islands be completely eroded, large wetland areas would lose their sheltering and become exposed to wind waves, ship wakes, and currents that could disrupt their ecosystem and result in significant habitat loss (due to changes in bed sediments and vegetation patterns).

There are many residential properties along the St. Lawrence River that have been only marginally affected by flooding in the past. For example, around 440 cottages are situated on the Sorel Islands. Most of them are on piles and are located in the floodplain of the River. An increase in peak water levels/flows in these areas will cause extensive property damage and human displacement.

In the same line of thought, many residential properties along the River are only slightly removed from the 100-year floodplain limits. The number of residences situated at the outer limits literally explodes: from less than 6,000 within the floodplain, the number of homes rises to over 60,000 near the perimeter of the floodplain (approximately 0.5 km (0.3 mi) above the floodplain limits). Obviously, the effects of water levels exceeding the actual 100-year mark would be dramatic in terms of property damage.

The stage-damage curves produced for the lower river are calibrated for the regulation plan actually in effect. The curves are representative of the risk that the property owners are willing to assume at the present time, considering the expected water level fluctuations. Should the IJC implement another regulation plan that would suddenly cause drastic changes in the water levels—in turn causing houses that were not usually at risk to be regularly flooded—then it is expected that property owners would react differently. In these circumstances, it might be appropriate to adapt the flood damage assessment method by including the application of a mitigation factor.

Finally, it is important to note that the damage functions cannot be used to assess the damage resulting from flooding due to the presence of an ice jam. Nevertheless, ice jams remain a significant factor in flooding, especially during winters with heavy snowfall or severe cold. For instance, in 1993, some 39,450 people were displaced, and assets worth an estimated $1.5 billion (not including municipal, industrial and agricultural producer losses) were damaged when an ice jam affected the St. Lawrence and its tributaries (Fisheries and Oceans Canada, 2005).

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10. Review Process

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External Review: PFEG and EAC

D. Commercial Navigation Technical Work Group Summary

The Commercial Navigation Technical Work Group (CNTWG) developed planning objectives and metrics, performance indicators and evaluation methodologies to evaluate the impacts on the U.S. and Canadian commercial navigation industry of alternative Lake Ontario outflow regulation plans. Changes in Lake Ontario outflows change water levels and velocities/currents in the Lake Ontario–St. Lawrence River System, which has impacts on commercial vessels transiting through this area.

Three key geographical areas were identified for which impacts on commercial navigation were developed: 1) Port Weller to Cape Vincent (Lake Ontario); 2) Cape Vincent to the Seaway entrance at Montreal Harbour (the St. Lawrence Seaway); 3) Montreal to Batiscan (St. Lawrence Ship Channel). Impacts from high Lake Ontario outflows, impacts from low Lake Ontario outflows, and impacts from the timing of discharges were developed for each of the three (3) geographical areas. Ice management operations, especially in the downstream area (Montreal to Batiscan), also have an impact on commercial navigation.

Objectives

The Commercial Navigation Work Group developed the following planning objectives for their interest:

- Optimize water levels and currents to minimize damages, maximize benefits and maintain navigational safety, without exceeding flood thresholds.
- Minimize extremes in water levels and velocities in terms of amplitudes and frequencies of variations to provide stability and predictability, in order to optimize long-term cargo load planning for commercial navigation.
- Maintain velocities in a safe range for commercial navigation.
- Maximize ice cover stability and integrity from Montreal to Batiscan in winter to prevent ice jams and resulting flooding and to maintain navigational safety.

The preferred plan for the Commercial Navigation interests is one that optimizes navigable conditions in Lake Ontario and the St. Lawrence River through Batiscan and balances impacts between the three reaches.

Data Collection and Evaluation Methodology

Baseline information on U.S. and Canadian vessel movements was developed for the study area. The 1995 to 1999 period represented the most recent information available at the time.

Data collection focused on four main types of data: data on commercial vessels, data on vessel trips, data on the cargo carried and data on the ports. This data was used to model economic impacts of various water regulation plans on commercial navigation.

The final database consisted of 28,390 individual vessel trips that took place from 1995 to 1999. The movement data was obtained from the Canadian Coast Guard, the St. Lawrence Seaway and the U.S. Army Corps of Engineers. The trip data included movement for all vessels with a draft equal to or greater than 7 m.

The Commercial Navigation Technical Work Group developed an economic impact model to evaluate integrated impacts on Canadian and U.S. commercial navigation of various Lake Ontario regulation schemes for the Lake Ontario-St. Lawrence River System. The model used the commodity movement database for 1995 to 1999 as representative commodities/tonnage and origins/destinations. The model was built by Innovation Maritime, in collaboration with HLB Decision Economics Inc., Lauga and Associates Consulting Ltd., J.D Pace and Associates Inc., and respective organizations of the Commercial Navigation Technical Work Group members.

Performance Indicators

Commercial navigation looks at the total transportation costs in U.S. dollars vs. water elevation, for the three geographic areas, per quarter-month.

Total transportation cost curves were derived for each quarter-month. Cost estimates were derived from 1995-99 commercial navigation traffic, and represent the best available data on commercial activities, cargo and vessel mix at the time the studies were initiated. The Seaway system in the study years (1995-99) was operating at approximately 45% of capacity in terms of transits. This does not reflect current vessel movements at Montreal, especially container traffic, and may underestimate the impacts on commercial navigation, particularly at Montreal.

Quarter monthly water levels for any alternative regulation plan were converted to daily water levels, assuming a linear interpolation between quarter-monthly data points. Vessel departure dates were used to identify the range of water levels that a vessel would encounter during its transit. These water levels governed the maximum load the ship could carry. The lowest water level encountered during the transit governed ship's carrying capability. These water levels were compared with the metrics developed for the geographical areas the vessel would transit. These metrics determined whether the vessel had to slow down or stop during its movement. A running summary of total transit times was computed for each vessel. These transit times were then converted to costs using daily vessel operating costs associated with various vessel types. Vessel operating costs were developed for 26 vessel types.

Two component sub-models were developed to isolate commercial navigation costs arising from three factors: costs due to ship transits based on tons carried according to available water levels; costs due to currents; and costs due to high gradient delays. Sub-model a) tracked a vessel through its movement and kept track of all three potential costs and the hours of travel associated with these three costs. Sub-model b) converted these hours of transits to dollars. Currents encountered during a movement affected vessel speeds and thus total transit times. Gradients encountered during a vessel movement also impacted total transit times. If specific gradients were exceeded during a voyage, the vessel would stop until the gradient returned to a level below the target gradient.

Baseline Economics – Commercial Navigation

The St. Lawrence Seaway opened in April 1959. In combination with the eight locks on the Welland Canal, the Seaway allows ocean-going vessels and lakers up to 23.8 m (78 ft) in width and 225.4 m (740 ft) in length to access all of the Great Lakes. The Montreal-Lake Ontario section of the Seaway is an integral part of this system. This section encompasses a series of seven locks, which allow ships to navigate between the lower St. Lawrence River and Lake Ontario. The system serves the area called "the Midcontinent region," which constitutes the industrial and agricultural heartland of North America. This area encompasses eight Great Lakes states, and the provinces of Ontario and Quebec. The system also serves the large Canadian mining operations in Quebec and Labrador, as well as large metropolitan areas located along the St. Lawrence River in the province of Quebec.

Overall, imports and exports to, from, and within the region average some 146 billion tonne-kilometres (100 billion ton miles) annually. Over 27 million tonnes (30 million tons) per year, representing some 2,950 ship movements, are shipped annually through the Montreal-Lake Ontario section of the system. Montreal Harbour is the most important container port in eastern Canada and one of the fifteen largest in North America, handling about a fourth of the container volume of the New York/New Jersey harbour. According to the Port of Montreal, container traffic grew from about 7.1 million metric tones (7.8 million tons) in 1994 to 10.8 million tonnes (11.9 million tons) in 2004. Vessel size and draft has increased substantially over the past 40 years. Containerized shipping through the Port of Montreal is expanding as part of a worldwide boom of containership trade.

More information on the socio-economic context, potentially significant benefits, key baseline conditions, key trends, etc. applicable to commercial navigation is available in the Commercial Navigation Contextual Narrative (Appendix F of the CNTWG Final Report).

The economic advisors recommended using shipping revenues under Plan 1958-DD as the economic baseline for commercial navigation. However, given that no data was available on average annual commercial navigation revenues, the economic advisors suggested using transportation costs under Plan 1958-DD. This necessary substitution most likely underestimates revenues. Fortunately, none of the candidate plans create losses for navigation (or even significant losses in any reach), so there is no need for an accurate baseline on which to judge whether the loss is disproportionate. The total average annual transportation costs for commercial navigation under Plan 1958-DD are shown in Table D1.

Table D-1: Economic Baseline for Commercial Navigation under Plan 1958-DD

	($US million)
COMMERCIAL NAVIGATION	**$194.4**
Lake Ontario	$29.2
Seaway	$108.8
Montreal down	$56.4

Analysis

Regulation of Lake Ontario outflows affects commercial navigation on Lake Ontario and the St. Lawrence River through Batiscan, Quebec, by changing lake and river levels and velocities in this portion of the Great Lakes-St. Lawrence Seaway. Impacts on commercial navigation occur not only from these changes but also from the timing of these changes (seasonal and weekly) and the resulting currents and their affect upon ice formation. Commercial navigation impacts can occur at both low and high water level extremes and are also influenced on the lower St. Lawrence River by flow from the Ottawa River.

The hydraulic attributes that negatively impact commercial navigation in each of the three geographical areas were identified. A total of forty two indicators or metrics were developed to track when impacts to navigation occurred. The indicators were developed for high flow/water level conditions, low flow/water level conditions, timing of discharges and gradients/velocities for each area. Metrics were also developed that would enhance the formation of the stable ice cover important to winter navigation at the Port of Montreal. Impacts on commercial vessels range from increasing vessel fuel consumption and transit times due to strong velocities/currents, reductions in vessel speeds to minimize vessel wakes during high level conditions, stoppage of vessel transits when velocities are too high for safe navigation, reductions in cargo carrying capacity when water levels are low, etc. A complete description of these metrics is provided in the document titled *Planning Objectives and Performance Metrics for Evaluating Impacts of Lake Ontario Outflow Regulation Plans on Commercial Navigation* (Appendix A to the CNTWG Final Report).

The economic evaluation model included the following: origin/destination commodity movement data, the physical system the vessels will use (ports, locks, channels), water level data, ice control parameters, transit times (including speed limits, average lock waiting and transit times and delays), vessel operating characteristics and vessel operating costs. Five major databases were required to run the model: the vessel traffic database; the hydraulic database for each plan; a voyage profile database; a ship operating cost database that includes fixed and variable ship operating costs as well as pilotage fees, Canadian Coast Guard fees and Seaway tolls; and finally an individual vessel operating characteristics database that includes ship length, mid-summer carrying capacity by commodity, tons per inch immersion factor, type of engine, etc.

Vessel operational data is stored about movements on each leg of a journey. A vessel may incur various delays based on the 42 hydrologic trigger levels and gradients. The output of the simulation documents the vessel transit times, including delays, the tonnage carried and the fuel consumption according to the hydraulic conditions encountered by each vessel for the simulation period. The vessel operational data is then translated into costs. Commercial shipping costs fall under the following three main cost categories: capital costs (vessel replacement costs), operating costs (crew costs, lubes and stores, insurance, maintenance and repair and administration) and voyage costs (fuel costs, Seaway tolls, pilotage charges and government fees). Trip costs are calculated for each vessel trip for each year of the 101-year simulation period. A detailed description of the Economic Impact Model is provided in *Impact Evaluation Model for Commercial Navigation on the St. Lawrence and Lake Ontario. Final Report* by Maritime Innovation (Sept 28, 2004), which is included in Appendix B of the CNTWG Final Report under separate cover.

The Commercial Navigation Technical Work Group developed their own plan ranking methodology, based on both the average annual transportation cost performance indicator and the 42 hydrologic metrics, to help assess the most favourable plan for this interest. In general, metrics violations will result in vessel speed reductions, draft reductions or vessel stoppages. While these do translate into increases in shipping costs, it is normally preferable, for example, to reduce speeds rather than vessel draft, and predictability/stability were also considered an important factor in determining which plan performs better for the commercial navigation interest. The two areas that seem most sensitive to changes in a regulation plan are costs induced by shipping delays on the St. Lawrence Seaway, and reliability and timing of adequate depths for the Port of Montreal.

Integration into the Shared Vision Model

The Commercial Navigation Model was used to develop transportation cost curves that are used by the Shared Vision Model. These curves, which are regulation plan independent, are used to approximate the total yearly transportation costs, given a set of water levels for each quarter-month. This allowed the Plan Formulation and Evaluation Group (PFEG) to develop a large number of potential regulation plans and assess their impacts on commercial navigation without having to run the very detailed commercial navigation model. The annual transportation costs estimated using these cost curves were determined to be very close to the annual transportation costs that the detailed model would calculate. The curves were developed for water levels in 10 cm (4 inch) increments above and below chart datum at a given gauging station in each of three geographical areas: Lake Ontario, the St. Lawrence River, and Montreal. A description of the generation of these curves is provided in *Impact Evaluation Model for Commercial Navigation – Model Improvements for Simulations of up to 100 Years and for Shared Vision Model Inputs*, by Innovation Maritime in collaboration with Lauga and Associates (Appendix C of the CNTWG Final Report).

Summary of Key Findings

One of the key findings of the Commercial Navigation Technical Work Group was that there is almost always enough water on Lake Ontario to keep ships fully loaded, so this is generally not an issue in evaluating regulation plans.

There is not much that can be done through regulation during extended drought periods to avoid shallow depths in the Seaway, but there are differences in how well a regulation plan can maintain minimal acceptable depths at the Port of Montreal, and this is a key consideration especially given the dramatic increase in container traffic in the Port of Montreal since 1994.

Costs induced by shipping delays on the St. Lawrence Seaway portion of the system are sensitive to various regulation plans and key to the evaluation of alternative regulation plans.

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Commercial Navigation Technical Work Group

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Maritime Innovation. *Details of the Great Lakes Commercial Navigation Economic Impact Model*.

Planning Objectives and Performance Metrics For Evaluating Impacts Of Lake Ontario Outflow Regulation Plans on Commercial Navigation, report prepared by the Commercial Navigation TWG.

D. Commercial Navigation Contextual Narrative

1. General Socio-economic Context

a. Production value of the interest

The Great Lakes and their connecting channels, the St. Lawrence River and the Gulf of St. Lawrence, provide a continuous deep-draft waterway from the Atlantic Ocean into the heart of the North American continent. Basically, the Great Lakes-St. Lawrence River Navigation System can be described as follows:

1) From the Atlantic Ocean to just downstream of Quebec City, the system is a deep draft waterway. Transhipment facilities in that section of the river are among the deepest drafts in the world.
2) From just downstream of Quebec City through Montreal Harbour, the system is defined as the St. Lawrence Ship Channel, with a 10.7-m (35.1 ft) to 11.3-m (37.1-ft) draft waterway.
3) From Montreal through Lake Superior, the system offers an 8.23-m (27.0-ft) deep waterway.
4) The Montreal-Lake Ontario section of the St. Lawrence River, with a total of seven locks, provides a lift of about 70 m (229.7 ft).
5) Lake Ontario is connected to Lake Erie by the Welland Canal and its 8 locks, which provide a lift of about 99 m (~325 ft).
6) From Lake Erie to Lake Michigan-Huron, the waterway is the natural and dredged channels of the Detroit River, Lake St. Clair, and the St. Clair River. There are no locks required to assist navigation in that section of the waterway.
7) From Lake Michigan-Huron to Lake Superior, the waterway rises about 6.7 m (22.0 ft) by way of St. Mary's River and five locks, all located at the outlet of Lake Superior.

On average, Great Lakes ports enjoy a nine and one half month ice-free navigation season. The Montreal and downstream ports of the St. Lawrence River are open year round.

In the United States, at the south end of Lake Michigan, the Great Lakes-St. Lawrence River Navigation System connects with the Mississippi River Inland Waterway System, which has about 3,100 km (1,926 mi) of navigable shallow draft channels and provides barge transportation through the Gulf of Mexico. The Great Lakes-St. Lawrence River Navigation System also connects with the New York State Barge Canal near Buffalo, New York, to provide a shallow draft link between the Great Lakes and U.S. east coast ports (Atlantic Ocean) via the Hudson River.

In Canada, the Rideau, Trent, and Ottawa Canal systems link the hinterland with the Great Lakes and the St. Lawrence River. In addition, the shallow draft Richelieu-Champlain Waterway provides a connection between the Hudson River (U.S.) and the St .Lawrence River just downstream of Montreal.

With 90 commercial harbors and ports located throughout it, the Great Lakes St. Lawrence River Navigation System is one of the World's major waterborne systems. Today, this integrated navigation system serves miners, farmers, factory workers and commercial interests from the western prairies to the eastern seaboard. The annual commerce exceeds 180 million tonnes (198 million tons). For every tonne of cargo, there are scores, and often hundreds of human faces behind the scenes.[1] Marine commerce on the Great Lakes/Seaway System each year generates more than $4.3 billion in personal income, $3.4 billion in transportation-related business revenue and $1.3 billion in federal, state, provincial and local taxes. Approximately 10,000 tonnes (11,000 tons) of general cargo handled by a Great Lakes port contributes more than half a million dollars in local economic benefits.

1 The St. Lawrence Seaway Management Corporation Annual Report 2002/03

b. Number of stakeholders

The St. Lawrence Seaway opened in April 1959. In combination with the eight locks on the Welland Canal, the Seaway allows ocean-going vessels and lakers up to 23.8 m (78 ft) in width and 225.4 m (740 ft) in length to access all of the Great Lakes. The Montreal-Lake Ontario section of the Seaway is an integral part of this system. This section encompasses a series of seven locks, which allow ships to navigate between the lower St. Lawrence River and Lake Ontario. The St. Lawrence Seaway portion of the system has moved more than 2.1 billion tonnes (2.3 billion tons) of cargo in 40 years, with an estimated value of C$258 billion (US$173 billion). The Seaway supports 75,000 direct and indirect jobs in Canada and 150,000 jobs in the U.S.

c. Organizational characteristics

The Great Lakes/St. Lawrence Seaway corridor is unique for the scale and sophistication of its market and the extensive integration of its economy. The system serves the area called “the Midcontinent region,” which constitutes the industrial and agricultural heartland of North America. This area encompasses eight Great Lakes states, and the provinces of Ontario and Quebec. The system also serves the large Canadian mining operations in Quebec and Labrador, as well as large metropolitan areas located along the St. Lawrence River in the province of Quebec. This area is home to almost 100 million people, a third of the combined U.S-Canada population. On the Canadian side, Ontario and Quebec represent over 60% of Canada’s gross domestic product, while the Great Lakes States generate some 26% of the entire U.S. manufacturing base.[2]

The Midcontinent of North America is a highly productive area. It produces about 34% of the combined gross national products of the United States and Canada, one third of their capital investments and about 30% of their combined personal incomes. Its industrial and agricultural based economy accounts for about 37% of values added to manufacture in Canada and the United States and, over 42% of the two countries' total agricultural income. The agricultural sector is concentrated on grains, livestock, dairy and poultry products, with much of this production being surplus to the area's requirements. At the same time, the region is a net importer of light and diversified industrial products together with fibre, fish, and forestry products.

The Midcontinent region depends heavily upon transportation, initiating about 42% of the total tonnage of rail freight in the United States and about 45% of the rail movement in Canada. It is also the destination of over 41% of the shipments of the United States, and 38% of those in Canada. The Midcontinent is also strategically located for both nations, as it is the centre through which most of the other east-west interregional traffic and much of the north-south contiguous trades must flow. The United States portion of the Midcontinent generates over one-third of that nation's exports of manufactured products.

Overall, imports and exports to, from, and within the region average some 145 billion tonne-kilometres (100 billion ton miles) annually. Over 27 million tonnes (30 million tons) per year, representing some 2,950 ship movements, are shipped annually through the Montreal-Lake Ontario section of the system. Since 1959, over 175,000 transits have been made through the St. Lawrence River above Montreal.

About 85% of the total tonnage carried on the waterway is iron ore, coal, limestone and grain. The remaining 15% of the traffic includes overseas general cargo such as petroleum products, newsprint, rock salt, iron and steel products, cement, chemicals, and many other goods.

2 Great Lakes – St. Lawrence Seaway System Directory 2003/04

In Canada, a large proportion of the Great Lakes commerce, particularly grain (downbound) and iron ore (upbound) transits the St. Lawrence waterway to and from ports on the lower St. Lawrence River. The Montreal Harbor facilities annually handle over 20 million tonnes (22 million tons) of cargo. Montreal Harbour is also the most important container harbour in Canada and one of the most important in North America.

d. Values and perceptions of the interest

In terms of environmental impacts, studies have demonstrated that ships emit one-tenth the environmental pollution of trucks and half that of trains. Seaway ships move a tonne of freight up to 800 km (497 mi) on 4 litres (1 U.S. gallon) of fuel.[3] Marine transport produces less noise, less waste and less traffic congestion. Marine safety and spill records are far superior to rail and truck transportation: one marine accident for every 13.7 rail and 74.7 truck accidents and one marine spill for every 10 rail and 37.5 truck spills.

e. Significant statutory, regulatory and policy restrictions

The signing and application of the Kyoto Accord may have significant impacts on the shipping industry. On the one hand, due to its low emissions per tonne-km, the marine sector is in an enviable position as an alternate transportation mode. Short-sea shipping is seen as having significant potential to reduce highway congestion and vehicular emissions, and is a viable alternative and complement to rail and truck transportation. On the other hand, decisions to close coal-fired electrical plants in Ontario Canada would reduce or eliminate the need to transport coal to these plants. The ongoing Great Lakes-St. Lawrence Seaway Study will assess the maintenance and capital requirements of sustaining and optimizing the Great Lakes St. Lawrence Seaway System and the existing marine transportation infrastructure on which it depends. The results of this study will have to be monitored closely. There is also generally an increasing demand for a longer navigation season.

f. History of the interest

The Seaway is a competitive mode of transport for a wide variety of bulk products (iron ore, grain, coal) serving Canada and the U.S., as well as steel products, heavy lift equipment and project cargoes going to and from Europe. Several Great Lakes ports are closer to European markets than east coast or gulf ports. Typically Great Lakes ports have lower port costs than competing ocean ports for the handling, wharfage, dockage and stevedoring of grain, iron ore, steel coils and machinery. Stevedoring costs for steel products are around US$2.20 per metric tonne lower at Great Lakes ports. Prevalent Seaway trade patterns include the following:

- Upbound movements of general cargo, including semi-finished steel in the form of slabs, coils, beams and other products, from overseas producers.
- Upbound movement of iron ore from mines in eastern Canada.
- Downbound shipments of export grain by Canadian bulkers to transshipment points on the lower St. Lawrence, and by ocean vessels for direct export overseas.
- Approximately 29 million tonnes (32 million tons) of cargo were shipped via the Montreal-Lake Ontario Section of the Seaway in 2003, and approximately 32 million tonnes (35 million tons) were shipped via the Welland Canal. The removal of steel tariffs will help the Seaway to return to its classic trading patterns.
- Traffic at the Port of Montreal is expected to grow from the 23.6 million tonnes (26 million tons) moved in 2004. Growth is expected to be derived mainly in the container sector and through an increase in liquid bulk traffic.

3 A Comparative Study of the Environmental Impacts of Modes of Freight Transport in the St. Lawrence Axis (November 2000)

g. Trade flows and current market conditions

The Port Of Montreal is a year round international port servicing shipping lines that trade with more than 100 countries around the world. The ports main markets are North Europe and the Mediterranean, with increasing penetration into markets in the Middle East and Southeast Asia. The port has also been connected to South Africa by a regular service for many years. The principal ports of origin or destination are as follows: Antwerp, in Belgium; Felixstowe, Liverpool and Thamesport, in England; Rotterdam, in the Netherlands; Hamburg and Bremerhaven, in Germany; Le Havre and Marseilles/Fos, in France; Cadiz and Valencia, in Spain; Genoa, Livorno, Naples and Gioia Tauro, in Italy; and Lisbon, in Portugal.

From Northern Europe and the Mediterranean, Montreal offers the shortest route to the vast markets of North America, which represent a pool of some 100 million Canadian and American consumers. The Port of Montreal contributes to the competitiveness of exporters from North America's industrial heartland and facilitates the supply of raw materials and all types of products to industry in central Canada, the U.S. Midwest and the U.S. Northeast.

The Port of Montreal handles all types of cargo year-round, creates some 17,600 direct and indirect jobs, and generates nearly $2 billion in economic impacts for Montreal, Quebec and Canada. The navigation channel to the Atlantic has a depth of 11.3 m (37 ft) beneath chart datum, which corresponds to the lowest water level. It can accommodate ships of all types and almost all dimensions, including containerships with operating capacities of up to 4,100 twenty-foot equivalent units (TEUs).

Electronic water-level monitors allow deep-draft vessels to optimize their loading. In 2004, the port handled over 23.6 million tonnes (26 million tons), comprised of general cargo, and dry and liquid bulk. More than three-quarters of the Port's total traffic is international. The Montreal Port Authority is an autonomous federal agency that builds and maintains infrastructures leased to private stevedoring companies and operates its own grain terminal, passenger terminal and railway network. The Port has 16 transit sheds for non-containerized general cargo and dry bulk, four ramps for roll-on/roll-off cargo, five dry bulk terminals and a grain terminal, 16 liquid-bulk berths and a passenger terminal for cruise ships. Every year, the Port of Montreal welcomes thousands of cruise ship passengers to its Iberville Passenger Terminal, located in the Old Port and historical district of Montreal.

Montreal is a leader on the North Atlantic container market. About half of its container traffic has its point of origin or destination in the United States. The Port of Montreal topped the one million container mark for the very first time in 2000. The Port handled 10.8 million tonnes (11.9 million tons) of container traffic in 2004, with 95% coming from northern Europe and the Mediterranean. The Port's four modern container terminals feature 15 dockside gantry cranes and other equipment for handling container cargo. Major container shipping lines offer frequent, regular liner services out of the port, and most make Montreal their one port of call in North America. Montreal is a terminus where container vessels can be completely unloaded and loaded, making for considerable savings in time and money.

The Port of Montreal has one of the best intermodal systems in North America. It has its own railway network, with 60 miles of railway tracks. This network provides two transcontinental railway companies (Canadian National and Canadian Pacific) with access to almost every berth, thereby eliminating double handling in transshipment. Both railway companies offer double-stack container service. Approximately 45 trains a week, each averaging 1.7 km (over one mile) in length, leave for such cities as Toronto, Detroit and Chicago. Sixty percent of the Port's container traffic is transported by rail, while some 25 trucking companies carry the remaining 40%. Trucking companies typically serve markets in Quebec, Ontario, New England and the state of New York.

h. Effect of last high or low water conditions

Shipping has changed significantly over the past 40 years. In the early years of the Seaway, the vessel fleet was mainly composed of smaller canalers, and vessel draft was limited to 7.6 m (25 ft). Since then, the fleet of vessels has changed drastically. Vessels of up to 225 m (740 ft) and 23.8 m (78 ft) beam now regularly transit the system. Vessel draft has also increased to 80.8 dm (26.5 ft) for the lakers and for specially equipped ocean vessels. For these reasons, the low water events of the 1960s did not have the impact that the same low water level conditions would have today. The lows of the 1960s could mean slower transits and/or reduced draft. In either case, the result is increased shipping costs, which, if conditions were to persist, could impact the general economy. The commercial navigation transportation industry is very competitive, and a slight increase in cost may mean lost business to another mode of transportation.

The channel depths available for navigation are a function of the water levels on the lakes and their connecting channels. Any change in the regime of these levels can have an effect on the cost of shipping of certain commodities in the system. As regulation of the Great Lakes waters can alter, to a certain extent, the Great Lakes-St. Lawrence River water level regimes, it has an influence on navigation.

High water levels are generally more favourable for navigation, unless they are accompanied by high currents. If currents are too fast, conditions may be unsafe for navigation, at which point vessels will be required to stop. This again would have an economic impact on transportation costs. In certain areas, high water levels may increase the susceptibility of certain riparian docks to flooding, and/or expose shorelines to vessel wave action. Traditionally, when water levels reach a certain high level threshold, vessels are required to proceed at reduced speeds, which again increases their transit times and transportation costs. If water levels become extremely high, the Iroquois Lock will be flooded if water levels reach 75.61 m (248 ft) (IGLD 85). At this level, operation of the locks will no longer be possible, and all vessels transiting through the area would stop until water levels return to an acceptable range.

2. Performance Indicators

The performance indicator chosen by the Commercial Navigation Technical Work Group is total cost of transportation associated with commercial navigation between Bécancour, Quebec, and Port Weller, Ontario. Transportation costs include vessel capital and operating costs, fuel costs, seaway tolls, pilotage charges and Canadian Coast Guard fees (marine navigation service and maintenance dredging service fees). Costs do not include port fees and port cargo handling costs. The Commercial Navigation Economic Impact Model provides cost estimates for various plans and uses 1995-1999 commercial navigation traffic, being the best available information at the time.

Total transportation cost curves were derived for each quarter-month for three geographical areas: Lake Ontario (from Port Weller to Cape Vincent), the Seaway (from Cape Vincent to St. Lambert) and Montreal to Batiscan (St. Lambert to Batiscan). These cost curves were incorporated into the Shared Vision Model. Note that impacts can vary significantly within the Seaway for locations above and below the dam at Cornwall.

Quarter-monthly water levels were converted to daily water levels, assuming a linear interpolation between quarter-monthly data points. Quarter-monthly data removes some of the high water, low water and high velocity events and presents more of an average, which will underestimate the economic impacts. Vessel departure dates were used to identify the range of water levels that a vessel would encounter during its transit. These water levels governed the maximum load the ship could carry. The lowest water level encountered during the transit governed the ship's carrying capability. These water levels were compared with the metrics developed for the geographical areas the vessel would transit. These metrics determined whether the vessel could proceed at normal speed, whether it had to slow down because of high water, reduce its draft due to low water, or stop because of high gradients and flows. A running summary of total transit time was computed for each vessel. These transit times were then converted to costs using daily vessel operating costs associated with one of the 26 various vessel types.

Commercial navigation costs actually arise from three factors: costs due to ship transits based on tons carried according to available water levels, costs due to currents, and costs due to high gradient delays. Commercial navigation costs are affected by water levels in that vessels are required to slow down, light load and/or stop for both high and low water levels. High water velocities/currents, which are represented by gradients between gauges, increase transit times and/or fuel usage for upbound transits. If water velocities become too high, vessels must stop because conditions are not safe for navigation. The cost curves only capture vessel transit costs due to ship loading according to available water levels and travel times and fuel usage based on traveling with or against the currents. Costs related to vessels having to slow down, stop, or offload cargo are calculated by the SVM based on other algorithms. All of these costs are computed by the Economic Impact Model.

Transportation costs can be used to rank plans. However, using transportation costs alone to evaluate/rank plans is not as straightforward as it may seem. Since all plans are compared with 1958-DD, any increase in transportation cost savings is an improvement over the current conditions. There are three possible types of plans with respect to transportation cost impacts: those that provide savings for all geographical areas (Lake Ontario, the Seaway and Montreal), those that provide losses for all areas, and those that provide gains for some areas and losses for others. The system of ranking plans could vary for each of these three plan grouping types. For example, given the following net transportation savings based on preliminary results, Cornell IV would be ranked number one based on total transportation cost savings. Ranking plans by minimizing impacts to all geographical areas and having them share in the losses equally would result in Benefits H being ranked number one.

Plan Transportation Savings

Plan	*L.O*	*Seaway*	*Montreal*	*Total*
Cornell IV	**$28,703**	**$2,221,285**	**$52,194**	**$2,140,388**
Natural A	**$42,881**	**$2,140,535**	**$83,372**	**$2,014,282**
Benefits H	**$ 5,220**	**$ 858,903**	**$ 7,132**	**$ 846,551**

Red: Losses ***Green: Savings***

The Commercial Navigation Technical Work Group has identified 42 metrics that can be used to rank various water level plans. The metrics identify at what water level specific impacts happen to shippers. The main link between impact to shippers and water levels is the effects that various water levels have on vessel carrying capacities, vessel speeds and the ability to transit the system.

Characteristically, for a transit through the Seaway, the maximum allowable draft is published and seldom changes. Typically, vessels have been allowed to transit at 7.9 m (26 ft) draft during Seaway opening and closing periods and at 8.0 m (26.25 ft) during the rest of the season. Last year, due to favourable water levels, some vessels were allowed to transit with a 26 ft, 0 in draft. These drafts assume a specific amount of under-keel clearance. Water levels needed to accommodate these drafts are known for various points throughout the Seaway System.

One way to rank various plans is to see how they perform against the 42 metrics identified by the Commercial Navigation Technical Work Group. Counts can be made of how many quarter months, over 101 years of water levels, that critical high levels are exceeded, levels drop below critical low levels and critical velocities/gradients are exceeded. Ultimately, the selection of a plan must be made based on both transportation costs and how well a plan performs based on the metrics. The CNTWG has provided this information to the Study Team so that it could be incorporated in the Shared Vision Model.

3. Potentially Significant Benefit Categories Not Addressed by the Current Performance Indicators (Secondary Impacts)

(a) Environmental benefits of marine transport over other alternative modes

In terms of environmental impacts, studies have demonstrated that ships emit one-tenth the environmental pollution of trucks and half that of trains. Seaway ships move a tonne of freight up to 800 km on 4 litres of fuel.[4] Marine transport produces less noise, less waste and less traffic congestion. Marine safety and spill records are far superior to rail and truck transportation: one marine accident for every 13.7 rail and 74.7 truck accidents and one marine spill for every 10 rail and 37.5 truck spills. Due to its low emissions per tonne-km, the marine sector is in an enviable position as an alternate transportation mode. Short-sea shipping is seen as having significant potential to reduce highway congestion and vehicular emissions, and is a viable alternative and complement to rail and truck transportation.

(b) Benefits to the economies of both the U.S. and Canada

Marine commerce on the Great Lakes-Seaway System each year generates more than $4.3 billion in personal income, $3.4 billion in transportation-related business revenue and $1.3 billion in federal, state, provincial and local taxes. The Seaway supports 75,000 direct and indirect jobs in Canada and 150,000 jobs in the U.S. Moreover, approximately 10,000 tonnes (11,000 tons) of general cargo handled by a Great Lakes Port contributes more than half a million dollars in local economic benefits. The eight Great Lakes states, and the provinces of Ontario and Quebec are home to almost 100 million people, a third of the combined U.S-Canada population. On the Canadian side, Ontario and Quebec represent over 60% of Canada's gross domestic product, while the Great Lakes states generate some 26% of the entire U.S. manufacturing base.

(c) Other waterborne transportation costs

Following a low water event, or when gradients and currents are such that vessels have to stop, the model assumes that all vessels resume navigation simultaneously. In practical terms, depending on the duration of the event and the number of vessels stopped, the rate at which navigation resumes is limited by the locks' capacity to process vessels. Consequently, the impacts of excessive flows/gradients or low water will be underestimated for any plan evaluated. This becomes even more important since all water level data used is based on quarter-monthly data. Quarter-monthly data masks high and/or low water and high gradient events that could impact vessel movements. Quarter-monthly data is an average of the water levels during that time period. It takes out the highs and the lows and presents an average.

4. Key Baseline Conditions

a. The impact model does not consider a widening or deepening of the navigation channel, or any changes to the current infrastructure, whether it be locks, bridges or regulating works.

b. The impact model does not consider any changes in fleet composition, which could occur should the infrastructure be changed dramatically.

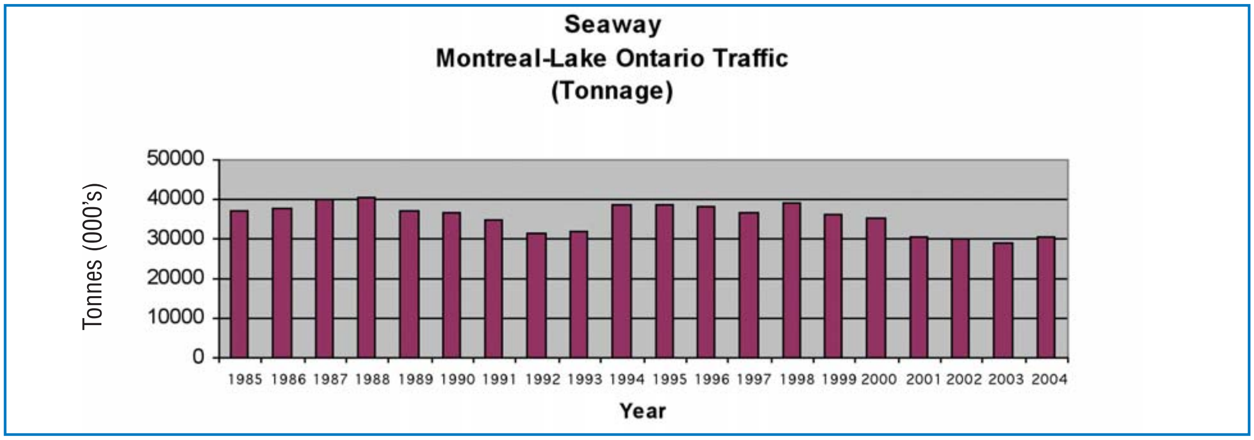
c. The Economic Impact Model uses actual vessel transit data in the Becancour to Lake Ontario segment from 1995 to 1999 (five years). It is using this same set of five years of data for all 101 years of water levels. It tracks the negative impacts of high and low water levels and high velocities/gradients, i.e.: vessels having to reduce speed, stop, light load or offload cargo.

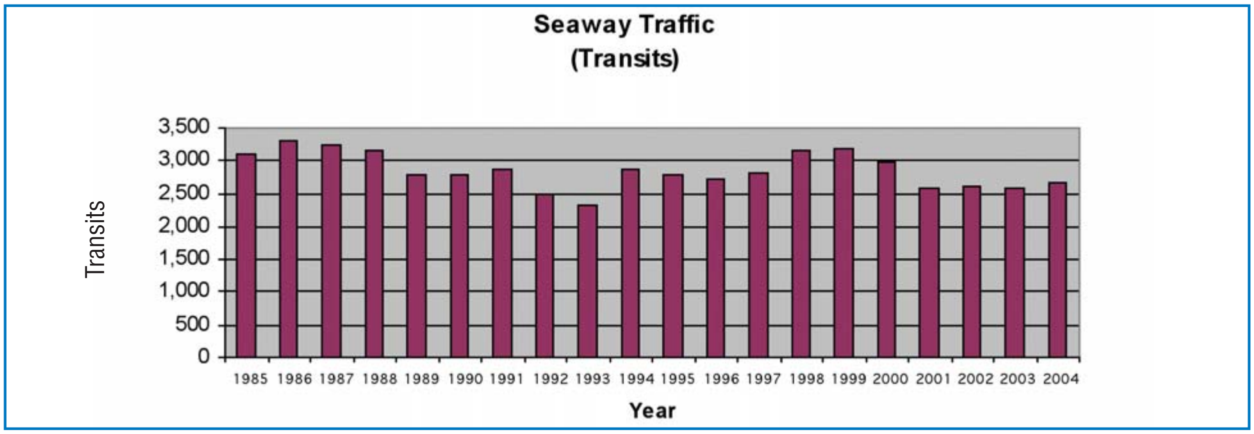
4 A Comparative Study of the Environmental Impacts of Modes of Freight Transport in the St. Lawrence Axis (November 2000)

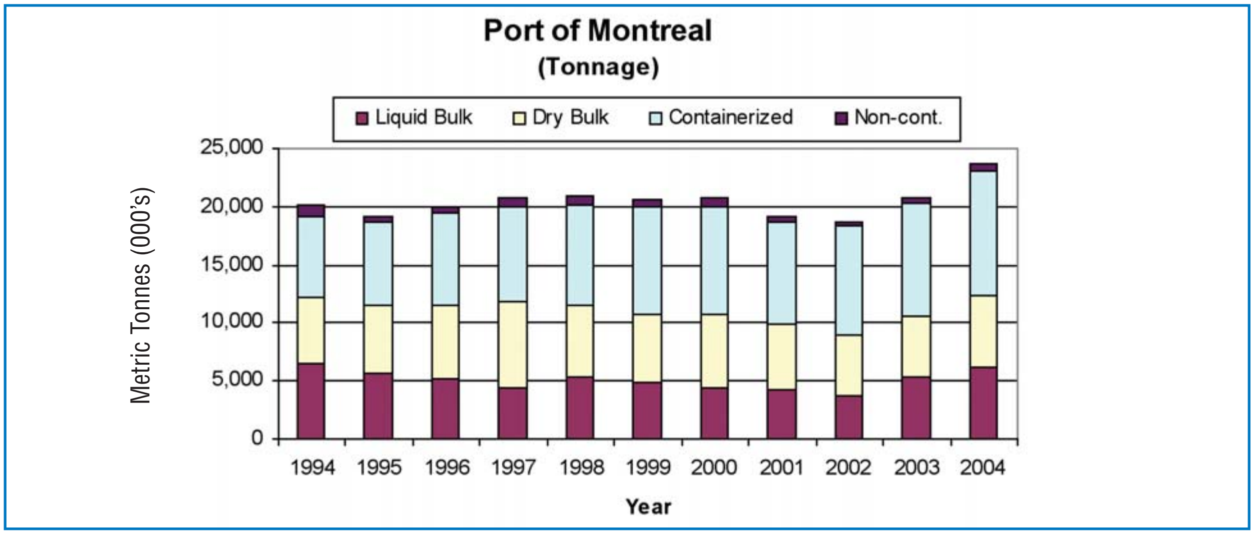
5. Key Trends

Provided below are historical tonnages for the St. Lawrence Seaway and the Port of Montreal. The Seaway shows a cyclical trend. Near term traffic levels in the Seaway (next five years) are expected to be at least equal to 2003 and 2004 levels. The tonnages moved during the 2004 season are estimated at 30,494,000 tonnes (33.6 million tons).

Montreal tonnages show a moderate growth, most of which takes place in container traffic. Montreal tonnages are expected to continue to grow. Growth is expected to be derived mainly in the container sector and an increase in liquid bulk traffic.







Key trends and issues that may affect the system include the following:

- Continued trend toward containerization;
- Short-sea shipping to alleviate highway congestion and facilitate trade, improve utilization of facilities and reduce greenhouse emissions;
- Demand for year-round service, one stop, door-to-door supply chain logistics;
- Seaway operating at approximately 50% of its capacity;
- GL/SLS Study to be completed;
- Ontario decision to close coal-based electricity production;
- Aging infrastructure – Seaway, Great Lakes Ports, Vessels;
- Fewer Seaway-sized ocean vessels.

6. Expected Consequences of Changes of Regulation

Dependable and predictable water levels within the existing parameters (or better) are required to maintain and possibly grow this segment of transportation. Because of the competitive nature of this industry, low water levels or unacceptably high water levels or flows could negatively impact the shipping industry as a whole and may cause some shippers to use other modes of transportation. Once lost to other modes, regaining this business would be very difficult.

7. Adaptive Behaviours

There are many responses to lower water levels that the shipping community can initiate depending on the magnitude and the duration of the low water event. If a low water event occurs and is anticipated to be of a short duration and only in a very specific area of the system, vessels can reduce speeds in that section and still maintain the amount of commodity carried. This increases transit times but not number of vessel trips. This adaptation also has limitations, since vessels must, at all times, maintain sufficient speed to not impact manoeuvrability and safety.

If the low water event is significant and is expected to last an extended period, vessel draft may be reduced. This will result in increased costs since more trips will be required to move the same tonnage, assuming vessel availability. Generally, the Seaway and the industry can adapt to low water conditions when basin supplies are low for extended periods, as all users must, but plan-induced low levels would not be looked upon favourably.

However, if falling water levels cause large reductions in draft and are anticipated to last for an extended period of time, the last approach is deepening of channels and harbors. This option has many concerns associated with it. The feasibility of dredging would require environmental assessments, including sediment quality, identification of depositional areas, possible containment, defining of costs and who assumes the costs.

For the Port of Montreal traffic, dredging is not an option in the case of a reduction in water column. The last channel dredging ($10M) was undertaken only after four years of debate with environmental groups and agencies. In the extremely unlikely event that the Port of Montreal would obtain permission to dredge even deeper, the cost would be significantly greater since, in some areas, channel bottoms have reached rock and channel deepening would necessitate changes to the port's existing infrastructure (docks).

Some proactive mitigation dredging was done in 1999 for existing channel depths. The Port funded the total cost of the effort. The dredging was done to accommodate large vessels to handle the growing volumes of traffic, and also to make the route less vulnerable to water fluctuations under 1958-DD. Any plan that would provide less water than 1958-DD would negate the positive impacts of dredging in 1999.

Another adaptive measure to falling water levels is a change in fleet composition. The fleet of vessels calling regularly at the Port of Montreal has been custom designed and built specifically for that trade. The last generation of vessels was built at a total cost of approximately US$1 billion. New vessels are likely to be on the drawing board in the near future, and the design may have to change again to accommodate the ever increasing volumes within the Port's actual draft limitations. The economic gains of building a new fleet will have to be evaluated very closely given that freight rates for exports are 60% of what they were in 1994 and rates for imports during the same period have failed to follow inflation.

As for Great Lakes vessels, the last new Canadian vessel was built in 1985 (MV Paterson). The U.S. has concentrated on modifying its existing fleet (adding self unloading capabilities, and converting vessels to tug barges). There is no indication that the economics of the Great Lakes trade could support a Great Lakes fleet modification.

8. Risk Assessment/Sensitivity Analysis

The following caveats must be identified when using total cost of transportation as the cost performance indicator.

a. The vessel database used to develop this PI (1995-1999 vessel movements) is only representative of the fleet, traffic volumes, and commodity movement patterns within the system at that time. The fleet mix that uses Montreal Harbour has already exhibited a shift to larger sized vessels.

b. Water level data was provided on a quarter-monthly basis. However, daily and even hourly changes in water level can impact vessel movements and loadings. The quarter-monthly data tends to "average out" these impacts and leads to an underestimation of transportation costs.

c. The PI can be used to distinguish a good year of water levels from a bad year. However, usage to determine the ranking of plans is more problematic. Two plans may result in the same average total transportation costs. However, the two plans may not be equal in ranking. A plan that provides a more consistent set of water levels would be preferred to a plan that has extreme fluctuations in water levels. Commodities moving by water require load and schedule planning that ensures that vessels have adequate water depths to accommodate their passage throughout the entire length of their trips. A plan that offers a more consistent set of water levels, provided that the levels are sufficient to maintain existing or deeper vessel drafts, would be preferred to a plan that involves extreme fluctuations in water levels.

d. This PI is also sensitive to seasonality. A plan that provides more water than the current plan, from approximately June through December, would be preferred. This is the time of year when water levels are typically decreasing and tonnage movements are highest.

e. The limiting factors[5] for navigation that are currently recognized in the Impact Evaluation Model throughout the Seaway portion of the system are as follows:

   (1) The minimum water levels (elevation above sea level in IGLD 1985) for navigation at 8.0 m (26 ft, 3 in) draft in the Montreal-Lake Ontario through Montreal reach of the system are as follows:

Location	Minimum Water Level (metres, IGLD85)
Lake Ontario	74.27
Ogdensburg	73.90
Cardinal	73.45
Iroquois	73.35
Morrisburg	72.79
Long Sault	72.50
Summerstown	46.58
Coteau Landing	46.48
Lake St-Louis	20.60

5 *Planning Objectives and Performance Metrics For Evaluating Impacts of Lake Ontario Outflow Regulation Plans on Commercial Navigation*

(2) The maximum gradients that represent velocities that are not safe for navigation are as follows:

Location	Maximum Gradients (cm)
Ogdensburg-Cardinal	72
Cardinal-Iroquois HW	26
IroquoisTW-Morrisburg	46
Morrisburg-Long Sault	35

(3) Water levels exceeding the following require vessels to slow down to prevent damage to shorelines and shore structures:

Location	Maximum Water Level (IGLD)
Lake Ontario	75.37
Ogdensburg	75.37
Morrisburg	74.00
Summerstown	47.00
Coteau Landing	46.58

(4) A level of 75.61 m (248 ft) at Iroquois Lock will flood the lock and make it inoperable.

As water levels approach those in the table in (1) above and continue to decline, vessels are required to reduce their speeds, and when levels drop below those in the table, vessels are required to anchor until levels recover. If the levels do not recover, cargo must be offloaded from those vessels before they can proceed. Vessels not yet loaded and headed for the Seaway will be light loaded to accommodate for lower water levels. The drafts in the Seaway have been set at 8.0 m (26.25 ft) since 1994. Recently, vessels have been allowed to transit the system at 8.08 m (26.5 ft) during the summer. Very low water levels for extended periods of time can translate into losses of competitiveness for ports, carriers and other industries that might end up paying more for the transportation of the raw material required for their specific activities. The economic activity of a whole region, state, province or country can therefore be affected by potential increases in terms of unemployment and the price of goods. For example, draft reduction in the Seaway will have the following economic effects:

	Effect per Ship			Effect per Year (1,300 ships)		
Draft Reduction	*Cargo reduction, tonnes*	*Loss of revenue, SLSMC*	*Loss of revenue, Shipping*	*Cargo reduction, tonnes*	*Loss of revenue, SLSMC*	*Loss of revenue, Shipping*
1 cm	40	$80	$800	52,000	$104,000	$1,040,000
8 cm	320	$640	$6,400	416,000	$832,000	$8,320,000

SLSMC = St. Lawrence Seaway Management Corporation

Vessels transiting areas having gradients in excess of those listed in the table in (2) above will be required to stop until gradients are below those listed. When water levels exceed those listed in the table in (3) above, vessels are required to reduce their speeds to prevent damages to shorelines and shore structures. If the water level at Iroquois Lock reaches 75.61 m (248 ft) (corresponding to a level of 75.56 m (247.9 ft) at the Iroquois Dam Headwater gauge that was modeled in the study), navigation must be suspended because the Lock will be flooded and therefore inoperable.

f. In Montreal, water levels impact the amount of cargo loaded or unloaded on a deep draft vessel. Ships having a loaded draft of 10 m or less are not considered deep draft and are typically not limited by variations in water levels. The available water is usually sufficient to allow full loading of this type of vessel. However, deep draft vessels, which represent 30% of tonnage transiting the Port of Montreal, require water levels of 0.6 m or more above chart datum in order to be economically viable. During periods of low water levels, such vessels might not be able to carry full cargo loads, or might have to partially discharge in an alternate port if not forewarned of low water levels. Both circumstances cause increased operating costs and reduce effectiveness in service. The Port of Montreal's competitiveness is therefore greatly affected by variations in water levels.

There is a direct relationship between lake levels and cost of transporting bulk commodities and this relationship is based on the allowable draft of shipping. Lake vessels tend to take advantage of every centimetre of available depth because shippers' profits essentially come from the last few centimetres of loading. For instance, 2.5 cm of vessel draft on a freighter of 23,000 tonnes (25,000 tons) carrying capacity represent 113 tonnes (125 tons) of cargo. For a 59,000-tonne (65,000-ton) capacity bulk carrier, 2.5 cm would mean a loss or gain of 200 tonnes (220 tons) or about 0.3% of carrying capacity. Similarly, a 30-cm reduction in available draft means that about 114 fewer 6-m containers can be loaded on a typical ship with a capacity of 1,800 containers.

While water levels on the Great Lakes in general are fairly stable, Montreal Harbour water levels are very sensitive to changes made in Lake Ontario outflow at the Moses-Saunders control structure for the purpose of regulation. For example, a 570-m^3/s (20,130-ft^3/s) flow reduction at Moses-Saunders would result in a drop of about 24 cm in the Harbour at equilibrium, while it would mean a rise of only about 0.25 cm per day on Lake Ontario. This means that, in the fall, when levels are generally at their lowest in the Harbour, the consequences of large Lake Ontario outflow reductions could be disastrous for the Montreal shipping industry, while the benefits provided by such reductions to the navigation interest upstream of the Moses-Saunders project would be negligible.

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E. Hydroelectric Power Generation Technical Work Group Summary

Objectives

The Hydropower Technical Work Group was charged with evaluating the potential impact of changes to water level and flow regulation on electricity production, the economic impacts of changes in electricity production and other issues that would affect production or maintenance at five affected generating stations.

Data Collection and Evaluation Methodology

There are five different generating stations that can be affected by levels and flows regulation in Lake Ontario and the St Lawrence River—the Moses and Beck generating stations on the Niagara River; the St. Lawrence–Franklin D. Roosevelt (Moses Dam) and Saunders generating stations on the St Lawrence River near Cornwall, Ontario; and the Beauharnois-Cedars complex just upstream of Lake St Louis. Each station is unique in its production characteristics and each is affected by water levels and flows differently. Therefore, the effects of flow regulation on electricity production were evaluated separately for each station. Representatives of the three companies that operate the generating stations served on the Hydropower Technical Work Group and worked with the Plan Formulation and Evaluation Group (PFEG) to develop quantitative algorithms for evaluating how electricity production might change under different regulation plans. Each algorithm was based on existing models already developed by each of the companies. The new algorithms relate Lake Ontario levels and St. Lawrence River flows to megawatt-hour electricity production at each generation station.

In order to assess the economic impact of electricity production, some prediction of likely market prices for electricity was needed.[6] Two initial sets of market price forecasts were used in early plan evaluation exercises. These two initial forecasts highlighted the importance of seasonal variations in electricity prices—large seasonal variations could result in significant differences in the economic impacts of different regulation plans. Therefore, to ensure the evaluation was based on a reliable forecast of market prices, the Plan Formulation and Evaluation Group and the Technical Work Group contracted with Synapse Energy Economics Inc. to conduct a short study of market data. Synapse analyzed hourly price data from the New York market and the Ontario market in combination with futures market prices to produce short-term and long-term forecasts of electricity prices (Synapse Energy Economics, Inc, 2005). The short-term price forecast was used in the Shared Vision Model (SVM) for plan evaluation. Those prices are shown in Figure E-1. Because of the nature of the regulated electricity market in Quebec, a constant price for electricity was used for evaluating the economic impact of regulation plans on the Beauharnois-Cedars generating station. The price used for Beauharnois-Cedars was US$70.47.

Performance Indicators

The New York Power Authority (NYPA) and Ontario Power Generation (OPG) together operate and market the power from the Moses-Beck and Moses-Saunders generating stations. Hydro Québec owns and markets the power produced at the Beauharnois-Cedars generating station. The performance indicators for each company were similar but were modeled separately. The New York price forecast shown above was used for NYPA, while the Ontario price forecast was used for OPG. The flat price for Quebec was used for Hydro Québec.

6 Pursuant to federal and state requirements, most energy produced at the Power Authority St. Lawrence-FDR and Moses power projects is sold pursuant to bilateral contracts at less than market prices. Market price is relevant to energy loss or surplus impacted by alternative regulation plans.

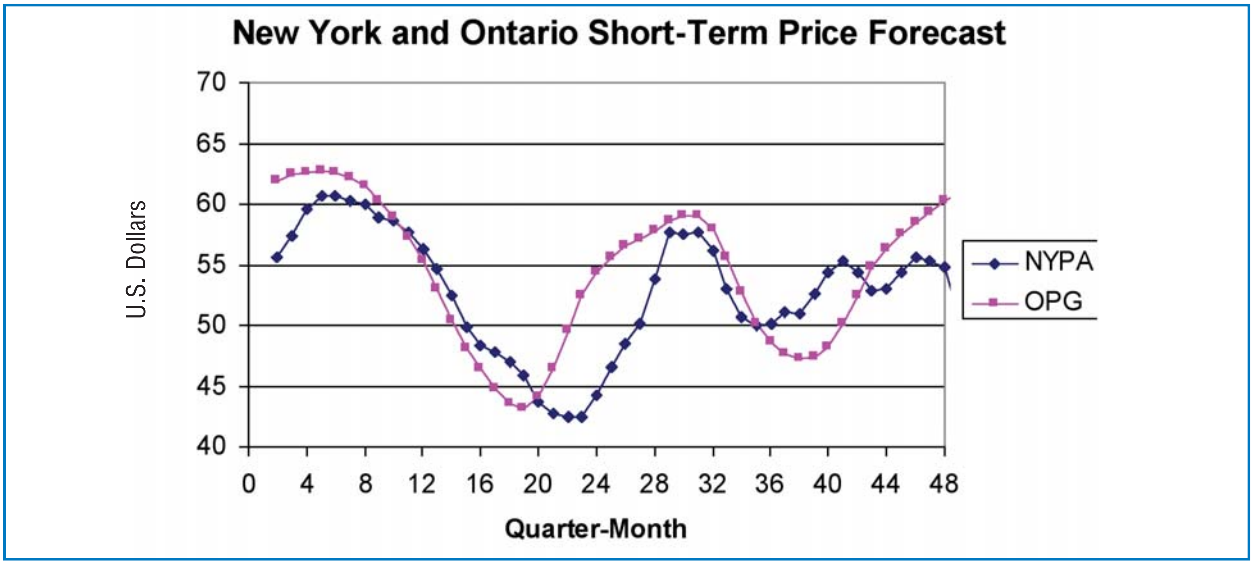

Figure E-1: Short-term electricity price forecasts

Electricity production

Electricity production at the Massena-Cornwall power project is affected by both Lake Ontario levels and Lake Ontario outflows. Up to a point, higher flows result in more electricity production, but above the maximum efficiency point (approximately 8,450 m^3/s (298,400 ft^3/s)), increasing flows have diminishing returns. Also, higher Lake Ontario levels generally result in greater station head at Moses-Saunders, which is also linked to greater electricity production. Furthermore, Lake Ontario levels have an effect on the efficiency with which a given flow produces energy. So there is a direct relationship among level, flow and power production. The TWG produced two algorithms to capture this relationship—one for the OPG side of Moses-Saunders and one for NYPA's side. Each algorithm uses the quarter-monthly flow and Lake Ontario level to calculate the electricity produced (in MWh) for that quarter-month.

Lake Ontario levels also affect electricity production at the Moses and Beck generating stations. Since Moses and Beck are located on the Niagara River above Lake Ontario, higher lake levels actually reduce the station head at Moses-Beck, which results in less energy production. Lower lake levels have the opposite affect. In order to capture this effect, the Technical Work Group provided an algorithm that calculates quarter-monthly electricity production at Moses-Beck based on Lake Ontario levels and other inputs.

Electricity production at the Beauharnois-Cedars complex is primarily dependent on Lake Ontario outflows. Larger flows generally result in more energy production, but flows above about 7,500 m^3/s (264,900 ft^3/s) produce electricity less efficiently. The Hydro Québec representative on the TWG developed an algorithm for calculating electricity production at Beauharnois-Cedars based on Lake Ontario outflows and other inputs. That algorithm was programmed into the SVM.

The value of electricity production

The market value of electricity varies through the year because of seasonal shifts in demand for energy. Electricity tends to be more valuable during the winter heating season and the summer cooling season, but less valuable in the spring and fall. Regulation plans that produce more electricity in the summer and/or winter will tend to yield greater economic benefits. The quarter-monthly electricity prices produced by Synapse Energy Economics Inc. were used in the SVM to determine the value of electricity produced under different regulation plans. Those prices were applied to the electricity production from both Moses-Beck and Moses-Saunders.

In addition to seasonal variations, the market value of electricity varies within a typical day, also because of changes in demand. Demand tends to be higher during the day and so market prices tend to be higher during the day. OPG and NYPA are allowed by the International Joint Commission to vary flows during the day so that more electricity is produced when it is most valuable, producing an economic benefit. However, the Commission's rules do not allow these peaking operations when flows exceed 7,930 m^3/s (280,000 ft^3/s). Plans that tend to have higher flows more often will allow for less peaking and a loss of some of the associated economic benefits. Using hourly price data from the Ontario market, the Plan Formulation and Evaluation Group estimated that the daily value of peaking is approximately US$40,500. The Shared Vision Model tracks the number of days that a regulation plan will allow peaking and, using the estimated daily value of peaking, calculates the economic benefit of peaking operations.

Because of regulation and the reliance on hydropower, the Plan Formulation and Evaluation Group and the Hydro Technical Work Group concluded that the economic value of electricity in Quebec does not vary through the year. Therefore, a constant price of US$70.47 was applied to Beauharnois-Cedars. Electricity production at the Beauharnois-Cedars complex is not affected by peaking operations.

Predictability of Lake Ontario outflows

The hydropower entities periodically shut down some of their turbines in order to perform regular planned maintenance. When Lake Ontario outflows are low, units can be taken out of service without loss of electricity production because all of the water can be passed through the remaining units. Therefore, in order to minimize the opportunity cost of performing unit maintenance, the companies try to schedule maintenance for times of the year when they expect Lake Ontario outflows to be low. If flows unexpectedly spike when units are down for maintenance, the remaining units may not be able to handle all of the flow, and some of the water will then be passed without producing electricity. So predictability of outflows is very important to the ability to effectively and optimally plan unit maintenance.

Hydropower Technical Work Group members concluded that, in general, if flows are premised on Lake Ontario levels then predictability will be high. Therefore, this performance indicator is measured by calculating the correlation between quarter-monthly outflows and quarter-monthly Lake Ontario levels. A higher correlation indicates a higher level of predictability. This metric is important for OPG/NYPA and Hydro Québec.

Stability of Lake Ontario outflows

Stability of outflows is a similar concern to that of predictability, but on a shorter time scale. Stability refers to quarter-monthly changes in flow. The rate of change of flows can affect maintenance planning and efficiency rates. Using past production data, Hydro Québec developed an algorithm for calculating electricity production losses (in MWh) as a function of quarter-monthly changes in outflow. OPG and NYPA concluded that the effect at Moses-Saunders would be similar, but half as large as it is at Beauharnois-Cedars. Using the appropriate price forecasts, the MWh losses are converted to economic losses. The stability performance indicator is measured as an economic loss due to lost electricity production.

Spill at Long Sault Dam

When a plan calls for extremely high outflows that exceed the capacity of the Moses-Saunders Dam, some of the water is passed via the Long Sault Dam. Spill via Long Sault was an environmental concern during NYPA's Federal Energy Regulatory Commission relicensing process. Spill via Long Sault from April to mid-June can negatively impact fish spawning. This performance indicator is measured by tracking the frequency with which a plan causes Long Sault spill during the spawning season, and, when it occurs, the magnitude of the flow via Long Sault.

Ice formation

Ice cover stability is necessary to enable the flows prescribed by the plan to be released throughout the winter. An ice jam will inhibit these releases causing a drawdown in head that could impact municipal water supplies in the vicinity of the Moses-Saunders Dam. The inability to pass the required outflows will cause levels on Lake Ontario to rise prior to the spring melt, adding to high level concerns. In addition, when ice jams release, damage to shorelines and flooding downstream will occur. An unstable cover or ice jam will force power generation to be reduced because flows will be inhibited and the operating head will be reduced. Therefore, managing flows in order to allow formation of a stable ice cover each winter is very important and it is particularly important to the hydropower entities.

Plan 1958-D (as originally formulated without deviations) simply assumes that ice forms throughout January and therefore reduces flows throughout January. In reality, the timing and duration of ice formation varies, and actual operations under 1958-D with deviations address ice formation as it actually occurs. Because this is so important, all new candidate regulation plans include the same ice management rules to reduce flow when and while ice is actually forming. In practice, ice management operations under any of the new candidate plans would continue as they have been conducted under 1958-D with deviations. Therefore, all the candidate plans meet this need equally well and no performance indicator is tracked.

Baseline Economics – Hydropower

The hydropower performance indicators are used to rank plans. They reflect the societal value of marginal differences in electricity production among the candidate regulation plans. The Board asked our economic experts to develop some measure of the scale of that change in relation to the overall scale of the economic activity for the Board's use in determining if a loss in one sector's benefits was disproportionate. For hydropower, the experts suggested that the scale of the overall activity is the net economic value to society of all the electricity produced at each of the generating stations (i.e., the economic surplus). Using information provided by the three power companies, and assistance from the Economics Advisory Committee, a producer surplus was derived from the total baseline market value of electricity produced.

The derived numbers should be taken as planning level estimates only and they are merely meant to provide some context for the net benefits results shown in the main body of this report. The actual value of electricity produced and the resultant producer surplus may be different in any given year, depending on market conditions and other factors (see footnote on page E1).

The economic baseline for hydropower under Plan 1958-DD was calculated as the economic surplus measured as net operating revenues minus the economic cost of capital, before deduction of taxes, transfer payments, and special pricing. The numbers derived were similar to those produced in other studies, such as the Federal Energy Regulatory Commission (FERC) relicensing analysis for the St. Lawrence-FDR generating station (Moses). Table E-1 below shows the derived baselines.

Table E-1: Estimated Hydropower Economic Baselines

	($US million)
HYDROPOWER	**$350**
NYPA-OPG	$250
Hydro Québec	$100

Analysis

Analysis shows that hydropower is best served by regulation plans that tend to keep Lake Ontario levels higher and tend to pass very stable flows with few occurrences of extremely high rates. Higher Lake Ontario levels usually result in greater station head at Moses Saunders, which produces more electricity at any given flow. Higher levels have the opposite effect at Moses-Beck—they reduce station head—but the positive effect at Moses-Saunders is usually greater. Further, stable flows result in high scores for predictability and minimal losses due to instability. Finally, a situation of fewer extremely high flows results in more peaking opportunities, less spill (which does not produce electricity), and less risk of impact on fish spawning at Long Sault.

Key Findings

- Hydropower benefits from high flows through turbines, minimal spillage and higher operating heads, but also from predictable and stable flows. The more minimal the changes in releases from month to month and from week to week, the better the plans will fare for hydro.
- Hydropower benefits are greatest when releases are similar to what would occur without regulation (assuming regulation limits ice jams in winter and early spring). Natural releases create a higher average head at Moses-Saunders, result in very little spillage and tend to be the most stable and predictable.

Participants

Hydroelectric Power Technical Work Group

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E. Hydroelectric Power Generation Contextual Narrative

1. General Socio-economic Context

(a) Production value of the interest

The New York Power Authority (NYPA), Ontario Power Generation (OPG), and Hydro Québec (HQ) are public utilities owned by New York state and the provinces of Ontario and Quebec respectively. The hydroelectric facilities they operate on the St. Lawrence River have a total average annual hydropower production of approximately 25,000,000 MWh (13,000,000 MWh at Moses-Saunders and 12,000,000 MWh at Beauharnois-Les Cèdres). Although the mission of these entities is to produce low-cost power, the market value of the energy produced at these facilities is approximately US$1.5 billion at current market rates

(b) Number of stakeholders

The energy produced by the St. Lawrence facilities is enough energy for the consumption of approximately 2,000,000 homes.

(c) Organizational characteristics

These facilities are major contributors to the interconnected power grid that services customers throughout the eastern part of North America. Electricity demand varies both seasonally and daily. Energy production at the Hydro Québec facility is consistent throughout the day, while energy production at the Moses Saunders power plant varies to some degree during the day to match demand.

(d) Values and perceptions of the interest

Hydroelectricity plays a significant role in providing clean, inexpensive, renewable energy to the region. The scale of these "heritage electricity generation investments" on the St. Lawrence also contributes to keeping electricity prices low. In New York, several significant industrial users such as ALCOA and GM rely on low-cost electricity from Moses.

Both New York and Ontario have made significant commitments to reduce the use of coal-fired generation and support the use of renewable energy sources. The St. Lawrence plants contribute to the base supply of clean, renewable energy. The ability to vary production to contribute to peak demands further reinforces the important contribution these facilities make to the health and welfare of the region's population. Air quality is one of the most important environmental concerns in southern Ontario and the northeastern United States. The St. Lawrence hydro facilities provide substantial air quality benefits; if the equivalent amount of energy from these facilities had been generated using fossil fuel, like 50% of the electricity in North America, 18,000,000 tons of CO_2 annually would have been discharged into the atmosphere. State and federal legislation is still evolving to further reduce air quality problems associated with power production, especially acid rain and the carbon emissions that drive climate change. Because overall electricity demand is rising, and environmental concerns may force the closure of some coal-fired plants, Lake Ontario regulation favourable to hydropower production will be more important, not less in the future. Reductions in hydropower production would have to be addressed by greater production from other types of plants, with consequent emissions and cost impacts. Much of the substitution will come from gas turbines, with some from coal-fired plants, both of which produce more carbon and airborne acids than hydropower. Nuclear production is more or less fixed, although there are industry efforts to promote new nuclear capacity.

Regionally, hydropower is seen mainly as a friend. The economy of northern New York state is strongly impacted by the regional allocation of hydropower from Moses to local industry. Hydropower provides low-cost electricity to the ALCOA Aluminum Recycling Plant and the GM Powertrain Production facility in Massena, New York. The importance of hydropower to the sustainability of Northern New York state has been formally recognized by the State's "Build Now–NY" program, and this will remain true for the foreseeable future. This low-cost power provides approximately 2,000 high-paying manufacturing jobs to the local economy. According to the ALCOA website, ALCOA contributes approximately $250 million annually in payroll, taxes and purchases to the local economy. These jobs are tied directly to the favourable electricity rates the company has with NYPA. NYPA also provides low-cost power to municipalities

(e) Significant statutory, regulatory and policy restrictions

In the next ten years the most significant statutory, regulatory or policy restrictions directly or indirectly affecting hydropower production at the NYPA facility will be U.S. and New York State air quality laws, which are expected to reduce coal-fired energy production and further limit emissions from fossil-fueled generation, which comprises about 70% of the energy in the New York system. These actions will affect the electricity supply market, increasing the importance of hydropower. NYPA has just completed its FERC relicensing of St. Lawrence-FDR, securing a licence under terms that will apply until 2054. The terms of that license are essentially reflected in the Shared Vision Model so far as they affect performance indicators for this study.

In Canada, the Provincial Government of Ontario has announced its intention to reduce its reliance on coal-fired generation and increase capacity from new renewable energy by 1,350 MW by 2007 and 2,700 MW by 2010. Canada is a signatory to the Kyoto Treaty. Canada's emission target is a 6% reduction from 1990 levels by 2012. The net impact of these actions will be to increase the importance of hydropower in Canadian markets.

(f) History of the interest

Commercial hydropower production began just upstream of Lake Ontario in Niagara Falls at the beginning of the twentieth century. Initial investments made more than 50 years ago, along with ongoing investments in facility improvement and life extension continue to provide clean renewable energy at a fraction of the cost of other, more polluting sources. Investment in these hydropower assets has provided the economic engine in the region and continues to keep energy prices in the region low.

Because there is no fuel cost associated with hydropower, once the investment in a hydropower plant is made, the additional costs of using the plant to produce energy are much smaller than in the case of other forms of power production. As a result, once hydropower plants are built, their energy production is rarely been reduced because of a decline in energy demand. The value of the energy produced in the long term is affected by the costs of electricity produced by other means and by the price of other energy sources such as natural gas and oil.

All generating sources of electricity have environmental costs, but surveys show that the public served by these three plants generally prefers hydropower production over other means, especially coal and nuclear, which are seen to have greater environmental impacts. Hydro producers, regulators, and water users are challenged to balance electricity production with environmental and social objectives. Concerns about the impacts of hydroelectric development on fish and other users must be balanced against the positive economic and societal benefits hydroelectric generation provides. To minimize the impacts of hydro development and operation on the natural environment, NYPA, Hydro Québec and Ontario Power Generation continue to invest million of dollars annually in science research. An example of this is recent work to reduce the mortality of the American eel as it moves through the St. Lawrence River.

The St. Lawrence power project (NYPA and OPG) is regulated by the International Joint Commission. The New York Power Authority is regulated and licensed by the Federal Energy Regulatory Commission (FERC). The IJC and FERC as well as provincial regulations in Ontario and Quebec mandate that hydropower dams and all related structures be operated safely within design limitations to ensure the stability of the structures and prevent loss of life and property.

Long Sault spills: During the process leading up to the issuance of a new FERC licence for the St. Lawrence project, spills at Long Sault became an issue for several parties. Two specific concerns were raised by NYSDEC (New York State Department of Environmental Conservation) and BIA (Bureau of Indian Affairs): cooler river water spilling into the warmer, shallow-water habitats of the upper end of the South Channel, causing concern for the propagation and survival of warm-water species immediately downstream of the dam, and the potential effects of gas bubble disease (GBD) caused by nitrogen supersaturation.

FERC incorporated these concerns into Article 402 of the new licence, which requires a monitoring plan for water temperature and dissolved gases in the South Channel; advance notification of DEC for all planned spills over Long Sault Dam, notification of DEC regarding any non-planned spills, and annual reporting of monitoring data.

Ice control: The IJC has charged the hydropower companies with forming a stable ice cover. Numerous flow changes are often necessary to help form and protect the ice cover. Since nature dictates when ice forms it is necessary for any regulation plan to be flexible to allow the ice to form and strengthen.

High flow conditions can cause potential flood conditions downstream of the Moses-Saunders project. Minimizing the number of occurrences and the duration of excessively high outflows would be desirable under all plans of regulation.

(g) Trade flows and current market conditions

The demand for energy is strong and growing. Oil and gas prices are fairly high relative to long-term values, and most analysts believe these prices to be essentially permanent adjustments. This is caused by the increased demand for oil worldwide and adjustments in the natural gas market (driven by both regulatory costs and the fact that lower historical gas prices have expanded the use of gas to the point where the lowest cost supplies have been fully subscribed). Given the combination of higher energy prices, the environmental and economic advantages of hydropower, and the well-recognized importance of hydropower to the regional economy, the overall value of hydropower production on the St. Lawrence will almost certainly increase in the next few decades.

The New York Power Authority, Ontario Power Generation and Hydro Québec are all public utilities, owned by New York state and the provinces of Ontario and Québec respectively. While they closely coordinate their operations through the Operations Advisory Group (OAG) of the International St. Lawrence River Board of Control, each operates in very different and independent market environments. The market rules, availability of generation, transmission constraints, demand for energy, and peak and off-peak demand times all contribute to making each of these systems unique.

New York: The New York electricity market is competitive and operated by the New York Independent System Operator (NYISO). The NYISO is a not-for-profit organization formed in 1998. The NYISO facilitates fair and open competition in the wholesale power market and creates an electricity commodity market in which power is purchased and sold on the basis of competitive bidding.

NYISO administers the Day Ahead Market (DAM) and Hour Ahead Market (HAM). The DAM requires that bids and schedules be submitted by 5 a.m. When the DAM closes at 5 a.m., generation bids are evaluated and units are committed beginning with the least expensive generation and progressing to more expensive generation until enough generation is committed to meet the forecasted load. The final unit of generation committed becomes the price for every megawatt during an hour for a given zone. In effect, the system energy price is determined by the most expensive block of power committed to serve the load. In the HAM, bids and schedules must be submitted 90 minutes prior to the hour in which service will start.

Ontario: The Ontario government is restructuring Ontario's electricity sector to ensure adequate supplies of electricity as well as stable prices. Under the *Electricity Restructuring Act, 2004*, a new wholesale pricing structure has been established that incorporates both regulated and market prices.[7]

Pursuant to the *Electricity Act*, the Independent Electricity Market Operator (IMO) was re-named the Independent Electricity System Operator, or IESO, effective January 1, 2005. The IESO manages the province's power system, balances demand for electricity against available supply through the wholesale market and directs the flow of electricity across the transmission system. A not-for-profit entity established by the Government of Ontario, IESO fees and licenses to operate are set by the Ontario Energy Board. The Ontario Power Authority has been created to oversee long-term supply adequacy and the development of a conservation culture in Ontario.

On a continual basis, the IESO forecasts how much power is needed throughout the province and takes in offers from generators and other suppliers to meet that demand. Each day, the IESO issues forecasts of how much energy will be needed throughout the following day and up to the month ahead. These forecasts are continually updated as new information comes in--such as changes in weather. Typically, the IESO's day-ahead forecasts are highly accurate, with less than a 2% variance from the actual demand figures.

Generators and importers of electricity review the forecast information and determine how much electricity they can supply and at what price. The IESO then matches the offers to supply electricity against the forecasted demand, first accepting the lowest-priced offers and then "stacking" up the higher-priced offers until enough have been accepted to meet customer demands. All suppliers are paid the same price, i.e., the market-clearing price. This is based on the last offer accepted.

The IESO collects bids and offers until two hours before the energy is needed. Based on the winning bids, the IESO will issue its instructions to power suppliers, who then provide electricity to the power system for transmission and distribution to customers. The IESO runs a real-time market, meaning that purchases of electricity are made as they are needed. There are occasions when the best-priced energy may not be available due to limitations on the transmission lines. In this case, that generator's offer is still used to help set the price, but another generator may be asked to provide the electricity.

Quebec: Hydro Québec does not operate in a competitive market environment within the Province of Quebec. Hydro Québec has implemented a functional separation of its three major business units: Generation (Hydro Québec Production), Transmission (TransÉnergie) and Distribution (Hydro-Québec Distribution).

The Trans-Energie mission in the market is essentially to transmit electricity at the lowest possible cost and with the expected level of reliability, in compliance with the regulations governing the North American Electric Reliability Council. Hydro-Québec Distribution is responsible for providing reliable electricity service to the people of Quebec and offering services designed to meet customer expectations.

7 Homeowners, small businesses and certain public-sector institutions pay a set rate of 4.7¢/kWh for the first 750 kWh of electricity consumed in a month and 5.5¢ for each additional kWh. Large-volume users pay the fluctuating market rate.

Hydro-Québec Production must supply up to 165 TWh of electricity per year to Hydro-Québec Distribution. Any production exceeding this volume may be sold at market prices. In Quebec, demand for electricity is increasing at an average rate of 1.2% per year. At this rate, Quebec's needs will exceed the heritage electricity pool in 2005. To meet demand beyond this volume, Hydro-Québec Distribution will have to issue calls for tenders from suppliers

In Quebec, there is no short-term bid system as there exists in New York or Ontario. Nevertheless, Hydro-Québec Production, as well as other producers, can bid in the New York, Ontario or any other market to buy or sell energy.

(h) Effect of last high or low water conditions

High water conditions in the past have generally increased the quantity of energy produced at these facilities, while lower water levels have had the opposite effect. The lowest flows have not historically forced brownouts due to lowered capacity.

2. Performance Indicators

(a) The objectives of regulation for hydropower are as follows:

Maximized power production: The generating units at HQ, OPG and NYPA are designed to operate within a design range. Within this range is a point of best efficiency. It is desirable to operate at the point of best efficiency because this enables the most megawatts to be produced with the water. High flows that exceed the best efficiency result in diminishing megawatt production through the plant. If flows are higher than the capacity of the plant, then the water must be spilled.

Maximized value of the power production: The price of power is determined by the demand for power and the resources available to meet that demand. During the day there are periods of high and low demand. The demand for power is also usually higher during the heating and cooling months than during the spring and fall months. Regulation plans that provide for higher outflows during the summer and winter (with the flexibility for ice formation) and lower flows during the spring and fall will enable more power to be produced during the higher value periods. In addition, the flexibility provided by peaking allows for generation to be varied within the day to match the variation in demand.

Flow predictability: Normally, power entities remove units from service for maintenance during the low flow period or try to match an outage with the expected flows. If units are down and flows increase unexpectedly, the power from that additional flow may be lost. Units that are out of service for maintenance are usually disassembled, which prevents them from being returned to service quickly. Plan 1958-DD is predictable because the outflows are primarily determined by the level of Lake Ontario, which rises and falls in a predictable seasonal pattern.

Flow stability: The metric used in the Shared Vision Model is a measure of the quarter-monthly variation in flow. A plan that minimizes the quarter-monthly fluctuations is preferable to a plan with large weekly fluctuations. This PI complements the flow predictability performance indicator as it allows for critical maintenance planning.

Ice cover formation: A properly formed ice cover allows flows to be maximized during the winter because flow friction and obstruction are minimized. Because stable ice cover is so valuable to so many interests, PFEG believes that all new plans include rules to limit discharges to between about 5,700 m^3/s (201,300 ft^3/s) to 6,300 m^3/s (222,500 ft^3/s) during ice formation. At a minimum, plans should be evaluated to determine how often releases outside this range occur during ice formation.

(b) The hydropower performance indicators concerned with flow predictability and stability will be best measured as frequency and duration of occurrences that exceed Plan 1958-DD. As stated in the discussion above, Plan 1958-DD is beneficial to hydropower for these measures because the outflows are dependent on Lake Ontario levels, which are inherently predictable and stable.

The performance indicator that measures the maximization of power (best efficiency) is quantifiable according to the ratings of the generating units. These ratings have been incorporated into the model and can be measured objectively.

The performance indicator that seeks to maximize the value of the megawatts will be determined by several variables. The cost of power, along with the determination of the periods of highest value will be addressed in the model. The Synapse report and historical demand data are available for model inputs. Regulation plans that prescribe flows that seasonally match the demand periods will be preferable. In addition, plans with fewer instances of flows above 7,930 m^3/s (280,000 ft^3/s) will be preferable in order to allow for peaking. Although the most subjective, this performance indicator also has the potential for understating impacts if the assumptions are incorrect or if they change in the future.

3. Potentially Significant Benefit Categories Not Addressed by the Current Performance Indicators (Secondary Impacts)

The St. Lawrence hydro facilities provide substantial air quality benefits and energy cost savings that are not directly addressed by the performance indicators.

The Federal Energy Regulatory Commission issued a licence for the NYPA's St. Lawrence-FDR Project (Moses) in October 2003. The Final Environmental Impact Statement prepared for that licensing effort estimated the amounts of pollutants that would be generated by a steam-electric facility of equivalent size (SOx, NOx, CO, CO_2, and particulates (FEIS at 4-118).

Table E-2: Approximate Annual Air Emissions from a Hypothetical 800 MW Fossil Fuel Power Plant[1]

	Coal (ton)	*Oil (barrel)*	*Gas (million cubic feet)*
Fuel Quantity	**2.8 million**	**11.2 million**	**69,000**
Oxides of Sulfur	55,000	3,500	170
Oxides of Nitrogen	25,000	54,000	500
Carbon Monoxide	1,300	2,900	40
Carbon Dioxide	6,400,000	5,900,000	4,100,000
Particulates	170,000	700	NA

1 Air emissions were calculated utilizing EPA AP-42 emission factors and annual production of 6,650 GWh.

The total air emissions offset by the three hydro facilities are approximately three times that presented in Table E-2 above.

Combined cycle gas-fired generation would likely be a major source of replacement power, along with renewables.

Hydropower is a price stabilizing factor in the competitive energy markets of Ontario and New York. While hydropower is bid as a low-cost supply, any replacement power would come from the most expensive source necessary to fill the system demand.

4. Key Baseline Conditions

The value of energy estimated in the Shared Vision Model assumes a market similar to that of today, with the same mix of energy producers, and the same influence of the navigational needs of the St. Lawrence Seaway. The near-term expectation is that the market will be at least as strong, with the available production capacity unlikely to outgrow the expansion of the market.

Future energy supply: The hydropower developed by the three facilities affected by the Plan of Regulation is integrated into the power supply of the northeastern states and provinces. Hydropower constitutes approximately 15% of New York's, 25% of Ontario's, and 95% of Quebec's energy supply, respectively. Changes to hydropower production would have to be offset by changes from other types of plants, which have significantly different cost and environmental characteristics. Substitution may come from gas turbines, with some from coal-fired plants; both of these produce more carbon and airborne acids than hydropower, which essentially emits no conventional pollutants. Nuclear production is more or less fixed and is expected to decline over the next few decades as older plants close and no new plants are built.

5. Key Trends

Air quality: Air quality is one of the most important environmental concerns in southern Ontario and the northeastern United States. State and federal legislation is still evolving to further reduce air quality problems associated with power production, especially acid rain and the carbon emissions that drive climate change. In the United States, there are several bills under discussion that would amend the *Federal Clean Air Act* to varying degrees. Regardless of what measures might be enacted, all will require stricter emission controls on fossil-fired generation during the 2010-2020 time frame. Although carbon controls remain controversial at the federal level, the northeastern states are moving forward with regulatory programs that would establish a regional cap and trade program for carbon dioxide by 2008.

In Canada, the Provincial Government of Ontario has announced its intention to reduce reliance on fossil fuel generation and increase renewable energy by 1,350 MW by 2007 and 2,700 MW by 2010. Canada is a signatory to the Kyoto Treaty and will be required to reduce carbon emissions beginning in 2005.

The net effect of these actions will be environmental and economic pressure on many of the existing facilities that contribute to the current energy markets in Canada and the United States. "Cheap" existing sources of power will be required to retrofit emission control technologies, or close. Short-term replacement facilities will likely come from gas-fired combustion technologies, which will continue to put upward pressure on gas prices. All jurisdictions in the region are pursuing additional sources of renewable generation (hydroelectric, wind and biomass). Wind technologies will likely be the most widespread renewable in the near term. These facilities, however, produce intermittent generation that does not contribute significantly to the base load or capacity needs of the region in the same manner that the hydro facilities do.

Because overall demand is rising and environmental concerns are expected to force the closure of some coal-fired plants, Lake Ontario regulation favourable to hydropower production will ensure the long-term supply of competitively priced, renewable, clean energy for the foreseeable future and will be more important, not less, as time goes by.

Demand and price: High water conditions in the past have generally increased the value of energy produced at these facilities, while lower water levels have had the opposite effect.

Synapse Energy Economics Inc. developed estimated prices for the electricity generated by the Moses/Saunders and Beauharnois/Cedars hydroelectric stations on the St. Lawrence (**Electricity Price Forecasts for St. Lawrence Hydroelectric Generation**) to help inform decisions about the regulation and operation of that shared water body:

> The primary factors affecting future long-term electricity prices are:
> - Fuel Prices
> - Technology
> - Environmental Factors
> - Electricity Demand
>
> There is considerable uncertainty about future fuel prices. The marginal cost of electricity in the US Northeast and Eastern Canada is strongly influenced by the cost of natural gas. In the last several years, there has been a large rise in the price of natural gas as demand has increased for new, clean electrical generation. The consensus view is that natural gas prices will decline from their current highs, but there is no consensus about how much they will decline or for how long. The futures market for natural gas goes out for six years and suggests a 30% decline in prices by 2010, but trading in the futures market very thin in the later periods and based on past history it is not always a reliable predictor of actual prices. Since natural gas demand in North America outpacing production, imported LNG is likely to establish the market price in the future. How rapidly these new supplies can be brought to market is uncertain.
>
> . . . .
>
> In terms of impacts associated with shifts in hydro generation, the most likely fuel to be displaced when electricity prices are high is natural gas which has a low carbon emission factor. When coal is the marginal fuel with higher carbon rates, the electricity prices are generally lower. To the extent that externalities are fully reflected in emission taxes, then the best policy for hydro plants is to generate more when prices are high and less when they are low.

Much effort has been put forth to determine the long-term pricing of megawatts and the future look of the electric industry. This is valuable to demonstrate the value of hydropower and to give an indication of the cost of replacing hydropower with more expensive substitutes. It does not however, give a true picture of the benefits or losses to hydropower. This is because our mission as a publicly owned entity differs from that of a stockholder owned corporation, whose mission is to maximize profits. Our mission is to provide low-cost, reliable power, and the St. Lawrence hydroelectric plants contribute to this mission by generating low-cost power.

As stated earlier, the cost of the last megawatt of power that is dispatched to serve a load in Ontario and New York becomes the cost of every megawatt in a particular zone for that hour. Inexpensive hydropower reduces the cost the entire load. Any hydropower generation that is removed from the base load would be offset by higher cost generation that would drive up the cost of the entire load.

Peaking and ponding: Megawatts produced from hydroelectric facilities cannot be stored. The value of that generation is directly tied to the demand for it. In the de-regulated electricity environment, the least-cost energy is supplied first (hydro), and more costly megawatts are subsequently added to meet the demand; namely nuclear and fossil fuel. The value of energy in peak can be significantly higher than that of energy off-peak. Energy demand varies on a daily and seasonal basis. The nighttime hours are considered low demand hours; high demand hours are generally from 7 a.m. to 10 p.m. High-demand seasons are typically summer and winter, while lower demand occurs in the spring and fall.

The power entities at Moses-Saunders conduct peaking and ponding operations to better match demand for electricity with its production. In this way, clean, inexpensive hydropower can be used to offset other energy sources. Peaking is the variation of the hourly flow about the daily mean flow so that the total daily flow is equal to that which would have occurred had the peaking not taken place.

Peaking is conducted when the maximum hourly outflows are 7,930 m^3/s (280,000 ft^3/s) or less. The maximum allowed peaking range is 850 m^3/s (30,000 ft^3/s) above/below the daily average flow.

Synapse looked at the incremental value of peak period generation. The period evaluated was short term and consistent with the emergence of the competitive markets in New York and Ontario. The company found an average ratio of peak to non-peak energy value of 1.17 for New York, and 1.26 for Ontario; compared with Moses, the Saunders values are higher and there is a much greater seasonal variation in the ratio.

Hydro-Québec makes very few peaking adjustments at Beauharnois-Les Cèdres.

Ponding is the storage of water on Lake St. Lawrence during the weekend for release during the week when power demands may be greater. While the power companies still have the authority to pond, they have done so less frequently over time and rarely do so now. The companies may not reduce flows more than 570 m^3/s (20,000 ft^3/s) below the average weekly flow on Saturday and Sunday to store water, and may not increase flows during the week more than 230 m^3/s (8,000 ft^3/s). If the weekly mean flow is above 7,700 m^3/s (272,000 ft^3/s), the allowances are decreased linearly up to 7,930 m^3/s (280,000 ft^3/s), at which point no ponding is allowed.

6. Expected Consequences of Changes of Regulation

Because the demand and price for energy is expected to be strong over the next few decades, the importance and value of St. Lawrence hydropower is almost certain to increase. In that light, the Shared Vision Model may well underestimate the future value of energy, but almost certainly will not overstate it.

7. Adaptive Behaviours

Energy demand is increasing, and hydropower will remain an important component of the energy supply in New York, Ontario, and Quebec.

The Hydropower infrastructure on the St. Lawrence is a critical component of the International seaway and power project, and represents a significant investment. Hydro facilities will continue to utilize available flows to generate in the most efficient manner possible. Any reduction of generation from these facilities will likely be replaced from a number of sources (combined cycle gas, coal, renewables, etc.) and originate either from the competitive market, or from sources chosen by the respective province or state.

If lower outflows are predicted for an extended period of time, the power entities would take the opportunity to perform maintenance and long-term refurbishment of the generating equipment.

8. Risk Assessment

There is some risk that the value of energy estimated in the shared vision model will underestimate the value of future production from these plants. Substantial changes to the pattern of water supply experienced in the twentieth century could reduce the dependable capacity of these facilities, and capacity benefits are not directly addressed in the Shared Vision Model.

9. References

The Hydroelectric Power TWG has relied on, and previously provided the following documents:

- The Hydroelectric Power TWG response to PFEG economic questionnaire.
- Executive Summary, *Effects of Peaking and Ponding within the St. Lawrence Power Project Study Area* (Study prepared for the International St. Lawrence River Board of Control (ISLRBC)).
- Executive Summary, *Effects of Project Operations on Aquatic and Terrestrial Habitats and Biota in Lake St. Lawrence* (NYPA relicensing study).
- Executive Summary, *Shoreline Erosion and Sedimentation Assessment Study* (NYPA Relicensing Study).
- Executive Summary, *Water Level Variations in the St. Lawrence River from Moses-Saunders Power Dam to Summerstown, Ontario* (NYPA relicensing study).
- Executive Summary, *Effects of Project Operations on Aquatic and Terrestrial Habitats and Biota Downstream of the St. Lawrence-FDR Power Project* (NYPA relicensing study).
- Executive Summary, *Shoreline Erosion and Sedimentation Assessment Study Downstream of the Moses-Saunders Power Dam* (NYPA relicensing study).
- Executive Summary, *Effect of Operation of the International St. Lawrence Power Project on Shoreline Erosion below Moses-Saunders Power Dam* (NYPA relicensing).
- *Estimating Hydropower's Contribution to the Control of Greenhouse Gas Emissions*, M.J. Sale and S.W. Hadley, Oak Ridge National Laboratory.
- "St. Lawrence Peaking and Ponding," March 1, 2002, presentation to the International St. Lawrence River Board of Control.
- Executive Summary, *Assessment of Potential Effects of Peaking/Ponding Operations at the St. Lawrence Power Project on Downstream Muskrat Populations* (March 1983 joint NYPA and Ontario Hydro report).
- Executive Summary, *Assessment of Shoreline Erosion and Marshland Recession Downstream of the St. Lawrence Power Project* (March 1983 joint NYPA and Ontario Hydro report).
- *Electricity Price Forecasts for St. Lawrence Hydroelectric Generation* (Final Full Report) David White, Bruce Biewald, Synapse Energy Economics, 22 Pearl Street, Cambridge, MA 02139

Please refer to the following websites for further information:
New York Power Authority: **www.nypa.gov**
Ontario Power Generation: **www.opg.com**
Hydro-Québec: **www.hydroquebec.com**
New York Independent System Operator: **www.nyiso.com**
Ont. Ind. Electricity System Operator (IESO): **www.ieso.ca/imoweb/infoCentre/ic_index.asp**
Regional Greenhouse Gas Inititive: **www.rggi.org**/
NYPA FERC License: **http://ferris.ferc.gov/idmws/search/results.asp** (doc 20031023-3050)
NYPA FERC FEIS: **http://ferris.ferc.gov/idmws/search/results.asp** (doc 20030923-0054)

10. Review Process

The Hydropower Contextual Narrative was jointly authored and reviewed by the following Hydroelectric Power Generation Technical Work Group participants:

Sylvain Robert (Hydro-Québec)
John Ching (OPG)
Robert Yap (OPG)
Cindy Lavean (NYPA)
John Osinski (NYPA)

The Hydropower TWG supports the submission of this document.

External review was afforded to Ian Crawford (Study Board) and Paul King-Fisher (PFEG)

J. L. Osinski

F. Municipal, Industrial and Domestic Water Uses Technical Work Group Summary

Objectives

The primary objective of the Municipal, Domestic, and Industrial Water Uses Technical Work Group (Water Uses TWG) was to assess the impacts of fluctuating water levels in Lake Ontario and the St. Lawrence River on municipal, domestic, and industrial water uses. Among these uses are drinking water treatment plants (WTP) and wastewater treatment plants (WWTP). For the first group mentioned, low water levels are a potential concern as they rely directly on the source to provide drinking water for the population. On the other hand, WWTPs are potentially affected by high water levels as they could limit the discharge into the water body. Similar to water and wastewater plants, industrial facilities could also be affected by extreme water levels, limiting withdrawal or discharge. Domestic (primarily residential) users who withdraw water directly from the Lake or River may also be impacted by water level fluctuations.

The mandate of the Water Uses TWG was to assess the potential impacts of water levels (low and high) on utilities located in the study area (adjacent to Lake Ontario and the St. Lawrence River). PMCL@CDM was hired to focus on Lake Ontario and the upper St. Lawrence River (U.S. and Ontario), and École Polytechnique de Montréal (EPM) was contracted to cover the lower St. Lawrence River (Quebec).[8]

Data Collection and Evaluation Methodology

The two consultant groups performed independent studies, pursuing similar objectives but reporting separate findings that were later integrated. As the accessible information varied from one region to another, the major topics were covered differently and some of them by only one of the two consultant groups. The depth of analysis was also representative of the detailed level of the information gathered as well as of the apparent criticalness of the facilities inventoried. The study performed by PMCL@CDM was based on public sources of information, questionnaires sent to utilities and interviews used to portray the situation of 43 Water Treatment Plants (WTPs) and 79 Waste Water Treatment Plants (WWTPs). As no public database was readily available for Quebec, the EPM project was based on a questionnaire and on-site visits for 30 WTPs and a phone survey for WWTPs. The EPM project did not cover the industrial plants as the information was made available only after completion of the mandate. However, the industrial interests were covered in the PMCL@CDM project. This latter study also included power facilities and shore wells located on Lake Ontario, interest groups that did not have counterparts in the lower St. Lawrence.

The ultimate goal of the studies performed by the two teams was to formulate criteria and performance indicators in order to support the interests of the municipal and industrial facilities in the future Lake Ontario-St. Lawrence River regulation plan.

Water level impacts on WTP and industrial intakes

Low water levels represent a major concern for the Water Uses TWG. First, extremely low water levels could limit the availability of the resource for withdrawal, and second, they could also impact water quality, which could imply greater treatment needs.

To address this issue, questionnaires were sent to WTPs to collect information related to critical water level and problems experienced in the past. The questionnaires asked for information regarding the following:

- water utility characteristics (e.g., treatment capacities and populations served) and physical characteristics of intakes (e.g., intake depth and length);

8 PMCL@CDM was also supported by two subcontractors: O'Brien and Gere Engineers Inc. of Syracuse, New York, and Earth Tech Canada Inc. of St. Catharines, Ontario.

- problems related to source water in terms of both quality and quantity; and
- "critical" water elevations, which were defined as water levels that would create concern regarding efficient operation of intake systems.

On-site visits (Quebec, New York and part of Ontario) and phone interviews (Ontario) were also performed to complete the data collection. The EPM project went deeper into the analysis and gathered the information required to calculate critical water levels based on head losses, during on-site visits. Two industrial plants (power plants) located on Lake Ontario were also investigated. Other problems related to water levels, such as frazil ice, were also addressed by both consultants (presented in complete reports).

In the context of low water levels, there was a concern that water quality would be adversely affected due to many phenomena like lower dilution or greater algae development. The water quality issue was addressed by EPM by holding an expert meeting to identify the potential water degradation sources that would be related to water levels. Based on the conclusions drawn during this meeting, the issue was addressed in three different ways: first, through the determination of increased chemical costs due to poorer water quality; second, by examining micro-pollutant concentrations and, finally, by evaluating the costs of treatment upgrades to deal with heavier taste and odour problems in low water level conditions. Taste and odour problems and algae blooms were also documented by the PMCL group and were mostly based on literature review.

Water level impacts on WWTPs and outfalls

Assessing how lake and river elevation potentially impacts wastewater discharges entailed conducting another survey to gather information. For the U.S. and Ontario, the survey activities consisted of developing a survey instrument, collecting baseline data, selecting a survey sample, distributing survey instruments and compiling and analyzing survey results. Surveys targeted major point source discharges in the Lake and River, including public wastewater treatment facilities, industrial discharges and power utilities. For the Quebec portion, a public database was used to position the outfalls and document the characteristics of the utilities. A phone survey was also conducted to obtain information concerning potential problems related to high water levels.

Water level impacts on shore wells and intake lines

The impacts of source water level variations on self-supplied residential water supply systems, such as shore wells and lake intake lines, were investigated in the upper St. Lawrence and Thousand Islands regions by PMCL. To accomplish this task, PMCL gathered and analyzed information from a variety of sources, including the New York State Department of Environmental Conservation (NYSDEC), Environment Canada, homeowners, homeowners associations, well contractors and local health departments. Furthermore, PMCL@CDM solicited information from shore-well owners by developing and placing banner advertisements in print media outlets in potentially affected areas so that affected residents could submit information regarding their experiences with lake or river water levels and their shore wells. Based on the preliminary analysis of the problem by the Canadian coordinator of the TWG, which did not identify particular interests in the lower St. Lawrence River, this issue was not addressed there.

Performance Indicators

Infrastructure performance indicator: drinking water production plant infrastructure costs required to adapt to levels lower than the critical levels identified. This performance indicator is based on cost estimations for building new intake structures when the critical level is reached. The costs provided probably overestimate the costs strictly linked to water level problems. Other solutions relieving part of the problem (lowering demand, etc.) would probably be put forward before a new intake is built.

Taste and odours performance indicator: the costs of upgrading municipal drinking water treatment plants to treat taste and odour compounds. Taste and odours are not regulated and are considered an aesthetic problem. However, the problem is a serious nuisance because it affects both the comfort and the confidence of the population. This performance indicator was once again based on cost estimation for the addition of a treatment stage. For this performance indicator to be trespassed, a low water level is needed for three consecutive years (during 1 quarter-month). More research is needed to define a clear link between water level and severe taste and odour problems resulting in investments from municipalities. In this case, the costs are probably underestimated as higher water levels could result in occasional problems, in combination with other factors.

Other municipal and private users impacted by water level (e.g., shoreline wells, groundwater contamination (Wilson Hill area), sewage overload) were evaluated but not represented as performance indicators in the Shared Vision Model. The impacts to those interests were found to be marginal in comparison with the performance indicators defined; however, a full discussion of all issues and problems is included in the analysis section below.

Baseline Economics

One of the Study Board's guiding principles for ranking a plan is that it should not produce a disproportionate loss in any sector in order to gain benefits in other sectors. In an effort to provide an objective basis for determining whether a loss is disproportionate, the Study Board asked that losses be compared against the overall economic scale of the activity affected. Unlike the other sectors, no estimate was made for the scale of municipal and industrial water use activity because there are no significant losses to this sector with any of the candidate plans.

Analysis

Various issues related to water levels were addressed in these projects. The methodology used to deal with these issues depended upon the type, availability and level of details of the information. The following section presents the types of uses evaluated along with a brief description of what was found.

Lake Ontario and Upper St. Lawrence River

Municipal and industrial intakes

Critical source water levels were defined as water elevations that create concern regarding efficient operation of intake systems. In general, critical levels were reported as the minimum amount of water or "cover" that an operator would prefer to have above an intake crib. In some cases, actual lake levels or deviations from the long-term average were reported. It is important to stress that critical elevations are approximations on the part of facility operators and are not based on site-specific engineering studies.

In New York and Ontario, the presence of algae was the most common problem reported by many water treatment plant operators, regardless of intake depth. Taste and odour problems associated with algae were reported by several water treatment facilities. Taste and odour impacts vary in intensity each year. However, two notable and extended events occurred during late summer in 1998 and 1999 when taste and odour levels were about 10 times higher than historical levels. While it is true that 1998 was a low water year, it is unclear as to whether lake levels were a significant contributor. Research by the Ontario Water Works Research Consortium (OWWRC) suggests that spring warming may be critical.

Only 10 facilities of 30 in Ontario and New York identified a critical water level (i.e., a water level that would create concern regarding efficient operation of intake systems): seven along Lake Ontario and three along the St. Lawrence River. The remaining 20 could not provide a figure since lake or river levels had never been a significant concern. Along Lake Ontario, reported critical levels range from 71.0 m (233.0 ft) to

74.1 m (243.0 ft). Three facilities along the St. Lawrence River upstream of the Moses-Saunders Dam (Ogdensburg, Morristown and Ingleside) reported critical elevations of 73.2, 71.6 and 71.2 m (240.0, 235.0 and 233.6 ft) respectively. When comparing with the record low, Albion (N.Y.) was the only facility along Lake Ontario that reported a critical elevation above this level. In general, most interviewees agreed that variations within long-term averages do not have a substantial impact on the ability of water treatment plants to effectively supply water. The one exception was the Monroe County Water Authority drinking water plant that did report impacts by high water levels which could flood the pumping station. The loss of the pumping station would stop delivery of water to about 650,000 customers. While the Water Authority did not quantify the damages associated with high water level situations, preliminary investigations show that the Authority has avoided this in the past by sandbagging the plant, that water levels that provoke sandbagging will occur a few times a century under the current plan, and that no matter what regulation plan the International Joint Commission selects, Lake Ontario levels will be a few feet higher than the sandbag trigger level during the most extreme wet periods.

On the other hand, low water levels appear to be a significant concern for industrial, and in particular power generation facilities, for two reasons: 1) they affect shipments of raw material including coal, and 2) low water levels can impact intake structures causing loss of pressure for vital cooling systems and may expose intakes to other conditions such as frazil ice that can also threaten cooling systems. Three facilities along Lake Ontario reported a critical low water elevation for adequate head over cooling water intakes: 1) the Russell Coal-Fired Power Station in New York (74.37 m/244.00 ft) and 2), Ginna Nuclear Plant near Rochester, New York (74.37 m/244 ft), and 3) the Darlington Nuclear Station in Ontario (72.0 m/236.22 ft). Both Ginna and Russell, located on the south shore of Lake Ontario, would experience problems within the historical record, and will require upgrading to remain fully operational under high and low water level conditions in the future under any plan, including the existing one. Low level problems are not a problem for the Darlington plant under any plan or supply sequence scenario evaluated, including the climate change scenarios.

Wastewater treatment plants and outfalls

Of the 79 facilities that responded to the survey, 32 reported critical water elevations. The remaining facilities either left the question blank or specifically indicated that they did not know or have the information.

Low critical levels for Lake Ontario range from 74.37 m (244.00 ft) to 67.12 m (220.22 ft). Only two facilities reported low critical levels above the Lake's record low (73.73 m/241.90 ft), and only one facility noted critical low levels above the lower bound (74.15 m/243.30 ft) of the IJC Orders of Approval.

High critical elevations for facilities along Lake Ontario range from 80.16 m (263.00 ft) to 75.59 m (248.00 ft). Only three facilities reported critical high levels that are below the Lake's record high of 75.80 m (248.69 ft), and none reported levels that were below the upper bound of the IJC Orders of Approval (i.e., the regulation plan) of 75.37 m (247.29 ft).

Similar to the case on Lake Ontario, critical high water levels at most facilities along the River are relatively high—between 4.14 m (13.58 ft) and 1.05 m (3.44 ft) above datum—while low critical levels are from 0.73 m (2.40 ft) to 15.42 m (50.59 ft) below datum.

Domestic uses

Source water elevation can and does affect self-supplied residential water systems, including shore wells and water intake lines; however, the number of people who use self-supplied systems is small relative to populations served by water utilities.

Determining a critical elevation for plan performance measures for residential systems is difficult given that little documented data exist. However, based on available information, a flurry of complaints from Thousand Islands area residents were filed with Environment Canada in the fall and winter of 1998, and other reports were documented near Massena, New York, during the same time period. Reports were also received in November of 2002 from U.S. residents in the Thousand Islands area. Furthermore, most reported problems from the August 2003 shore well survey appear to have occurred from 1998 onward. At the time the reports occurred, Lake Ontario was at its lowest level in 30 years—a monthly average in November 1998 of 74.40 m (244.03 ft). In 2002, when other reports surfaced in the same geographic area, lake levels were only slightly higher than in 1997—74.46 m (244.30 ft). Therefore, based on available information, a lake elevation of about 74.37 m (244.00 ft) could serve as plan performance measure for shore wells along Lake Ontario. Along the upper St. Lawrence, substantial problems with water levels and lake intake lines were reported beginning in August of 1997 and throughout 1998 along Lake St. Lawrence. Long-term historical data for Lake St. Lawrence (e.g., the Long Sault gauge) were not available at the time this report was written, but the above dates could serve as a reference point for selecting an appropriate critical water level.

PMCL advertised in local papers asking people if they had problems withdrawing water from the River, and the few responses received indicated that people fixed any problems themselves. The Wilson Hill community, which had been affected by this problem, has since obtained municipal water supplies. Although the economic impacts associated with this phenomenon could not be quantified, it was tracked to see how reliably each plan produced water levels above the elevations at which such problems were said to begin.

Lower St. Lawrence River

Municipal and industrial intakes

Based on the survey results, the main problems experienced by water utilities are taste and odour, frazil ice and capacity. Taste and odour and frazil problems are not necessarily directly related to low water levels in all cases but tend to increase in such conditions, according to utilities. A total of 42% of the utilities suffer from taste and odour problems, while 50% experience frazil problems. Capacity limitations in low water levels were mentioned by three utilities out of 30.

The impacts of low water levels on plant operation were characterized by **red** and **yellow** production performance indicators. The red production performance indicator describes a severe consequence corresponding to the water level at which a plant will no longer be able to supply nominal capacity using the available infrastructures (i.e. pumping stations and water intakes). Alternatively, the yellow performance indicator describes the water level at which a plant will need to open its emergency intake to supply nominal capacity (i.e., modify its normal operating condition). This performance indicator therefore represents an alarm sign indicating that the nominal capacity of the plant can no longer be maintained by the principal intake. A yellow performance indicator could only be determined for plants disposing of more than one intake.

The critical water levels (red performance indicator) for each plant downstream of Ste-Anne-de-Bellevue are summarized in Figure F-1.

With respect to the red production performance indicator, the plants that are the most affected by water levels are: Lavaltrie, Montreal (Atwater and DesBaillets), Verchères, Pointe-Claire, St-Lambert and Candiac. These seven systems will reach the red production performance indicator at water levels above the worst case scenario studied, which is 1.0 metre (3.3 ft) below the chart datum at Pointe-Claire (70 cm (28 in) below the historical minimum level). These plants represent 23% of the plants investigated (7/30) and more than 74% of the population of the study area (1,720,000/2,320,000). The Varennes WTP would see its normal operating conditions restricted (yellow PI) under the worst water level scenario considered.

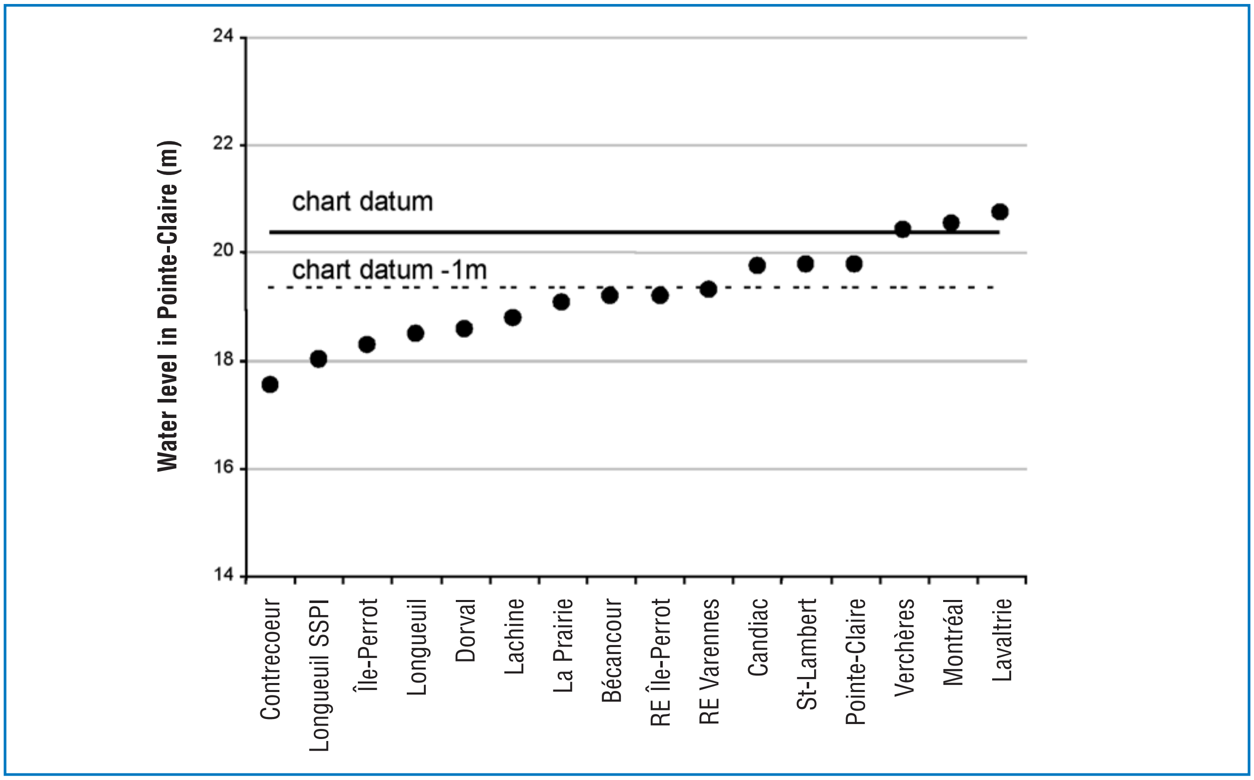

Figure F-1: ***Critical water levels (red performance indicator) referenced to Pointe-Claire. Red performance indicators describe the minimum water level required at Pointe-Claire to supply nominal capacity using all intakes available (IGLD 85)***

A special black performance indicator was defined for the intake structure of Montreal's Atwater and DesBaillets WTPs. Contrary to the other cities, they are in a unique situation in which capacity is lost gradually. Their red performance indicator means that the nominal capacity can no longer be supplied but 91% of the production can still be distributed. The black performance indicator corresponds to the level at which the Atwater plant is lost completely; at this point, a large portion of the distribution system would be unpressurized.

The impact of water levels on plant capacity can also be expressed with respect to the total number of plants or the total population affected. This information is presented in Figure F-2. The representation highlights the relative weights of each treatment plant with respect to the total population of the study zone.

Municipal and industrial water use has generally not been vulnerable to water level changes, except in 2001, when the critical level of 20.53 m (67.36 ft), with reference to Pointe-Claire, was reached temporarily in Montreal; almost the same situation occurred in 1999 (20.54 m) (67.39 ft). The Montreal main water intake pipe, located just below Lac St. Louis, is relatively shallow and situated in uneven, mildly sloping marine topography. Access to deeper water is possible about 400-500 m (437-547 yd) from the actual intake site, but with major constraints to be overcome (strong current, bedrock to dynamite, large pipe) to gain little depth. The City of Montreal rebuilt its emergency intake in 2003 to support its main intake (Atwater and DesBaillets), allowing an increase in total adduction capacity of 21%. Under projected normal conditions, proper operation should be maintained until the 20.53-m (67.36-ft) level is reached, potentially causing a 9% drop in nominal capacity. However, during the next 50 years, with climatic changes, the Montreal major intake (main and emergency) could still be at risk if the chart datum level is reached at 20.35 m (66.77 ft) or lower, with reference to Pointe-Claire.

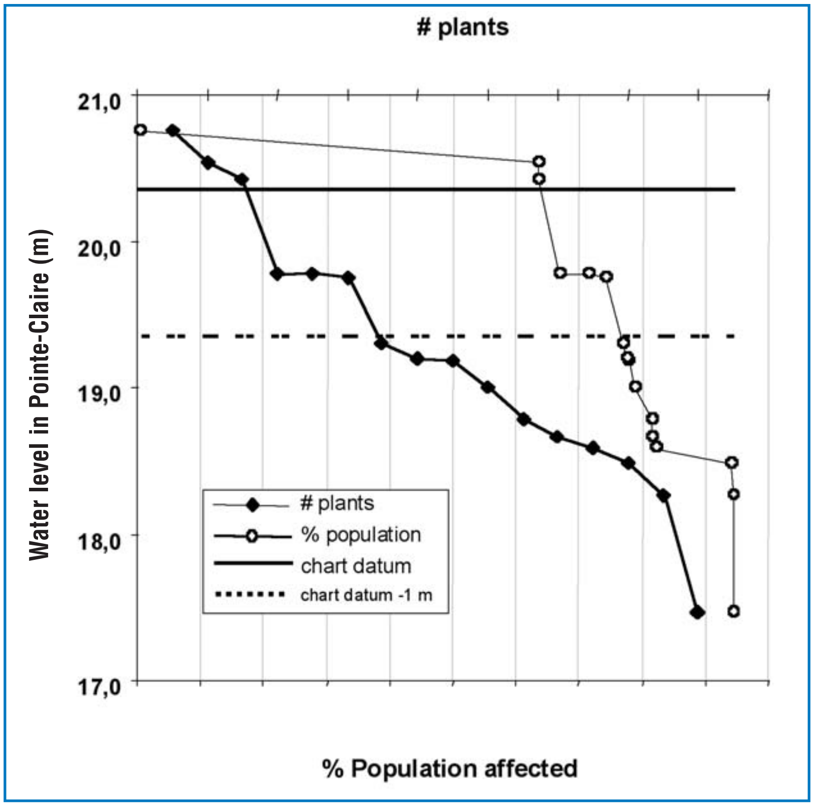

Figure F-2: Impacts of water levels (referenced at Pointe-Claire) on the number of plants reaching the red PI and the corresponding % of the total population affected in the study zone

Wastewater treatment plants and outfalls

Contrary to water treatment plants, high water levels were suspected to have an impact on wastewater treatment plants. According to the director of Montreal's wastewater plant, WWTPs are not really affected by water levels, except in the case of floods (i.e. extremely high water levels). Even in this situation, most of the wastewater outfalls are equipped with check valves protecting them from backflow.

With regard to industrial outfalls, the situation remains unknown in the lower St. Lawrence. However, this issue was addressed in the Lake Ontario/upper St. Lawrence region and the general conclusion is that outfalls are less at risk than water intakes.

Domestic uses

Domestic uses for water supply, like intake lines or shore wells, were not identified as a key issue in the lower St. Lawrence River. No region was identified as having several residences withdrawing water from the River, as is the case in the Thousand Islands region.

Integration into the Shared Vision Model

The research was integrated into the SVM in the following three ways:

1. Economic models;
2. Estimates of the probability, severity and duration of water levels that caused negative impacts on municipal and industrial water uses; and
3. General water level statistical reports that could be used after the study to answer new questions raised by the municipal and industrial water uses community.

First, the STELLA portion of the Shared Vision Model includes modeled estimates of the economic impacts on water quality and water supply. Second, the STELLA model calculates statistics regarding the stages of concern for municipal and industrial plant operators. Water supply response is divided into four categories represented by the colours green, yellow, red and (worst) black.

Third, the SVM was used to produce general water level statistics that could then be applied to questions raised after the reports were completed (e.g., "What is the chance that sandbagging of the Monroe County Water Authority plant will be necessary under each candidate plan?).

Summary of Key Findings

- Municipal, industrial and domestic water use is generally not vulnerable to water level changes. The Study found that the Montreal system could be at risk later in the century, assuming that climate change induces the dry, hot scenario modeled in the Study.
- Other exceptions are the Russell and Ginna power generating stations and the County of Monroe potable water pumping and treatment plant on the south shore of Lake Ontario in New York state. The two power generating facilities report critical low water elevations for their cooling water intakes at levels within the historical record under the current regulation regime. However, the Study Board was informed that Russell is closing and Ginna would take measures to deal with this design flaw.
- The Monroe water pumping and treatment plant experiences flooding problems at Lake Ontario elevations within the historical maximum range.
- Shoreline wells, groundwater contamination and sewage overload were evaluated in terms of the recurrence of water levels likely to induce these problems, but not in economic terms, since impacts were either small relative to other categories or because plant operators were unable to estimate the impacts.

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F. Municipal, Industrial and Domestic Water Uses Contextual Narrative

1. General Socio-economic Context

(a) Production value of the interest

There is no production value associated with the use of water for drinking water production, but it represents a very high social cost that can be affected by water levels. A large majority of municipal demand is linked to the residential population as well as to other major installations such as hospitals, schools, commercial centres and buildings; industries also rely on water for production and cooling systems. The availability of water either from municipal water treatment plants or through private intake systems could have serious financial impacts (e.g.: industry closures).

(b) Number of stakeholders

There are 2.3 million residents who rely on the lower St. Lawrence River, and 6.3 million residents who rely on Lake Ontario and the upper St. Lawrence (both Ontario and the U.S.).

(c) Organizational characteristics

The stakeholders are located all along the systems, but two different groups can be distinguished in terms of interest and location: 1) domestic users in the Greece and Thousand Islands area, and 2) municipal water treatment plants in the lower St. Lawrence River (Montreal metropolitan area).

(d) Values and perceptions of the interest

The municipal water supply is obviously considered an essential interest. In general, however, this interest is perceived as not critical as it is only affected in extreme situations. This is also true of other uses such as industries and wastewater treatment plants. Smaller users (intake line, shore residents) may feel they are left aside, but mitigation measures may be more appropriate to solve their problems.

(e) Significant statutory, regulatory and policy restrictions

In the next ten years, the most significant statutory, regulatory or policy restrictions that could affect water regulation are more related to discharge in low water level conditions. Pollutant dispersion, the impacts of outfalls on aquatic biota (*Clean Water Act*), and thermal dispersion are the main concerns. However, the low water levels at which these concerns should be seriously considered are much below actual regulation levels. In general, Lake Ontario–St. Lawrence River water is of very good quality and eventual regulation regarding water quality for drinking water production should not be problematic.

(f) History of the interest

This interest was introduced in the regulation plan mainly for the downstream portion because municipal plants were identified as vulnerable to water level fluctuations.

(g) Trade flows and current market conditions

Municipal water uses of the system could slowly increase as the population grows.

(h) Effect of last high or low water conditions

High water conditions in the past have not been a problem as low levels are generally more problematic. High water levels experienced more recently, combined with an increased population on some islands resulted in the appearance of new concerns (groundwater contamination). Low water levels were not reported as problematic, possibly because of a smaller withdrawal that can tolerate lower levels.

2. Performance Indicators

- **Infrastructure performance indicator:** drinking water production plant infrastructure costs required to adapt to levels lower than the critical levels identified. This PI is based on cost estimations for building new intake structures when the critical level is reached. The costs provided probably overestimate the costs strictly linked to water level problems. Other solutions relieving part of the problem (lowering demand, etc.) would probably be put forward before a new intake is built.

- **Taste and odours performance indicator:** the costs of upgrading municipal drinking water treatment plants to treat taste and odour compounds. Taste and odours are not regulated and are considered an aesthetic problem. However, the problem is a serious nuisance because it affects both the comfort and the confidence of the population. This PI was once again based on cost estimation for the addition of a treatment stage. For this PI to be trespassed, a low water level is needed for three consecutive years (during 1 QM). More research is needed to define a clear link between water level and severe taste and odour problems resulting in investments from municipalities. In this case, the costs are probably underestimated as higher water levels could result in occasional problems, in combination with other factors.

Other municipal and private interests impacted by water level (e.g., through shoreline wells, groundwater contamination (Wilson Hill area), sewage overload) were evaluated but not represented as performance indicators in the Shared Vision Model. The impacts to those interests were found to be marginal in comparison with the PIs defined.

3. Potentially Significant Benefit Categories Not Addressed by the Current Performance Indicators (Secondary Impacts)

As the Lake Ontario–St. Lawrence River system will remain an abundant source of good quality water, no secondary impacts to municipal and industrial uses were identified.

4. Key Baseline Conditions

The critical values calculated for the Shared Vision Model consider the nominal capacity of plants, thus taking into account future population growth (for the existing plants). The construction of new plants should not be problematic as lower levels would be considered. The impacts were evaluated for the actual Seaway configuration. The change in water depth in the lower St. Lawrence River resulting from widening or deepening of the Seaway would change the conclusions of the analysis.

5. Key Trends

The use of water for municipal and other purposes is not expected to skyrocket in the near future. Water is available throughout the system, but water levels can limit the availability for actual installations. The infrastructure of any new facility that would rely on water (water production plants or others) should be designed to account for more variability in water levels.

6. Expected Consequences of Changes of Regulation

The possibility of relying on other sources of water than the St. Lawrence system is almost inexistent for plants located along it. Mitigation would thus have to be considered. The costs estimated in the Shared Vision Model include the costs of new withdrawal infrastructures for vulnerable municipal facilities. These solutions, however, take a long time to be effective and would require planning. Another impact of level fluctuations is quality deterioration (position of emergency intake) for the Montreal plants. This impact will be alleviated by the treatment upgrade scheduled in the next few years. The taste and odours problem is also linked to lower water levels, and costs of treating them were estimated. Globally, mitigation strategies could be applicable, but the costs would have to be taken into consideration.

The potential loser as a result of new regulation or change in the water system (Seaway) is the lower St. Lawrence, where variations are greater and the infrastructure more sensitive to changes.

7. Adaptive Behaviours

The evaluation of alternatives is based on the most likely future conditions and so where there is evidence that adaptive behavior was expected, it is already included in the analysis.

8. Risk Assessment

The vulnerability of the various water uses to level fluctuations was identified as fairly low under the regulation scenarios considered (very low probability of reaching a critical level). However, the risk associated with very rare events is very high if they are not predicted (e.g., water shortages in Montreal). The information gathered during this project highlighted the need for planning and raised awareness, among the people in charge, of low probability-high risk events.

9. References

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Review Process

Author: Annie Carrière and Benoit Barbeau
Reviewed by: N/A
Received TWG Support: Denis Peloquin
External Review: N/A

G. Aboriginal Peoples Contextual Narrative

This context focuses on the intersection of the lives of the people of Akwesasne and the issues at play in a revision of the rules for regulating releases from Lake Ontario. Study team members also communicated with the Tyendinaga Mohawks, about 2,200 people who live along the shores of the Bay of Quinte, just east of Belleville, Ontario, and the Kahnawake Mohawks, about 8,000 people living south of Montreal along the south shore of Lac St. Louis. The Study Board addressed the primary concerns these communities have with regulation in its work on Lake Ontario flooding (Tyendinaga) and low and high levels of Lac St. Louis (Kahnawake). Comparisons of plan results for those issues are in the Main Report.

1. General Socio-economic Context

(a) Number of stakeholders

The Akwesasne community numbers about 13,000 mostly Iroquois people living in a 104 km^2 (40 mi^2) area that straddles the border between the United States and Canada along the St. Lawrence River in the immediate vicinity of the Moses-Saunders Dam.

(b) Organizational characteristics

Akwesasne is the only North American reservation with land on both sides of the Canada-U.S. border, and this unique geographic setting has brought sovereignty issues to the surface that might be less pressing for other tribes that did not deal with customs duties and border checks (Hoxie). The superimposition of the U.S. and Canadian governments has produced three Akwesasne governing bodies. The Mohawk Council of Akwesasne administers the Akwesasne north of the Canadian border, including the Quebec and Ontario portions, while the St. Regis Tribal Council administers the New York portion. These bodies were formed with Canadian and U.S. agreement. The older Mohawk Nation Council is not recognized by Canada or the U.S. but is supported by people who maintain allegiance to the Iroquois Confederacy. This study is one part of a larger fabric of interaction and discussion, between the International Joint Commission and aboriginal people along the Canada-U.S. border, on Lake Ontario regulation and other issues. Two positions on the Study Board were reserved for Akwesasne representatives to ensure that the interests and perspectives of the Akwesasne Mohawks would be considered. These seats are held by James Snyder and Henry Lickers, who were the primary conduits for information between the Akwesasne Mohawks and the Study Board.

(c) Values and perceptions of the interest

Maxine Cole of the Akwesasne Task Force on the Environment (ATFE) wrote the principal summary of Akwesasne concerns and perspectives (Akwesasne Task Force on the Environment). The ATFE was formed in 1987 to promote environmental protection and restoration based on "traditional tribal teachings about the obligation to honor the sacred web of life and guard it for future generations." According to those teachings, the process of collaborative natural resources management should include the following:

- *Skennen*, which is a state in which all people rationally and empathetically try to achieve a just resolution;
- *Kariwiio*, a condition wherein the participants "use their purest and most unselfish minds," remembering that creation is intended for the benefit of all, including plants and animals; and
- *Kasastensera*, a strength of purpose that results when people act collaboratively and unselfishly in pursuit of wise and just decisions.

The goal is to ensure that seven generations are endowed with the same gifts as the current generation.

(d) History of the interest

The Akwesasne community was established in 1755 near a Jesuit mission, but the Iroquois Confederacy predates the arrival of Europeans and includes the five founding nations (Mohawk, Seneca, Oneida, Onondaga, and Cayuga) and the Tuscarora. The majority of people in Akwesasne are Mohawk or Kanien'kehake, but there are also Abenaki, Onondaga, Oneida, Cayuga, and Huron. The four largest Akwesasne towns are St. Regis Village and Chenail Districts in Quebec, Cornwall Island District in Ontario and Hogansburg in New York.

(e) Effect of last high or low water conditions

The Akwesasne live primarily along Lake St. Francis and so are mostly not directly affected by the regulation plan. Levels in the upper part of the Lake, near Summerstown, are only partly dependent on the release from Lake Ontario and vary within a small range (between about 46.4 and 47.1 m (152.2 and 154.5 ft)), regardless of the plan, when modeled over the range of twentieth century water supplies. Levels in the lower part of Lake St. Francis near Coteau Landing are not affected by the release and are controlled by the operation of Hydro-Québec facilities.

2. Performance Indicators

The Akwesasne Task Force on the Environment has repeatedly pointed out the impact on the Akwesasne community of construction of the regulation dam and the St. Lawrence Seaway project and of pollution from industrial sources. In addition, throughout the Study, the Akwesasne have raised concerns about the operation of the Seaway, including ships' wakes and the effects of ice breaking and of peaking and ponding within the week for hydropower production. Although changes in the weekly regulation of the project have little direct effect on the Akwesasne lands, the Akwesasne people are concerned about the environmental quality of the entire system. The Task Force report lists the environmental indicators of specific concern, and for the most part these are included in the Environmental TWG performance indicators. Because the Task Force report was commissioned after the environmental research was nearing completion, there are no direct studies of the expansion of wild leek or the impact of regulation on medicinal plants.

3. Potentially Significant Benefit Categories Not Addressed by the Current Performance Indicators (Secondary Impacts)

Because the global concerns of the Akwesasne people are environmental, the same limitations that apply to the Study's analysis of secondary environmental impacts apply here

4. References

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H. Hydrology and Hydraulics Modeling Technical Work Group Summary

Water level and flows in Lake Ontario and the St. Lawrence River are primarily influenced by the will of nature. Precipitation, evaporation, spring runoff and ice conditions are each elements of the hydrologic cycle. This cycle must be taken into consideration by the St. Lawrence River Board of Control when regulating the outflows of the Lake Ontario–St. Lawrence River system. Much of the regulation of the system is dictated by a forecasting of seasonal weather conditions and current water levels upstream and downstream of the power project at Cornwall, Ontario, and Massena, N.Y.

Due to the complexity of the system and the number of interests affected by water levels and flows, there is a need for computer simulated hydrologic and hydraulic modeling to fairly assess current regulation criteria and allow the International Lake Ontario–St. Lawrence River Study Board to develop and recommend a fair and equitable regulation plan.

Objectives

The primary objectives of the Hydrology and Hydraulics Modeling Technical Group (H&H TWG) were as follows:

- To provide hydrologic and hydraulic modeling information that allows other TWGs to develop and evaluate regulation plans. The information included the following:
  - hydrologic scenarios; water supply inputs in the Great Lakes, Ottawa River and other key tributaries to the St. Lawrence River;
  - recorded historical averages;
  - randomly generated variables;
  - climate variability from General Circulation Models (GCMs);
  - basin supplies to each of the Great Lakes;
  - outflows from the Ottawa River and other key downstream tributaries;
  - hydraulic effects of ice and vegetation; and,
  - flow diversions.
- To simulate water levels and flows from Lake Ontario and in the St. Lawrence River to Trois-Rivières, Quebec, under various regulation plans and water supply scenarios.
- To provide weekly average water levels and flows and estimate, within any given week, the potential variability in levels and flows (i.e., peaking and ponding cycles).
- To assist in the modeling of detailed hydraulic information (e.g., velocities and levels), as requested by other TWGs.

The TWG was also tasked to undertake temperature modeling of the key areas in Lake Ontario at the request of the Environmental TWG.

Key Technical Studies

Great Lakes Net Basin Supply and Ottawa River Inflows Synthetic Generation

In order for the regulation plans to be evaluated by PFEG, it is paramount that these plans be tested for robustness, flexibility and system representation. These aspects are evaluated not only by testing the proposed regulation plan against the recorded historical supplies and flows, but also against simulated series of stochastically generated supplies. The stochastic nature of the simulation process implies that the statistical properties of the simulated and historical supplies are generally similar.

Under this project, the H&H TWG provided PFEG and other TWGs with a 50,000-year supply sequence. For consistency with the historical series, these 50,000 years of sequence were split into 500 series, each 101 years long. These 500 series not only preserve statistical properties such as the mean, standard deviation, skew, etc., but also embed flow sequences outside of the experienced range or sequences of dry or wet supplies historically not observed. In this simulation process, it was not only required that year-to-year temporal properties be conserved, but also that the lake-to-lake and lower-lakes-to-Ottawa-River spatial relationships be preserved. For example, the simulation exhibited wet supply conditions in both lower lakes (Lakes Erie and Ontario) and the Ottawa River system.

In order to match the regulation plan time steps for the Great Lakes and operational model time steps for the Ottawa River system, the stochastic simulation was carried out in four distinct steps. At the first step, yearly time series were computed for the entire system while maintaining the spatial relationship of lakes Erie and Ontario with the southern portions of the Ottawa River system. For the second stage, the yearly supplies were divided into monthly sequences while ensuring the seasonality was preserved. In the third step, monthly sequence of supplies to lakes Erie and Ontario are temporally disaggregated into quarter monthly equivalents. In the last stage, which is applied only to the Ottawa River and the lower tributaries, the quarter-monthly supplies are further disaggregated into daily flow sequences.

For the purposes of simulation, the project was carried out in three distinct spatial zones, namely the Great Lakes, the Ottawa River System and the local tributaries downstream of Lake Ontario control structures and the downstream study limits. These are described briefly:

- **Great Lakes**

  The supplies into the Great Lakes are characterized by the size of the basins and are spatially represented by four geographic areas. The supply nodes are for Lake Superior, lakes Michigan and Huron, Lake Erie and Lake Ontario. The spatial dimensions of Lake St. Clair required that it become part of the supply sequence for lakes Michigan and Huron.

  The final stochastic series for the Great Lakes are based on monthly time steps for the upper lakes, while lakes Erie and Ontario are simulated at quarter monthly time steps. This is to maintain the consistency with the available hydrologic models for system operations.

- **Ottawa River**

  With the constraints imposed by the unique features of the Ottawa River watershed and the structure of reservoirs operated by Hydro-Québec, the system was resolved at finer scales both spatially and temporally. For the stochastic series computations, the Ottawa River was divided into 48 sub-watersheds and the supply sequence computed at a daily time step.

  Some of the sub-watersheds in the Ottawa River system were employed to establish a spatial correlation with the Great Lakes basins. For example, the southern sub-watersheds of the Ottawa River exhibit a fairly strong correlation with Lake Ontario supplies and a less strong correlation with Lake Erie supplies. Similarly, the south-eastern sub-basins of the Ottawa River have a strong relationship with the local tributaries below Cornwall.

- **Local Tributaries**

  For the area below Cornwall there are several key streams, individually not significant but collectively important, in the operations of the control structures and the regulation of Lake Ontario. The drainage area of the local tributaries is marked by a group of four major streams that characterize the local inflows. These streams are strongly and spatially correlated with several Ottawa River sub-basins. As such, the sequence of supplies was established using regression relationships developed from the historical flow records.

Climate Change Scenario Development

In recent IJC and U.S. Global Change Research Program studies, the Great Lakes Environmental Research Lab (GLERL) completed modeling of hydrologic impacts of climate change for the Great Lakes region. This work used meteorological outputs from two GCMs and transformed them into hydrological impacts with models of rainfall/runoff, lake evaporation, connecting channel flows, lake regulation, and lake water balances. However, climate change projections were not included in this work for the Ottawa River basin and lower St. Lawrence River. GLERL made GCM results available over these extended areas, and hydrologic modelers at Hydro-Québec expanded the estimation of climate change hydrological impacts over these areas. GLERL and Hydro-Québec compared their climate change projections in preparation for a new joint assessment of climate change impacts on hydrology over the entire Great Lakes-St. Lawrence River basin in conjunction with the latest GCM simulations (the Canadian and U.K. Hadley GCM).

The project focused on a future 20-year window for 2050 (2040-2060). GLERL acquired GCM scenarios for the latest versions of the Canadian and U.K. Hadley models. In order to evaluate the climate change impact, thirty-year windows were chosen with four critical scenarios. Of these, two scenarios were from the third generation Hadley GCM, with the other two from the second generation Canadian GCM. For the purposes of this project, these are termed HADCM 3A representing a warm and wet climate regime, HADCM 3B for a not so warm and wet condition. For the Canadian GCM, these are CGCM 2A for a warm and dry regime and CGCM 2B for a not so warm and dry condition. It was noted that the term "dry" implies conditions with less precipitation than the Hadley simulations and not necessarily less precipitation than the current climate regime. These models were refined from the versions used in the U.S. National Climate Change Assessment. In particular, the Hadley Centre model exhibited a better agreement between the effects of atmospheric sulphate aerosols, as represented by the simplified parameterization that they routinely use, and much more lengthy and precise calculations.

GLERL extracted and provided Hydro-Québec with GCM output changes between a baseline period of 1961-1990 and the future 30-year periods. These changes provided for several variables: daily precipitation increase (ratio), minimum daily air temperature increase at 2 m (ºC), average daily air temperature increase at 2 m (ºC), maximum daily air temperature increase at 2 m (ºC), wind speed increase at 2 m (ratio), specific humidity increase (ratio), and cloud cover increase (ratio). GLERL adjusted historical meteorology data for the Great Lakes basin with the GCM climate changes, while Hydro-Québec and the Ministère de l'Environnement did the same for the Ottawa River basin. GLERL then simulated Great Lakes hydrology under the various scenarios while Hydro-Québec and the Ministère de l'Environnement did the same for the Ottawa River basin.

- **Key Findings**
  - The Hadley scenarios generally increase precipitation more than the Canadian GCM scenarios. Precipitation is greater than the base case on all lakes for the Hadley scenarios. For the Canadian scenarios, precipitation is greater on all lakes except Michigan, St. Clair, and Erie. The largest values are seen on Georgian Bay for the HADCM3A scenario and on Erie for HADCM3B.
  - Net basin supply is generally less than the base case for all changed-climate scenarios for all lakes except for the HADCM 3B scenario on lakes St. Clair, Erie, and Ontario. The greatest reductions in net basin supply occur on all lakes under the CGCM 2A (warm, dry) scenario, followed by either the CGCM 2B (less warm, dry) or HADCM 3A (warm, wet) scenarios, depending on the lake; the smallest reductions occur on all lakes under the HADCM3B (less warm, wet) scenario.
  - The higher air temperatures under the changed-climate scenarios lead to higher over-land evapotranspiration and lower runoff to the lakes, with earlier runoff peaks since snow pack is diminished and the snow season is greatly reduced. This also results in a reduction in available soil moisture. Water temperatures increase and peak earlier; heat resident in the deep lakes

increases throughout the year. Mixing of the water column diminishes, as most of the lakes become mostly monomictic, and lake evaporation increases. Ice formation is greatly reduced over winter on the deep Great Lakes, and lake evaporation increases; average net supplies drop the most where precipitation increases are modest.

Hydraulics

Hydrodynamic Modeling of the St. Lawrence River

Hydraulic information consisting of water surface elevation, flow directions and velocities was needed by other TWGs to fulfill their own objectives. To meet this obligation, the H&H TWG developed two hydraulic models to address the two distinct reaches, one above the Moses Saunders Dam and one below. These models are briefly described below.

A 2-dimensional hydrodynamic model of the St. Lawrence River system from the outlet of Lake Ontario near Kingston/Cape Vincent to the control structure at Cornwall/Massena was developed and made operational. The 2-dimensional hydraulic model was used to determine detailed velocities, levels and flows in the upper St. Lawrence River to support evaluation of the regulation plans by the navigation, recreational boating and tourism, environmental, coastal/riparian, water supply and/or hydroelectric power TWGs.

The simulations were prepared and processed to allow easy access to the hydrodynamic data for the St. Lawrence River by the TWGs of the Study. A total of 19 simulations were performed to cover the expected range of hydrological conditions. For each of these simulations, an ArcView shapefile was created for the water surface elevation, water depth and 2-dimensional velocity spanning the entire upper St. Lawrence River study area. The shapefile format was created to provide wide compatibility with other numerical modeling and processing tools.

The Commercial Navigation (CN) TWG expressed a need for detailed mean channel velocities for the St. Lawrence River along the main shipping channel. The mean channel velocity in the upper river is dependent on both the level of Lake Ontario and the outflow of the St. Lawrence River as specified at the Moses Saunders plant. For ease of use in the CN TWG evaluation model, a set of equations relating the mean channel velocity by channel leg to the level of Lake Ontario and the outflow of the St. Lawrence River, were developed using the hydrodynamic simulation data.

The Recreational Boating TWG consulted the H&H TWG for assistance establishing the precise water level for the docks and marinas in the upper St. Lawrence River. The computation of water levels at points intermediate to the Shared Vision Model output locations is complicated because the water level depends not only on the upstream level of Lake Ontario but also on the river outflow as specified at Moses-Saunders. The water level information was used by the Recreational Boating TWG to establish stage-damage curves for the docks and marinas in the River.

The members of the Environmental TWG have confirmed accessing the hydrodynamic modeling simulations and are currently making use of the information in their ongoing work related to fish habitat in the upper St. Lawrence River. The scenario outputs encompassing all anticipated hydrological conditions have been generated and placed on the IJC study ftp site. The scenario data includes water levels, point velocities, and water depths over the entire model network covering the Kingston to Cornwall Reach.

A 2-dimensional hydrodynamic model was developed to establish the basic hydrodynamic information for the Lake Saint-Louis area. The simulations were used to assess water depths and velocities for defined discharge scenarios, and also to provide basic data for other types of models that are needed by the other TWGs, such as sedimentation-erosion, wave action and habitat simulations.

Hydrological Information and Forecasting Integration

The U.S. H&H TWG reviewed existing operational net basin supply (NBS) and lake level forecast methods on the Laurentian Great Lakes above Cornwall. The following methods were reviewed: the Corps of Engineers (Detroit District) arithmetic moving average, trend, and multiple correlation methods, the Corps of Engineers (Buffalo District) Lake Ontario and downstream water level heuristic methods, the Canadian historical NBS Monte Carlo analysis, the U.S.-Canadian coordinated data, and GLERL's Advanced Hydrologic Prediction System (AHPS). Conceptual descriptions of each were provided. Extended weather forecasting, pertinent to use in Great Lakes water level forecasting, was also reviewed. NOAA and EC extended forecasts were considered and their bases described conceptually. The relative impacts (worth) of near-real time data availability (initial conditions) and weather forecasts on hydrological forecasts were evaluated by developing forecasts with and without their use and assessing agreement with observations over recent data periods. All existing operational NBS and lake level forecast methods on the Great Lakes were explored above Cornwall by inter-comparing them and their "goodness of forecast." For the most part, deterministic comparisons were used since all but the Canadian, the Coordinated, and AHPS are deterministic only. Some probabilistic analyses for these latter three, as well as deterministic analyses, were performed.

Forecast agencies are already beginning to incorporate current hydrologic conditions and, in some cases, probabilistic meteorological outlooks into their Great Lakes water level forecasts. They are using combinations of regression, other statistical relationships, and engineering judgment to consider current conditions antecedent to a hydrological forecast. However, much potential exists for forecast improvement if initial conditions could be estimated continuously and then directly used in forecasts through the application of hydrologic process models. Of course, the use of process models requires that adequate meteorological data be available in near real-time and that a near-real-time data reduction package exist to support them.

The following two recommendations emerge:
- consider the use of process models for rainfall-runoff, lake evaporation, and precipitation in forecasts; and
- improve near-real-time data acquisition and reduction for support of hydrological forecast models.

Forecast agencies in the Great Lakes are beginning to notice extended probabilistic meteorology forecasts, appropriate to long-term lake level forecasting, that are available from several agencies over multiple locations, time periods, time lags, and meteorological variables. While the utility of extended probabilistic meteorological outlooks is limited at present, the potential is growing and their use should be planned in future hydrologic forecasting developments. The following recommendation applies:
- incorporate extended probabilistic meteorology outlooks quantitatively into Great Lakes hydrology and water level forecasts.

Evaluations of existing and candidate methodologies for making extended Great Lakes water level forecasts reveals the varying relative performance levels of such approaches. Furthermore, these methodologies will continue to evolve. It is important for Great Lakes forecasting agencies to begin or to continue ongoing evaluations of candidate forecast methodologies so that the strengths and weaknesses of each may be determined and appropriate modifications made, as needed. The following recommendation applies:
- evaluate, in an ongoing manner, alternative methodologies for making extended Great Lakes hydrologic and water level forecasts.

Finally, while allowing the use of initial hydrologic conditions and probabilistic meteorological outlooks, the use of operational hydrological approaches to making extended Great Lakes forecasts also permits the generation of probabilistic hydrological forecasts. This is important since such approaches offer the proper manner in which to consider the wide range of possibilities that always exist, incorporate some of the uncertainty inherent in forecast estimates, and allow consideration of risk by decision makers. The final two recommendations regarding forecast improvements are as follows:

- build operational hydrology forecast systems that estimate and use initial hydrological conditions and the use probabilistic meteorology outlooks, to generate extended Great Lakes probabilistic hydrology and lake level outlooks for use by decision makers to evaluate the risk associated with their regulation decisions; and
- incorporate probabilistic hydrologic forecasts into regulation so that consideration of risk becomes part of the decision process.

Recommendations for future work in applying risk-based management to Lake Ontario regulation for the present IJC Lake Ontario–St. Lawrence River Study are as follows:

- identify and develop technical applications and tools for risk-based decision making with a focus on linkages between hydrologic variables and decision-making parameters, and reformulation of current tools (Criterion k, lake level forecasts, risk-optimized regulation plan, etc.);
- apply the tools to retrospective case studies to assess their utility and identify the acceptable levels of risk of the various interests;
- develop an effective means of communicating risk-based information to policy-makers, agency operators, and the public; and
- implement the tools and objectively measure their performance.

Temperature Modeling of Selected Areas

The objective of this project was to develop and make operational a tool or suite of tools capable of computing the water temperature regime of Lake Ontario, the Bay of Quinte and the upper St. Lawrence River. The water temperature model(s) were applied to develop several time series of water temperature data for use by the Environmental TWG, in combination with water level data, to assess the impact of regulation on the fish species in the region.

For the purpose of analysis, Lake Ontario was divided into three zones, the Lake zone, St. Lawrence River zone and the Bay of Quinte zone. For the Lake zone, modeling was carried out using a quasi 3-dimensional model developed at the Ohio State University. The St. Lawrence River zone was analyzed at Clarkson University in Potsdam using a thermal budget approach. This zone also provided thermal load for the downstream reaches of the St. Lawrence River. The Bay of Quinte zone was analyzed by Environment Canada using a coupled hydrodynamic model with a thermal/heat budget component.

The results from the three components were translated into Access databases and provided to the fish biologists for analysis of the fish models.

Other Projects

Several other projects were required to fulfill the objectives of the H&H TWG, among them the following three notable initiatives:

- A prediction model to account for the effects of ice on flow retardation and adjustments required for climate change scenarios;
- A hydrologic forecast model to simulate the impact of flow from the lower tributaries and its routing in the lower reaches; and
- Improvements in the results of the U.S.-based watersheds on flow contributions below the Moses-Saunders dam. Five watersheds that drain below the dam were calibrated to improve the modeling and prediction capabilities.

Participants

Hydraulics and Hydrologic Modeling Technical Work Group

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I. Common Data Needs Technical Work Group Summary

Data Collection Prioritization

An extensive analysis was conducted early in the Study to evaluate the utility of existing data, including information on landforms (elevation), land cover classifications and photographic/imagery, for all nearshore wetlands and erodable and flood prone areas. This prioritization effort was based on anticipated needs of other technical work groups in terms of numeric modeling and impact analyses.

The shoreline of Lake Ontario and the St. Lawrence River was segmented into shore units based on consistent geomorphic or hydraulic characteristics. Each shore unit was evaluated in terms of existing conditions (e.g., shore type, substrate, structural protection, adjacent and projected land uses), sensitivity to water level fluctuations, economic damages expected due to hazards, existing geospatial data, and needs for additional data collection. These evaluations were ranked based up degree of risk and anticipated need for new data collection. Figures I-1 and I-2 showcase the results of this analysis for the Lake Ontario and St. Lawrence River shorelines, respectively. As a function of this analysis, priority assignments were made for airborne topographic and bathymetric LIDAR collection for elevation data and for image collection (e.g. aerial photography or satellite imagery) (Figures I-1 and I-2).

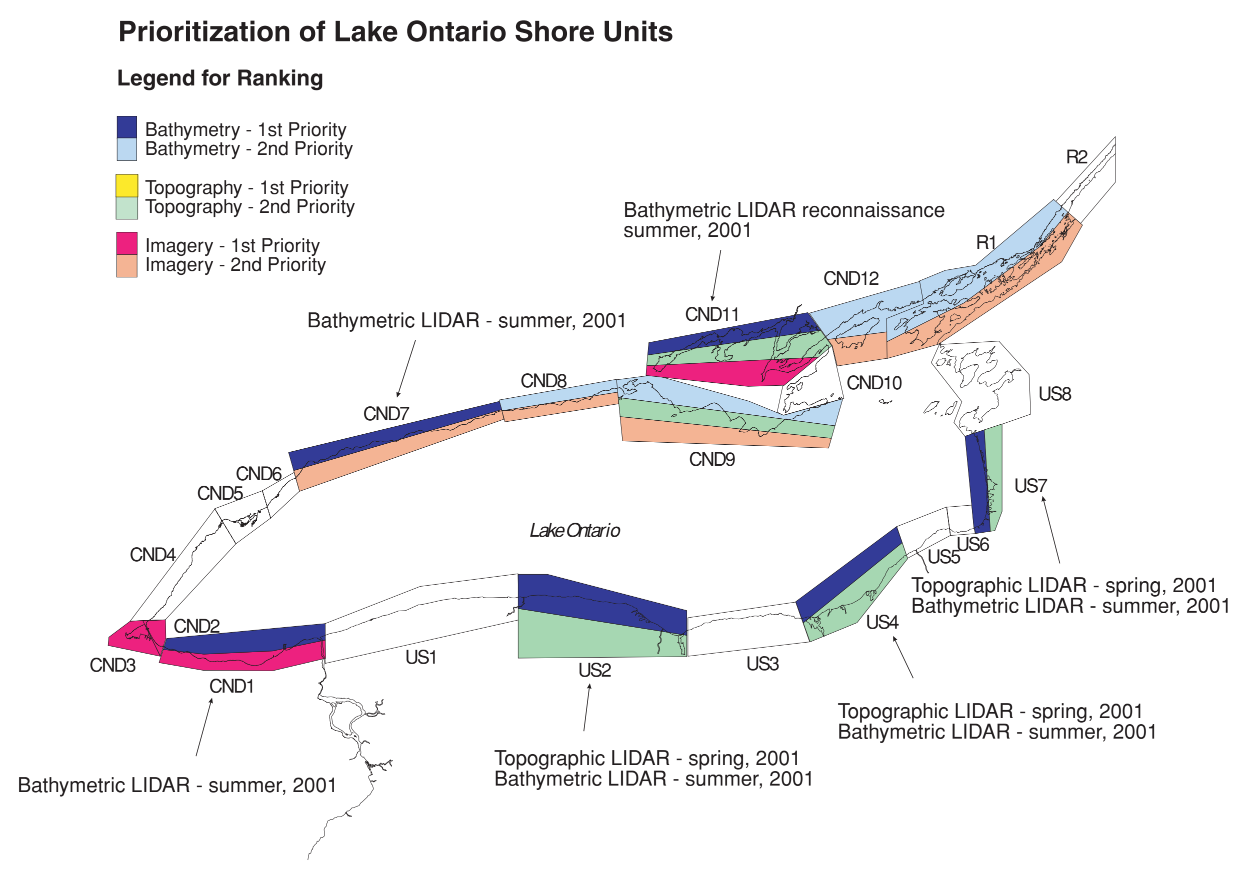

*Figure I-1: **Lake Ontario shoreline data collection prioritization***

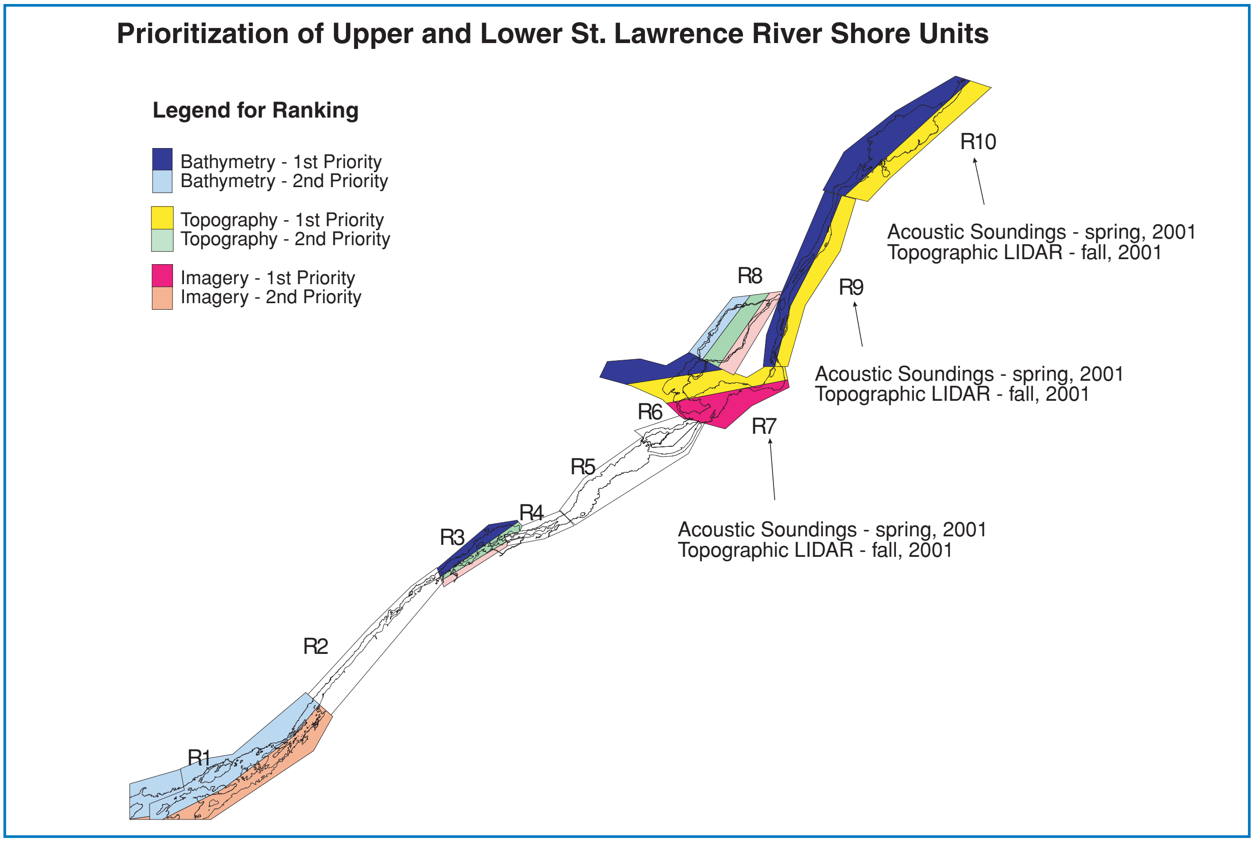

Figure I-2: ***St. Lawrence River shoreline data collection prioritization***

Elevation Data Collection/Processing

Detailed new bathymetric and topographic data collection was critical for predicting coastal geomorphic changes in both the open lake and riverine environments.

Bathymetric LIDAR surveys were conducted over the Lake Ontario shoreline in July and August, 2001.

The airborne bathymetric LIDAR collection included 4-metre postings of subsurface depths for large tracts of nearshore areas, with some nearshore wetland areas being sampled with 2-metre postings for greater definition. These data generally met U.S. National Map Accuracy standards for 0.5-metre contouring. This is the minimum acceptable level of detail needed to support predictive coastal modeling.

Collection of airborne bathymetric LIDAR through the USACE Mobile office was successful for this endeavour. The USACE monopoly on this technology, however, may have required the Study to pay a premium price for these services. Further, this monopoly could restrict data collection timelines for similar data collection activities in the future. Conventional hydrographic surveys may create more accurate end products, but these surveys are much more expensive since they require substantially more time and manpower to complete.

Collection of topographic elevations through airborne LIDAR surveys or photogrammetric means were extremely useful and relatively cost-effective. Contouring at 0.5-metre intervals was achieved in these surveys as well, with substantial feature collection (e.g., building footprints, bluff lines, transportation and hydrology) occurring at 16 coastal model calibration sites through photogrammetric means.

Merging of bathymetric and topographic surveys was problematic with substantial emphasis having to be placed on ensuring that the vertical datum references were consistent.

Collection of detailed bathymetric and topographic surveys in wetland areas using boat surveys was acceptable, although not all wetland sites were mapped with desired sounding densities due to dense vegetation growth. Surveys of this type are expensive and require substantial labour to conduct.

Use of Flood Damage Reduction Program (FDRP) maps in Ontario to delineate topographic detail in wetland areas was unacceptable. The accuracy of these base maps was not sufficient to derive dependable 0.5-metre contour accuracies in these environments.

Airborne LIDAR data collection was carried out on the lower St. Lawrence River floodplain in November and December 2001. Collection of conventional bathymetric and topographic LIDAR survey data was conducted in Quebec in early May 2001, and within acceptable error bounds, providing maximum utility throughout the remainder of the Study process. The upland extent of these surveys included all areas that could be inundated under all potential regulation scenarios. Collection of topographic LIDAR surveys of the floodplains along the lower St. Lawrence River in autumn was very successful, providing maximum coverage with the lowest-cost technology.

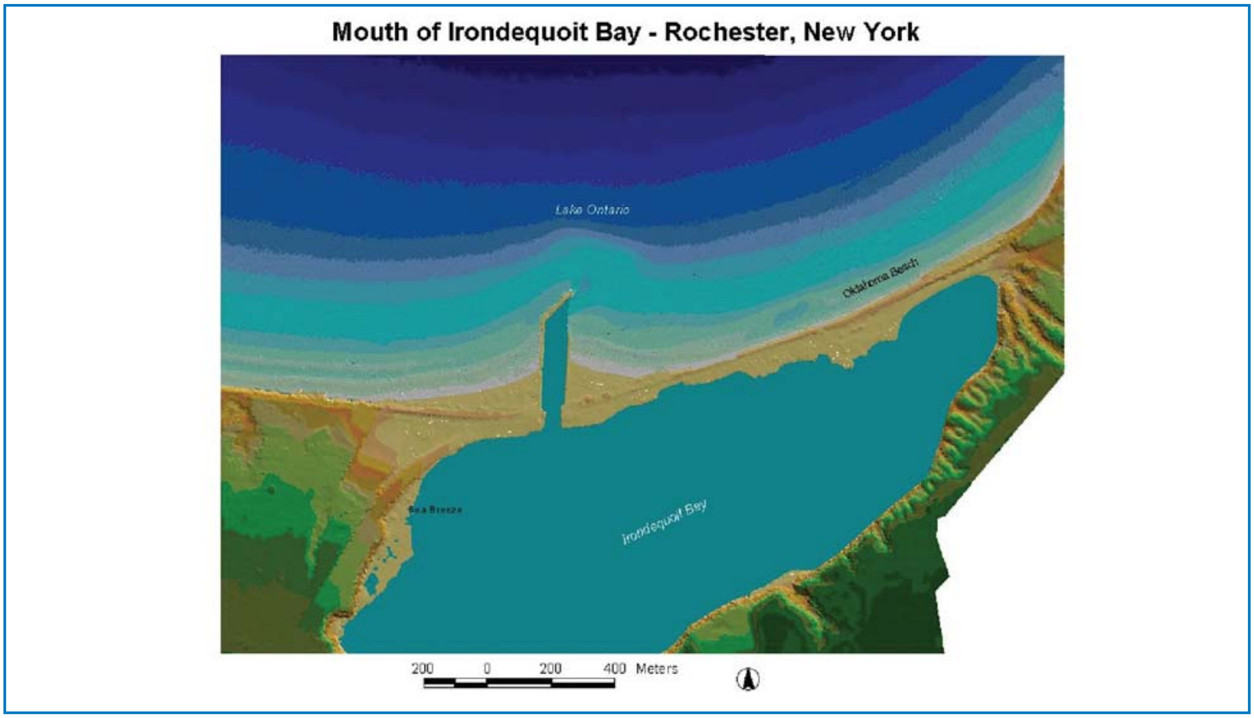

Figure I-3: Irondequoit Bay and Rochester, New York, digital elevation model

Imagery Collection/Processing

Aerial photography was collected over many of the nearshore areas where intensive investigations would be conducted by other technical work groups (e.g. Coastal, Environmental, Recreational Boating, Municipal Water Use). Aerial photography was also the basis for photogrammetric terrain derivations and feature collection efforts. If resources were more extensive, comprehensive collection of high resolution (i.e., 0.15-m (0.5-ft) pixels) photography/imagery would have been preferable.

High resolution satellite imagery (1 to 5-m (3 to 16-ft) pixels) was only utilized for the Montreal archipelago region. This type of information could have utility elsewhere, but can be expensive, and it can also be logistically difficult to obtain coverage over large tracts of irregular geography.

Figure I-4: ***South Colwell Pond (New York) color infrared photograph***

GIS Standards Development

The Study Board established geographic information system (GIS) standards in the first year of the Study. The initial standards were developed for the following:

- Characteristics of base maps

  Base layers include standard topographic and planimetric information usually portrayed on a map. Topographic data include elevation contours, spot heights, and shorelines. Planimetric data include roads and streams as well as administrative and political boundaries.

- Map Projections

  Map projections are used to portray a portion of the Earth on a flat surface. Some distortions of conformity, distance, direction, scale, and area always result from this process. A Lambert Conformal Conic projection with associated attributes was selected for use for all study geospatial datasets.

- Horizontal and vertical control datums to be used

  Geodetic datums define the size and shape of the Earth and the origin and orientation of the coordinate systems used to map it. The Study used the NAD 83 horizontal datum with the GRS 80 ellipsoid. Two common vertical datums for North America were used in the Study, the North American Vertical Datum of 1988 (NAVD 88) and the International Great Lakes Datum of 1985 (IGLD 85).

- Measurement units

  Since Canada and the U.S. use different measurement systems, it was decided that all data would be in metric units.

- Metadata requirements

  Metadata is "data about data" and is used to describe the content, quality, condition, and other characteristics of data. The production of compliant metadata was strongly recommended to all study participants to enable the discovery and distribution of study holdings.

- Common geographic nomenclature

  The purpose of common geographic nomenclature was to ensure that consistency within the Study in terms of the names of geospatial entities.

Framework Data Creation

The Study participated in a bi-national project funded by GeoConnections, a federal entity in Canada, and the U.S. Federal Geographic Data Committee (FGDC) to create geospatial framework data that was consistent across the border. Geospatial framework data include: political boundaries, hydrologic features, transportation networks, elevation data, imagery and horizontal/vertical control networks. The additional funding provided through this project enhanced the quality of datasets used in coastal process modeling and environmental analyses.

Emphasis on horizontal integration of geospatial data across jurisdictional boundaries was problematic due to varying scales of source information. Different jurisdictions have used different data standards and processing methods, preventing common digital data themes from connecting cleanly at the jurisdictional boundaries. Adjustments to one or more data layers were necessary to insure connectivity. Vertical integration of data (e.g., more information content at smaller scales) was particularly difficult due to inconsistencies of classification approaches and incomplete datasets. Hence, the framework data themes were corrected to a large degree, but required substantial manpower. Many non-framework geospatial data themes (e.g., environmental, recreational boating and municipal features) did not have the same level of horizontal and vertical integration.

J. Information Management Technical Work Group Summary

Information Management Strategy

The development of an Information Management Strategy (IMS) was important for long-term utilization of data assets compiled or created within the Study. The IMS included a comprehensive assessment of available information resources, likely future additional resources, capabilities of partners and alternative approaches for integrated information management. The IMS promoted improvements in data discovery, evaluation and access, all of which were substantially addressed under the Study.

The IMS promoted the development of a distributed approach to information management, rather than central repositories of information. The distributed approach required collaborative work among the Province of Ontario, the State of New York, Environment Canada (Ontario and Quebec Regions) and the Great Lakes Commission. The IMS focused on using the Internet for information discovery, evaluation and access. Unfortunately, many of the stakeholders within the Lake Ontario–St. Lawrence River region have inadequate connections to the Internet or do not have sufficient knowledge to use many of the tools created by the Study. This situation is not permanent, however, since Internet usage is steadily increasing over time. The architecture behind the IMS is shown schematically in Figure I-1.

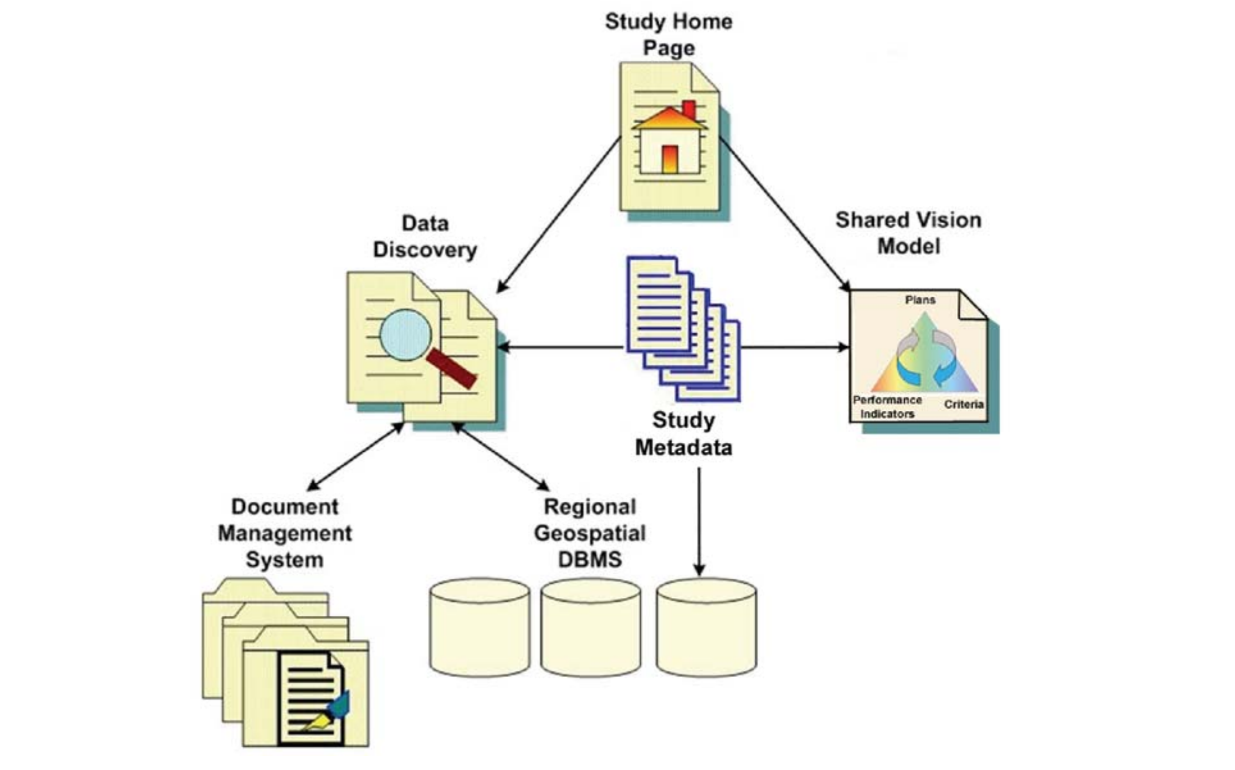

*Figure J-1: **Information Management Strategy schematic***

Information management tools created for the Study are available at **http://mds.glc.org/loslrs/** and will be maintained throughout the foreseeable future as part of the IJC's cooperative support of the Great Lakes Information Network (GLIN). The Study Board decided early on that it could not afford to produce bilingual versions of all information resources (English and French). Rather the Study Board required that all metadata be bilingual to provide equal access for the discovery of Study information.

FTP Support

The first component of the IMS to be implemented was an FTP server, operated and maintained by Environment Canada, Ontario Region. A standard template was created for each TWG to upload digital files to the FTP site, which was used throughout the Study to facilitate information exchange within and among TWGs.

The FTP site, however, should have been policed more rigorously throughout the Study. Information holdings were often poorly documented, without the use of naming conventions, and in some cases, more than one version of the same file appeared. The FTP site had inadequate security provisions (anyone who had access to the site could delete, modify or add files).

The contents of the FTP site were backed-up for archival purposes on a regular basis throughout the Study, with most of the data holdings being moved to the Document Management System. The FTP site will not be available after the Study has been completed, as it was intended for internal Study use only.

Metadata Production

Metadata are records that identify the salient characteristics of data files, including lineage, history, production dates, accuracy, precision, appropriateness for use, distribution limits, etc. The Study Board stressed the importance of completing this necessary documentation, but few TWG members were sufficiently knowledgeable to create metadata without an appropriate template for their information type. Production of compliant metadata was not fully accomplished due to the large volume of data produced within the Study. Instead, metadata production forms were created to ensure that all critical data and Study information resources were documented to the degree necessary to support basic Study information needs.

For some TWGs, metadata production was a substantial burden that was not covered adequately during project budgeting. The Coastal TWG in particular produced several thousand geospatial files to support their predictive modeling. Practical “work-arounds” were created to assemble data files into “families” of datasets with a fraction of metadata records (e.g., profiles along shorelines were grouped within counties with one metadata record).

Metadata has been created for all documents produced by the Study Board, PIAG, PFEG and the TWGs. All geospatial datasets that can be used in future GIS applications are expected to have compliant metadata produced before the end of the Study. The shortcomings in the area of metadata production are likely to affect non-geospatial data holdings, specifically level and flow time series data, hydropower analyses, and commercial navigation, recreational boating and municipal water system datasets. These non-spatial information resources may not be discoverable in the future without metadata.

All digital files should have compliant metadata produced to support their discovery (through search engines) and evaluation (assessment of the type and quality of information) as well as the means of distribution of these resources. Through the largess of Study participants, work is expected to continue after the study is completed to ensure that all critical geospatial data files created by the Coastal TWG are fully documented, since these data have long-term utility for other coastal zone management applications throughout the Lake Ontario–St. Lawrence River system. As well, these data holdings would be useful if adaptive management practices are implemented in IJC outflow control operations.

Document Management System

The document management system developed for the Study is an especially valuable asset. It includes all metadata for all documents produced by the Study and has hypertext links to these resources on secure servers. The document management system was used to pre-determine long-term disposition of Study information resources and to anticipate approaches for continuous access to these resources after the Study is concluded.

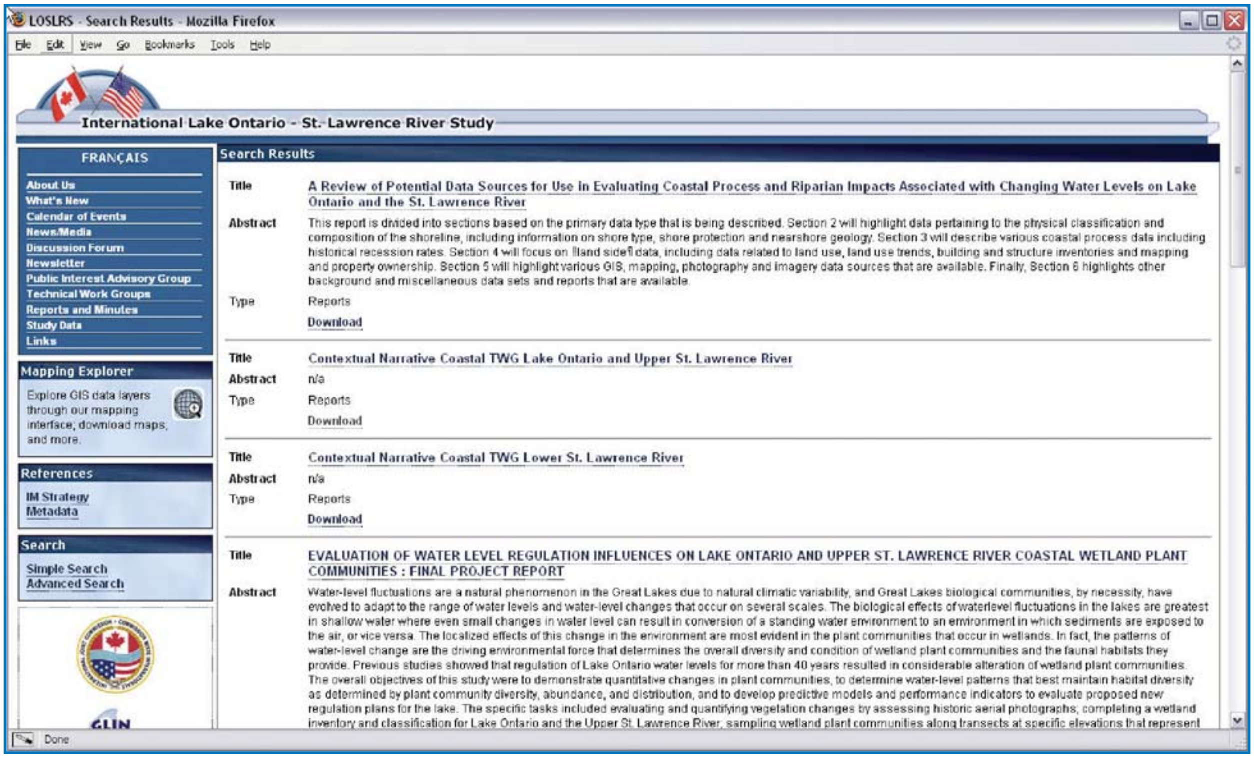

Figure J-2: Document management system query

Development of the document management system put initial emphasis on reports, publications, correspondence and guidance materials. It was significantly expanded to include graphic elements such as tables, graphs, questionnaire results and geospatial data themes. It allows users to search for background information and data based on keywords, geographic locations and relationship to performance indicators used for the Study. In the future, this system is expected to be maintained under the Great Lakes Information Network (GLIN) as a clearinghouse tool for regional information management.

Web Mapping Application

When the web mapping application was developed for the Study, it was too late to be an important element in the plan formulation process. This was due to late delivery of geospatial data from the TWGs in the Study process and corresponding changes in distributed web service technologies. The web mapping application includes most geospatial data from the TWGs and provides the linkages to related documents and other materials within the document management system for further information retrieval about a specific geographic region, coastal unit or performance indicator. Using current web mapping service protocol, the application allows dynamic access to geospatial data hosted and maintained by Environment Canada (Ontario and Quebec regions) and by other federal, state and provincial partners. These tools have been improved and enhanced and are expected to be used well into the future, if adaptive management approaches are included in IJC outflow control operations.

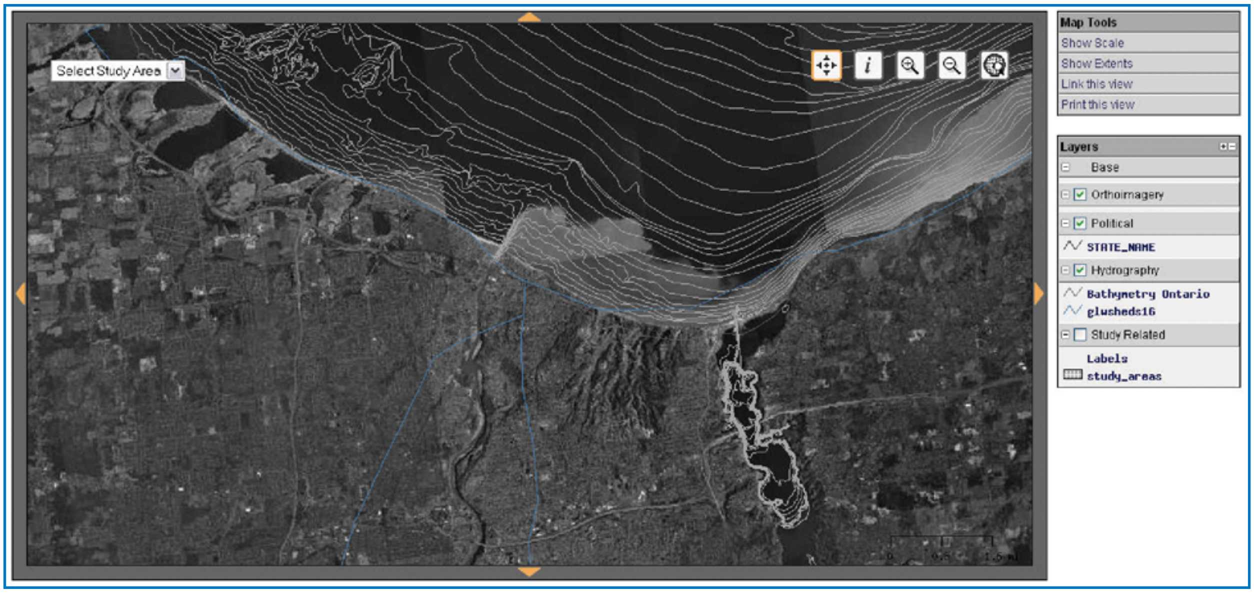

Figure J-3: ***Typical product of web mapping application***

Shared Vision Model/Plan Formulation Support

The original intent of linking the information management toolkit to the Shared Vision Model (SVM) was largely unmet. For the most part, this can be attributed to delays in fielding information management tools and to wholesale changes that were made in the Shared Vision Model over time. Equally problematic were the license limitations on the software that was used for the SVM and the inability to move Model's results to a web format. Finalization of the performance indicator suite did not occur until late in year four of the Study, which meant that all metadata produced prior to this date had to be modified to directly relate to these important factors. Few resources were applied to adequately linking the plan formulation products to the information management web pages.

The plan formulation process made use of an Excel spreadsheet, "The Boardroom," that was housed on the FTP site. While using Excel was ideal for data manipulation, and sharing it within the Study group was relatively easy on the FTP site, the entire contents of the Excel application could not be easily moved to a web format. To this end, a trimmed down web version of "The Boardroom" has been developed and is available on the Study's website.

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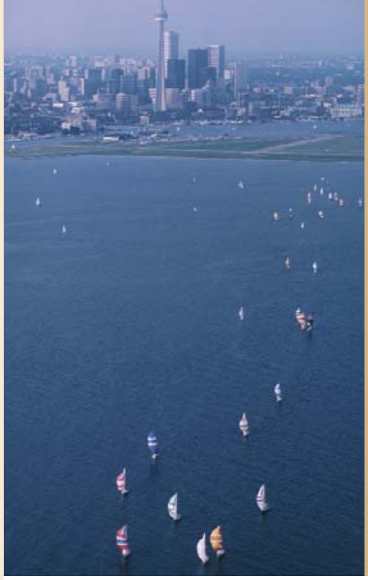


Annex 3
Plan Descriptions and Summary Results

Introduction

Annex 3 provides a summary of all regulation plans addressed in the main report. Section A of this annex provides a guide of constraints and assumptions used in the plan formulation process. Section B provides plan descriptions for each plan and includes:

- the baseline plan 1958-D with simulated deviation (1958-DD);
- the three candidate plans,
  - Plan A+ - the balanced economics plan
  - Plan B+ - the balanced environmental plan
  - Plan D+ - the blended benefits plan;
- the reference and interest specific plans,
  - Plan E - the natural flow plan
  - Plan 1958-D without deviations
  - Plan 1998
  - Plan OntRip3 - designed specifically to minimize flooding and erosion damages on Lake Ontario
  - Plan RecBoat - designed to maximize recreational boating benefits.

Section C provides summary tables of plan results for all the regulation plans described under the historical time series, and where available for the stochastic and climate change supply sequences.

Note: All of the plan formulations presented in Annex 3 were developed and performed in metric terms (metres and cubic metres per second) and represent precise calculations. Imperial conversions shown are estimates of these metric values and are provided for illustrative purposes only.

A. Plan Formulation Guide: Summary of Constraints and Assumptions for Plan Formulation

The following is a guide of constraints and assumptions used in the plan formulation process. These were developed to ensure that all plans were comparable and met required ice formation and stability requirements as well as the physical, and structural constraints of the system.

Maximum Outflow Limits

The following describes the maximum outflow limits that are based on physical or structural constraint limits.

Maximum Flow with Open Water, Quarter-months 13 to 47 Inclusive (Seaway Season)

Since 1960, when regulation began on a quarter-monthly mean basis, the historical maximum flow is 10,200 m^3/s (360,000 ft^3/s). This occurred at Lake Ontario levels of about 75.55 m (247.87 ft) and consisted of roughly a day at 11 000 m^3/s (388,500 ft^3/s) and alternate days at 9,900 m^3/s (349,500 ft^3/s) to allow Seaway ships to pass. The assumption that the risk damage due to high gradients stops ships on the Seaway is based on the experience of this event. At even higher levels, it is conceivable that higher flows would be passed on alternate days, and, with a change in the damage function of the Shared Vision Model (SVM) to reflect a Seaway shutdown, it could be assumed that the high flows are released constantly.

A maximum outflow from Lake St. Francis (Hydro-Québec facilities) with "limited" flood damage to the houses along the Coteau outlet channel is roughly 12,000 m^3/s (424,000 ft^3/s). It is suggested that about 500 m^3/s (17,700 ft^3/s) be allowed for local inflows to Lake St. Francis. Data provided by Hydro-Québec show that this quarter-month flow has varied from as low as 5 m^3/s (177 ft^3/s) to as high as 1,419 m^3/s (50,000 ft^3/s), and the 5% exceedence flow is 520 m^3/s (18,400 ft^3/s). This is a rough assumption for modeling. To be more precise, the historical data for each quarter-month could be used, and this will be done operationally in reality. The bottom line is that a maximum Lake Ontario outflow of 11,500 m^3/s (406,100 ft^3/s) seems to be reasonable if the assumption is that the Seaway is stopped. If the same assumption in the Seaway evaluation of the Shared Vision Model (SVM) is maintained, then a maximum Lake Ontario outflow of 10,700 m^3/s (378,000 ft^3/s) should be used to reflect that this higher flow could be maintained only about half the time, with a reduction to 9,900 m^3/s (349,500 ft^3/s) the other half.

If the Study Team could estimate the flood damages to the houses along the Coteau outlet channel, then plan formulators could estimate the impact of even higher flows of up to about 14,000 m^3/s (495,000 ft^3/s). There may be other damages that have not been considered at such flows, but the flows may be physically possible. A recommendation that such possibilities be investigated in detail through future data gathering and model study may be warranted.

Maximum Flow with Ice limits

Ice formation

Maximum Lake Ontario flow = 6,230 m^3/s (220,000 ft^3/s) if the present quarter-month's or the previous quarter-month's ice indicator is 2.

Winter J limit

The second part of the ice constraint is the "J limit," which limits the amount that flow is allowed to change from quarter-month to quarter-month. This is intended to prevent flow from increasing to the point where the ice cover fails. Plan 1998 **and 58-DD** limit the increase to 570 m^3/s (20,000 ft^3/s) if the Lake Ontario level is below 75.2 m (246.72 feet), and not more than 1,420 m^3/s (50,000 ft^3/s) if the Lake is above that level (this higher limit was developed from actual events). The J limit also specifies that, in either situation, a decrease is limited to 570 m^3/s (20,000 ft^3/s).

After discussions, the Plan Formulation Team agreed to a maximum J limit increase in winter (i.e. ice indicator > 0) of 700 m^3/s (25,000 ft^3/s) for the plans being developed, rather than the 570 m^3/s (20,000 ft^3/s) limit provided in Plan 1958-D and normally assumed in 58-DD. The 58-DD code will not be altered for winter, so it will still provide for a 570 m^3/s (20,000 ft^3/s) limit, as well as a limit of 1,420 m^3/s (50,000 ft^3/s) in the case of levels above 75.2 m (246.72 ft), assuming the other part of the ice limits are met.

Capacity with ice in international channels

The third part of the winter constraint is a limit on the flow to prevent the level at Long Sault from falling too low. This limit may apply from quarter-month 48 to 12 (i.e., the assumed non-Seaway season) whether ice is present or not. The flow that results in a Long Sault level of 71.8 m (235.56 ft) is the maximum limit in this case. This flow limit is calculated using the stage-fall discharge equation for Kingston-Long Sault and the Long Sault ice roughness parameter (a naïve forecast). Note that, in 1993, the hourly level at Long Sault fell to about 71.2 m (233.60 ft), at which point there were severe impacts at the Ingleside Water Treatment Plant. The 71.8 m (235.56 ft) level was chosen as the quarter-monthly limit due to the variations in the ice conditions within the week. Also, the Ingleside water supply is in the process of being moved. Although this limit was designed with the prevention of damaging low levels in mind, it also serves to limit the shear stress on the ice cover and is viewed as necessary to maintain the integrity of the ice cover. A recommendation for further study in this regard is warranted.

Capacity with ice in Hydro-Québec channels

Based on a review of the recorded outflows since 1960 with ice in the Beauharnois and/or international channels (i.e. quarter-month with ice indicator either 2 or 1), the maximum Lake Ontario outflow was found to have been 9,430 m^3/s (333,000 ft^3/s). This may have been limited by the capacity at the outlet of Lake St. Francis, rather than conditions in the international section. Although there may be many circumstances in which the “with-ice” flow capacities from Lake St. Francis are greater than this amount, the use of 9,430 m^3/s (333,000 ft^3/s) as a maximum Lake Ontario outflow with ice in the channel (i.e. quarter-month with ice indicator 1) is proposed. (See the following section, Maximum Outflow with Open Water, Quarter-months 48 to 12 Inclusive.) Since the outflow capacity of the Lake St. Francis outlet channels is independent of the Lake Ontario level, this may be a problematic constraint for the most extreme of the stochastic supplies.

Maximum Outflow with Open Water, Quarter-months 48 to 12 Inclusive (Non-Seaway Season)

The Shared Vision Model assumes that Seaway navigation is stopped between quarter-months 48 and 12, inclusively. If the ice indicator is 0, then there is no ice upstream of Moses-Saunders. If the period precedes the ice season (i.e. the 0 precedes the first 2 in the ice indicator), then it is assumed that the capacity of the Hydro-Québec flow control structures to control flow from Lake St. Francis is such that a maximum Lake Ontario outflow of 11,500 m^3/s (406,100 ft^3/s) is reasonable (see above), given that navigation is stopped and there is no ice in the Beauharnois Canal.

* If the period follows the Moses-Saunders ice season (i.e. the 0 follows the last 1 in the ice indicator), then a conservative assumption is that ice may remain in the Hydro-Québec channels that are downstream (and therefore melt a little later) and the flow should be limited to the capacity of the Hydro-Québec flow control structures to control flow from Lake St Francis. An analysis (1963-2000 data from Hydro-Québec) shows that 95% of these periods were associated with a Beauharnois Canal capacity of about 6,900 m^3/s (243,700 ft^3/s) or more, and in the following periods (the second after the last 1 in the ice series), the Beauharnois Canal capacity was about 7,300 m^3/s (257,800 ft^3/s) or more. Once ice formation is complete, the stated maximum capacity range of the Coteau channel is 2,500 to 3,000 m^3/s (88,300 to 106,000 ft^3/s). Assuming the higher end of this maximum capacity range of 3,000 m^3/s (88,300 ft^3/s), then the total maximum capacity (i.e. Beauharnois + Coteau) from Lake St. Francis in these periods would be 9,900 m^3/s and 10,300 m^3/s (349,500 and 363,800 ft^3/s). The plans can check the previous two values of the ice status indicator to limit flows in these periods.

A more sophisticated approach would be to use historical data to estimate this capacity in each period in the plans, but Hydro-Québec did not provide the actual Coteau channel capacity in each period in its dataset. (This approach was used in Plan B, with assumed capacities of 3,000 m^3/s (106,000 ft^3/s) in the ice period and 4,000 m^3/s (141,300 ft^3/s) outside the ice period). In addition, these data for Beauharnois are not available operationally in near-real time and were only calculated by Hydro-Québec after the fact for the evaluation model in this study. However, this approach could be treated as a operational limit that is only applied if the Hydro-Québec flow capacity is less than the otherwise specified flow. (This is similar in concept to the mid-week adjustment for ice and downstream flooding.)

Maximum Flow Due to Upper St. Lawrence Channel Capacity

The outflow from Lake Ontario cannot exceed the capacity of the upper river channel. For Lake Ontario levels above 75.90 m (249.02 ft), this capacity has been estimated (Lee et al., 1994) by the following equation:

$$Q = 747.2\ (\text{Lake Ontario level} - 69.10)^{1.47},$$

where level is given in metres, IGLD 1985, and flow in m^3/s. This flow capacity assumes that all gates of the Long Sault Dam spillway are open.

None of the plans are in violation of this limit, but it should be recognized.

Maximum level at Iroquois Lock

The level at the Iroquois Headwater gauge shall not exceed 75.6 m (248.03 ft). Levels above this threshold will overtop the lock and violate our assumption that the Iroquois Dam can be used to control the level of Lake St. Lawrence.

Forecasting

For the final plans, the assumption is that perfect foreknowledge of the coming period's ice status is known (reflecting operations). The forecast shall not assume that ice forecasts for any further periods are known.

A one-period-ahead foreknowledge of the local flow into Lake St. Louis is assumed if the fair forecast indicator is 0.

Otherwise no perfect foreknowledge of supplies, tributary flows or channel roughness conditions is assumed.

Plan B^+ assumes a one-period-ahead perfect forecast (reflecting operations) of Lake St. Francis local inflows and Beauharnois maximum capacity in formulating maximum flow limits during ice periods for the Coteau Control Structure (Hydro-Québec channels).

Summary

The following table summarizes each of the constraints used in plan formulation and the manner in which each is addressed by Plan 1958-DD and the four candidate plans.

References

Lee, D.H., Quinn, F.H., Sparks, D. and Rassam, J.C. (1994) Simulation of Maximum Lake Ontario Outflows. *Journal of Great Lakes Research* 20(3) 569-582.

Table A-1: Constraints Applied to Each Plan

Constraint	58-DD	A^+	B^+	D^+
6,230 m^3/s (220,000 ft^3/s) ice formation	Yes.	Yes.	Yes.	Yes.
J+ limit in winter	570 m^3/s and 1,420 m^3/s (20,000 and 50,000 ft^3/s) > 75.2 m (246.7 ft).	During ice mgmt – 700 m^3/s (25,000 ft^3/s). Outside of ice mgmt – 700 m^3/s (25,000 ft^3/s), unless Lake Ontario > 75.5 m (247.7 ft), then 1,400 m^3/s (49,400 ft^3/s).	During ice mgmt – 700 m^3/s (25,000 ft^3/s). Outside of ice mgmt – 700 m^3/s (25,000 ft^3/s) unless Lake Ontario > 75.5 m (247.7 ft) then 1,420 m^3/s (50,000 ft^3/s). J limit rarely comes into play outside of ice mgmt due to plan stability of releases; sometimes required during fall drawdown in high lake years.	Usually 400 m^3/s (14,000 ft^3/s) but 700 m^3/s (25,000 ft^3/s) if Lake Ontario level > 0.3 m (1 ft) above target.
Limit to min. level at Long Sault or Saunders HW in winter	Yes. Incremental down to 71.8 m (235.6 ft) at Long Sault.	Yes. One hard constraint at 71.8 m (235.6 ft).	Yes. One hard constraint at 71.8 m (235.6 ft) at Long Sault.	Yes. Progressive constraint down to 71.2 m (233.6 ft).
With Ice Qmax = 9,340 m^3/s (330,000 ft^3/s)	Yes.	Yes.	Yes. A specific rule that limits flows through Coteau Control Structure to maximum of 2,500 m^3/s (88,300 ft^3/s) based on local inflows and maximum Beauharnois capacity.	Yes.
Qtrm after ice Qmax = 9,900 m^3/s (349,500 ft^3/s)	Yes. Set at 9,500 m^3/s (335,500 ft^3/s).	Yes. Set at 9,900 m^3/s (349,500 ft^3/s).	Yes. A specific rule that limits flows through Coteau Control Structure to a maximum of 2,500 m^3/s (88,300 ft^3/s) based on local inflows and maximum Beauharnois capacity.	Yes. Set at 9,500 m^3/s (335,500 ft^3/s).
2nd qtrm after ice Qmax = 10,300 m^3/s (363,800 ft^3/s)	Yes. Set at 10,000 m^3/s (353,000 ft^3/s).	Yes. Set at 10,000 m^3/s (353,000 ft^3/s).	Yes. A specific rule that limits flows through Coteau Control Structure to a maximum of 4,000 m^3/s (141,200 ft^3/s) based on local inflows and maximum Beauharnois capacity.	Yes. Set at 10,000 m^3/s (353,00 ft^3/s).
Open water with Seaway Qmax = 10,700 m^3/s (377,900 ft^3/s)	Yes, if Lake Ontario level > 75.8 m (248.7 ft).	Yes.	Yes, if Lake Ontario level ? 75.7 m (248.4 ft), else the lessor of 11,500 m^3/s (406,100 ft^3/s) or channel capacity.	Yes, if Lake Ontario level > 0.77 m (2.5 ft) above target, otherwise 9,910 m^3/s (350,000 ft^3/s).
Open water closed Seaway Qmax=11,500 m^3/s (406,100 ft^3/s)	Yes.	Yes.	Yes.	Yes.
Qmax < max hydraulic channel capacity	Yes.	Yes.	Yes.	Yes.
Iroquois HW < 75.6 m (248.0 ft)	No rule applied, but there were no occurrences in the stochastic case.	No rule.	Yes. A specific rule is applied that supercedes all other constraints.	No rule applied, but there were no occurrences in the stochastic case.
Perfect ice indicator forecast	Yes.	Yes.	Yes.	Yes.
"Fair" St. Louis forecast	Yes.	Yes.	Yes.	Yes.

B. Regulation Plan Descriptions

Plan 1958-DD: The Baseline Plan (Plan 1958-D with Simulated Deviations)

Introduction

The outflows from Lake Ontario are set each week under the direction of the International St. Lawrence River Board of Control to meet a number of criteria established by the International Joint Commission in their 1956 Supplementary Orders of Approval. Several "regulation plans" were developed in the late 1950s and early 1960s to aid in determining the amount of water to be released each week. These regulation plans are sets of rules or methodologies that specify a release based on the hydrologic state of the system. In addition to approving the use of the regulation plan, the Commission granted the Control Board the authority to deviate from the plan-specified flows under a number of broadly defined circumstances. Thus, the present method of regulating the releases from Lake Ontario is known as "Plan 1958-D with deviations." This paper explains this method of regulation and describes a method of estimating the releases from Lake Ontario that simulates those that occur under Plan 1958-D with deviations. The primary need for this simulator is to estimate releases that would be made under hydrologic sequences and conditions other than those recorded, but that would reflect the outflow deviation decisions made by the International St. Lawrence River Board of Control in the recent past.

Plan 1958-D

(Taken from the 1997 report of the International St. Lawrence River Board of Control.) The regulation plan in use since 1963, Plan 1958-D (International St. Lawrence River Board of Control 1963), was designed to regulate flows to fit the Commission's criteria with the 1860-1954 sequence of water supplies to the Lake Ontario-St. Lawrence System.

Plan 1958-D consists of two sets of rule curves, as well as a supply indicator, seasonal adjustments and a number of minimum and maximum outflow limitations. The regulated outflow is determined in the following manner. The water supply to Lake Ontario for the previous week is determined. The supply indicator is calculated as the difference between the actual weighted supply for the week and the weighted normal supply for that time of year. An adjustment, based on the change in the supply indicator in the previous three months, is added to the supply indicator to form the "adjusted supply indicator." The basic regulated outflow is then computed from one of the two sets of rule curves, depending on the season, using the computed end-of-period lake level and the "adjusted supply indicator." The outflow specified by the rule curve increases as the Lake Ontario level rises and as the adjusted supply indicator increases. The rule curve flow is then adjusted by adding the seasonal adjustment. The resultant seasonally adjusted flow is compared with a number of maximum and minimum outflow limitations, which vary throughout the year. These limits include seasonal minimum flows for hydropower, maximum flows for stable ice cover formation and safe velocities and levels for navigation in the international section, maximum flows in the last half of December to promote ice cover formation at the outlet of Lac St. Louis, maximum and minimum flows to ensure that downstream flows/levels are no greater than would occur without regulation, and a limit to the maximum change in flow from week to week. If the seasonally adjusted flow is between the least maximum limit and the largest minimum limit for the period, then it becomes the Plan Flow. Otherwise, the applicable outflow limit becomes the Plan Flow.

Deviations

The outflow calculated according to Plan 1958-D is directed to be the weekly flow unless the International St. Lawrence River Board of Control or the Commission opts for a different flow to better manage the system. A flow different from that specified by the plan is called a deviation from the plan. From the beginning of regulation plan development in the 1950s, it was recognized that deviations from the flow specified by the plan would be required in some circumstances. Criterion (k) was included in the Commission's Orders to guide deviations from the plan during supply situations that were outside the bounds of the 1860-1954 supply sequence used to design the regulation plan. Soon after regulation of outflows began in the early 1960's, the Commission recognized the benefit of deviations from the plan in more common circumstances and granted the Board limited discretionary authority to deviate from the regulation plan to provide beneficial effects or relief from adverse effects to one interest without appreciable adverse effects to others.

Although Plan 1958-D satisfied all of the Commission's criteria under the 1860-1954 design supply sequence, and has generally worked to satisfy the criteria when supplies are in the design range, it does not work well under extreme water supply conditions. This is largely due to the absolute constraints on outflow that Plan 1958-D imposes. During the very low supply period of 1964-1965, flows below the minimum outflow limits of the plan were necessary to maintain levels of Lake Ontario. During the high supply sequences in the mid-1970's, the mid-1980's and again in the 1990s, the upper flow limits were too restrictive, and significant over-discharge deviations from the plan had to be made to minimize flooding on Lake Ontario. Also, Plan 1958-D is not responsive to the relatively fast rise of the Ottawa River and other downstream tributary flows in the spring. To satisfy Criterion (d), Plan 1958-D, limits maximum Lake Ontario outflows in the spring to no more than would have occurred prior to regulation, but it does not consider the state of downstream inflows. By temporarily reducing the flow below that specified by Plan 1958-D during the Ottawa River spring peak flow, significant reductions in flooding on Lac St. Louis and downstream have been accomplished without significant harm to upstream interests. At other times, when Ottawa River outflows were relatively low, reductions in Lake Ontario flood levels were achieved by increasing the Lake Ontario outflow above that specified by the "no higher than pre-project" limit in Plan 1958-D. The benefits of this approach were recognized by the Levels Reference Study Board (1993), which recommended that Criterion (d) be modified accordingly.

In actual operations, to enable the formation of a complete, smooth, stable ice cover, Lake Ontario outflows are reduced when ice begins to form in the Beauharnois Canal. Lower flows are maintained until the ice cover progresses upstream and is completed in the reach above Iroquois Dam. This is done to prevent ice jams/restrictions or, in other words, to reduce the hydraulic head loss caused by the ice. In turn, this enables higher flows to be maintained in the rest of the ice season. Plan 1958-D assumes that ice will begin to form on Lake St. Louis on December 15th of each year and continue forming upstream until January 31st. Plan 1958-D limits the maximum outflow during this entire period. Variations in weather are such that the ice formation period rarely coincides with these dates, and in actual operations, flows are not usually reduced until ice begins to form, and are increased as soon as the ice cover stabilizes.

As a result of these and other deviations from the plan, the actual levels and flows experienced in the Lake Ontario-St. Lawrence River system since the beginning of regulation only partially reflect the performance of Plan 1958-D.

Need for a Simulator of Plan 1958-D with Deviations

Plan 1958-D "with deviations" has been selected by the Study Board as the Baseline Plan for comparison purposes. Plan 1958-D with deviations, made under the direction of the International St. Lawrence River Board of Control and the Commission, represents the method now in use for regulation of Lake Ontario outflows. These deviations from the specified Plan 1958-D outflow may be made for a number of reasons, under several different authorities granted to the Board by the Commission. Reasons for such deviations include winter ice formation operations, discretionary deviations (to benefit one or more interests without adverse effects upon others), or extreme supply conditions beyond those for which Plan 1958-D was designed (Criterion (k) operations). A record of these deviations from Plan 1958-D exists for the period since regulation began. Although the needs of the interests have evolved since regulation began in 1960, and the membership and perspective of the Control Board has changed, one might assume that similar deviations from Plan 1958-D would again be made by the Board given the same circumstances, both in terms of hydrology and user needs. With that assumption, the historical deviations could simply be added to the computed 1958-D flows generated from the historical hydrologic sequence to arrive at a series of 1958-D-with-deviations flows. However, if the Baseline Plan is to be compared with other regulation methods under different climate and water supply sequences (be they stochastic or based on climate change or the pre-regulation period from 1900 to 1959), a method is needed for estimating what deviations in flow, if any, would be made from flows specified by Plan 1958-D to represent the Baseline Plan.

58-DD Development

The task began with a review of the historical deviations from Plan 1958-D, along with the hydrologic and other conditions existing at the time of the deviations, to determine if there were consistent patterns. Based on these patterns involving the recorded hydrologic conditions and the deviations that were made at the time, various new logical "if – then" type rules were developed and incorporated, where possible, using an empirical trial-and-error approach. The adequacy of these empirical rules was tested by comparing the estimated and recorded levels and flows for the 1960-to-2001 period, with emphasis on the last decade (~1990 on), since it is the most recent and assumed to be the most representative of the present regime. Plan 1998 was a regulation plan developed for the Board of Control and intended to replace Plan 1958-D with deviations. The work conducted to formulate Plan 1998 was reviewed to assist in the development of the rules to estimate the deviations. Those new or revised rules that were determined to be useful estimators of the plan with deviations were programmed as extensions to the Plan 1958-D regulation model.

In actual operations, deviations from the plan are sometimes made several times within a week in response to changing conditions, such as ice formation or rapid increases in Ottawa River flows. Accordingly, the rules of the Plan 1958-D with deviations simulator (58-DD) were established based on the assumption that current hydrologic and ice conditions are known at the time the flow decision is made.

Determination of the 58-DD flow starts with the calculation of the Plan 1958-D flow. Then, 58-DD checks this flow to determine whether flow reduction deviations are appropriate due to low Lake Ontario levels. It then checks the flow against a number of modified flow limits that attempt to mimic the flow decision made by the Control Board. The effects of the deviations on the Lake Ontario level are tracked so that both the level with and the level without deviations are simulated. The computed Plan 1958-D flow is based on the level that would have occurred without deviations, while the 58-DD revised limits are applied based on the level with deviations.

The following list summarizes the additions and revisions made to the limits of Plan 1958-D to simulate the flow with deviations.

- Ignore the ice formation maximum flow limit of Plan 1958-D during the last half of December. (This "I" limit was originally included in Plan 1958-D in anticipation of a hydropower plant at the outlet of Lake St. Louis that has not been built.)
- Apply revised maximum outflow limits in the winter using a method similar to that used in Plan 1998. This limit is based on actual ice formation and ice roughness conditions rather than simply the date used in Plan 1958-D.
- During the navigation season, at high Lake Ontario levels, use increased maximum outflow limits developed from experience and with regard for the level of Lake St. Lawrence.
- Apply Plan 1998-type maximum outflow limits for Lac St. Louis to reduce flooding.
- Use modified minimum outflow limits to simulate deviations to maintain levels for navigation.
- Add rules to reduce the outflow under certain conditions in the spring and summer to raise Lake Ontario levels and/or store water for later use.
- Add rules to accumulate and reset the deviations to zero. (This resets the computed Plan 1958-D level to the "actual" level that results from deviations.)

A detailed description of these additions and revisions is included in the appendix to this report.

58-DD Compared with Recorded-Plan-1958-D-with-Deviations Flows

As mentioned above, the adequacy of 58-DD as a model of the present regulation regime was tested by comparing the simulated and recorded levels and flows for the 1960-to-2001 period, with emphasis on the last decade (~1990 on). This was done using the recorded quarter-monthly net total supply series to Lake Ontario and the recorded ice status indicator, river roughness factors and added inflow to Lac St. Louis.

Comparisons of the recorded Lake Ontario average quarter-monthly levels and those produced by 58-DD as values and differences are shown in Figures B-1 and B-2 for the 1960-2001 and 1990-2001 periods, respectively. The figures show that, on average, the 58-DD simulator reproduces the average Lake Ontario levels well, with a small bias to higher levels in winter.

Figures B-3 and B-4 show comparisons of the recorded Lake Ontario average quarter-monthly outflows and those produced by 58-DD as values and differences for the same 1960-2001 and 1990-2001 periods. Again the 58-DD simulator reproduces the average Lake Ontario outflows well. The late December outflows for the 1990-2001 period average somewhat more than recorded, while those in early January are slightly lower.

Note that for all figures in this section, the conversions from metric to Imperial are as follows:
1 m^3/s = 35.31467 ft^3/s and 1 metre = 3.28084 feet.

Figure B-5 is a plot of the 1960-2001 time series of recorded and 58-DD-simulated quarter-monthly Lake Ontario levels. The root mean square error (RMSE) of the difference in levels in this period is 0.075 m (0.246 ft), with a maximum error of 0.22 m (0.722 ft) and a minimum error of -0.24 m (-0.787 ft). The average error is 0.006m (0.02 ft), meaning the average simulated Lake Ontario level is slightly higher than the actual. For the last decade, 1991 to 2001, the RMSE of the difference in levels is 0.057 m (0.187 ft), with an average error of 0.018 m (0.059 ft), a maximum error of 0.14 m (0.46 ft) and minimum error of -0.17 m (-0.56 ft).

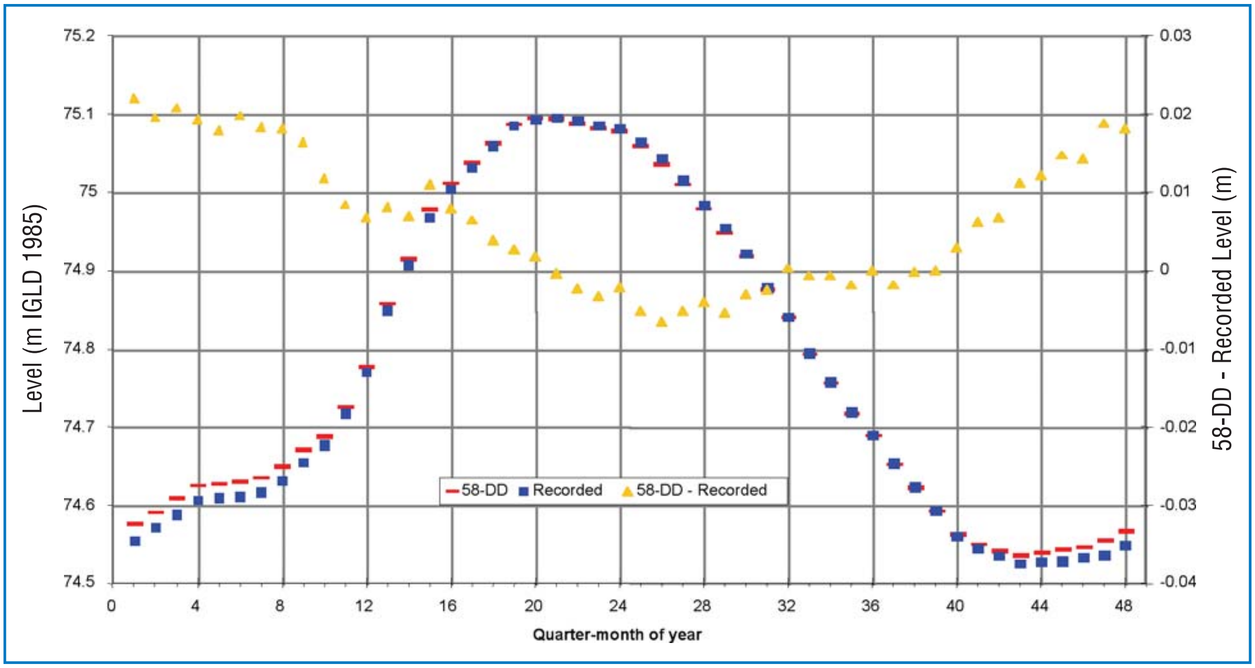


Figure B-1: Lake Ontario Average Quarter-Monthly Level 1960-2001 58-DD vs. Recorded

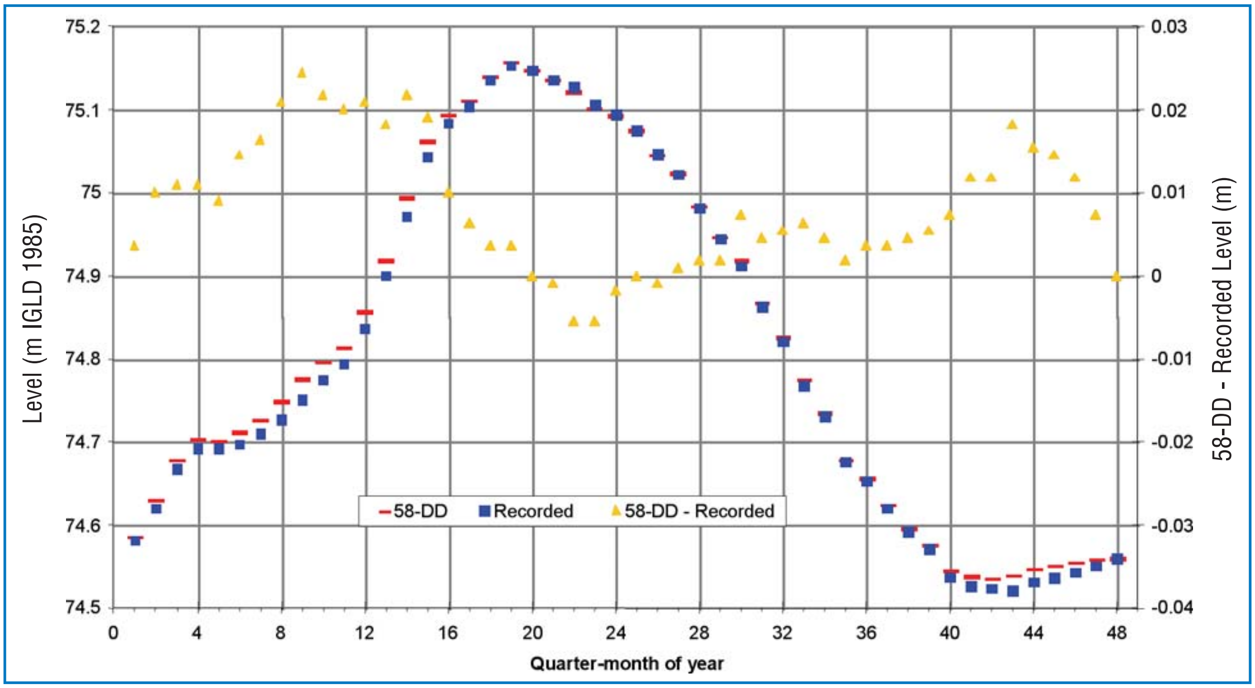


Figure B-2: Lake Ontario Average Quarter-Monthly Level 1990-2001 58-DD vs. Recorded

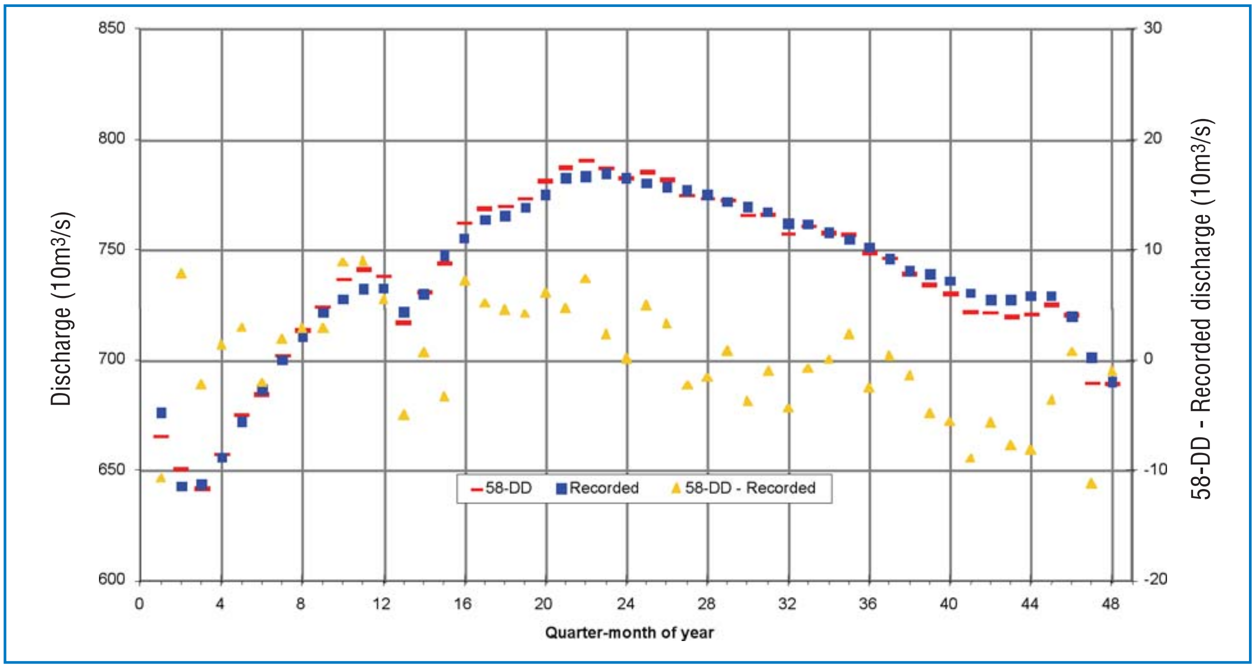


Figure B-3: Lake Ontario Average Quarter-Monthly Outflow 1960-2001 58-DD vs. Recorded

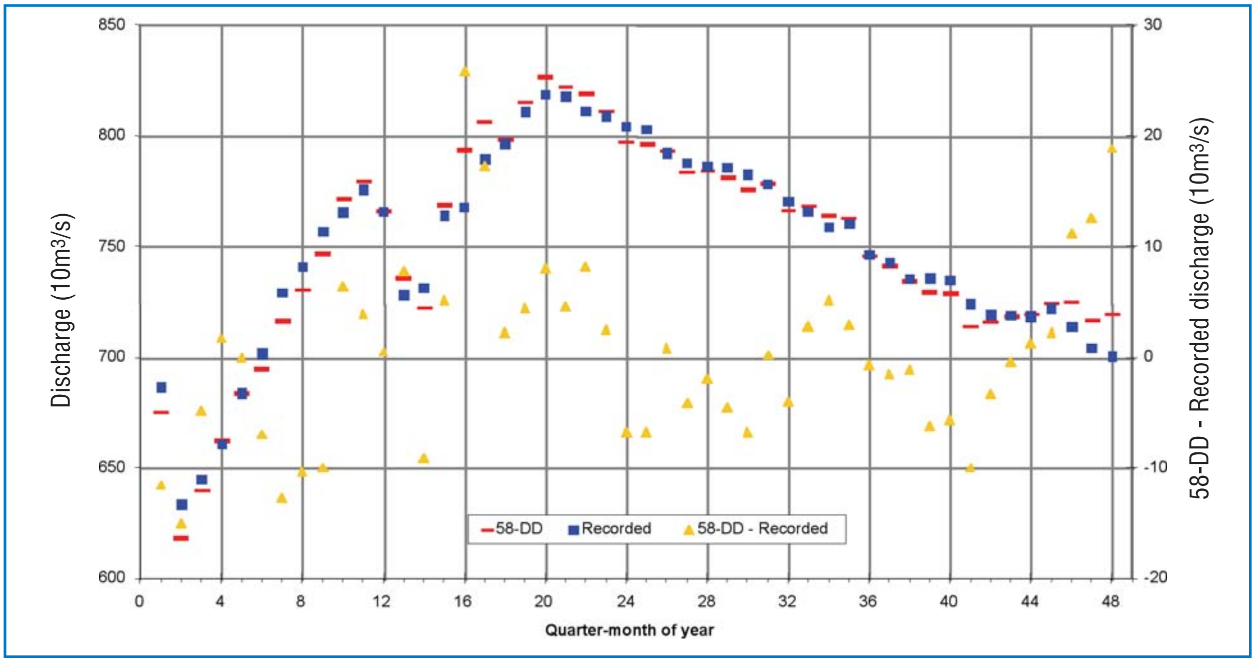


Figure B-4: Lake Ontario Average Quarter-Monthly Outflow 1990-2001 58-DD vs. Recorded

Figure B-5 shows that there are three periods in the last decade (1990-2001) in which the departures between the 58-DD simulator and the recorded Lake Ontario level are greater than 0.1 m (0.33 ft). Levels in 1991 were higher than simulated in 58-DD due to a combination of factors. Although lake levels were relatively high and ice had not yet formed, at the end of December 1990, the Board of Control did not increase flows much above the restrictive and obsolete "I" limit of Plan 1958-D. At the end of December 1990, 58-DD simulated higher flows due to the high lake level and lack of ice. In June and July of 1991, after significant over-discharge deviations had been accumulated in order to prevent the lake level from rising above the Criterion (h) level, the Board of Control released substantially less water than specified by Plan 1958-D in order to offset the earlier over-discharge deviations, even though the Lake Ontario level was still well above average. In this case, 58-DD did not reduce the outflow as far below Plan 1958-D as actually occurred. In the fall of 1992, the Board agreed to a request to reduce the release from Lake Ontario to less than that specified by Plan 1958-D in order to reduce spillage at the Hydro-Québec hydropower facilities, which at the time had a number of turbines out of service for maintenance. As a result, about 0.1 m (0.33 ft) of additional water was stored on Lake Ontario relative to Plan 1958-D in the fall of 1992. This turned out to be an ill-fated decision since Lake Ontario received high supplies that fall, which resulted in higher than desired levels. Since then, the Board of Control has not agreed to such requests under similar conditions in the autumn. The second exception to the generally good match in the 1990s is a period from late 1998 to late 1999. During the relatively dry period in late 1998, the Board of Control made a decision to release more water than specified by Plan 1958-D in order to prevent the level at Montreal Harbour from declining below Chart Datum. As a result, the level of Lake Ontario was drawn down further during a period of already low water level, raising concerns on the Lake in late 1998 and early 1999. The Board was thus forced to stop the discharges above those specified by Plan 1958-D in 1999, even though water levels at Montreal Harbour were further below Chart Datum than they would have been in late 1998. After this experience, during subsequent periods of low supplies, the Board has no longer attempted to keep the level at Montreal Harbour at Chart Datum, but instead has augmented the Plan 1958-D flow to maintain levels at Pointe Claire of not less than 20.6 m (67.59 ft) during the Seaway season (see Figure B-5A), as Lake Ontario levels permit. This latter practice has been programmed into 58-DD and, as a result, 58-DD simulates a higher Lake Ontario level than was recorded in late 1998 and 1999.

To eliminate the possible error in the comparison of recorded versus 58-DD levels of Lac St. Louis at Pointe Claire that might be introduced by the Lac St. Louis stage-discharge-roughness equation, Lake Ontario outflows for both the recorded and the 58-DD cases were entered into the same Lac St. Louis stage-discharge-roughness equation to generate comparable levels at Pointe Claire. The average quarter-monthly levels and those produced by 58-DD as well as recorded Lake Ontario outflows are shown in Figure B-6 for the 1960-2001 period. The figure shows that, on average, the 58-DD simulator reproduces the average Lac St. Louis levels well, with a small bias to higher levels in the spring and lower levels in the fall. The 1990-2001 quarter-monthly levels at Pointe Claire are shown in Figure B-5A.

To compare the frequency distribution of levels produced by 58-DD with the recorded case, cumulative frequency curves were produced. Three periods were selected: the entire year, April and August. Results for individual months are included as a check that the distribution of levels in key months was adequate. April was selected, as levels in this month are thought to be important for fish spawning, while August levels are important for recreational boating. Figures B-7, B-8 and B-9 compare the frequency distributions for Lake Ontario, while Figures B-10, B-11 and B-12 show similar results for Lake St Louis.

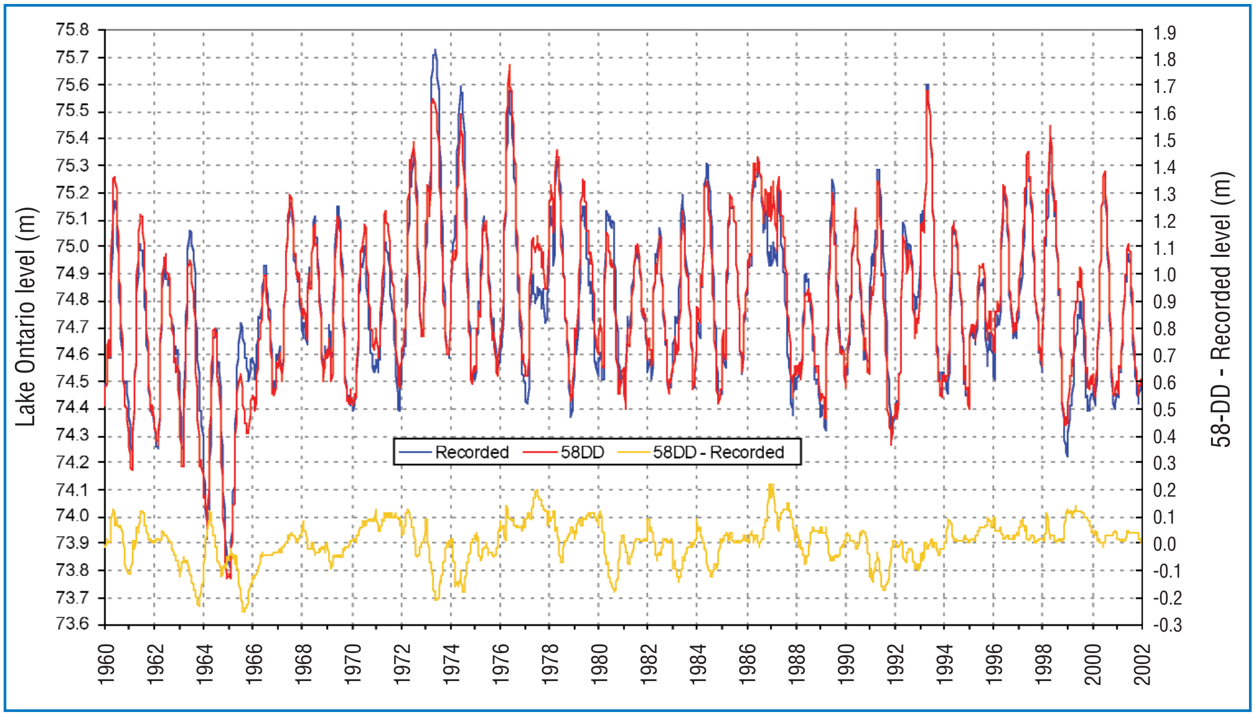


***Figure B-5:* Lake Ontario level 58-DD Simulated vs. Recorded 1960-2001**

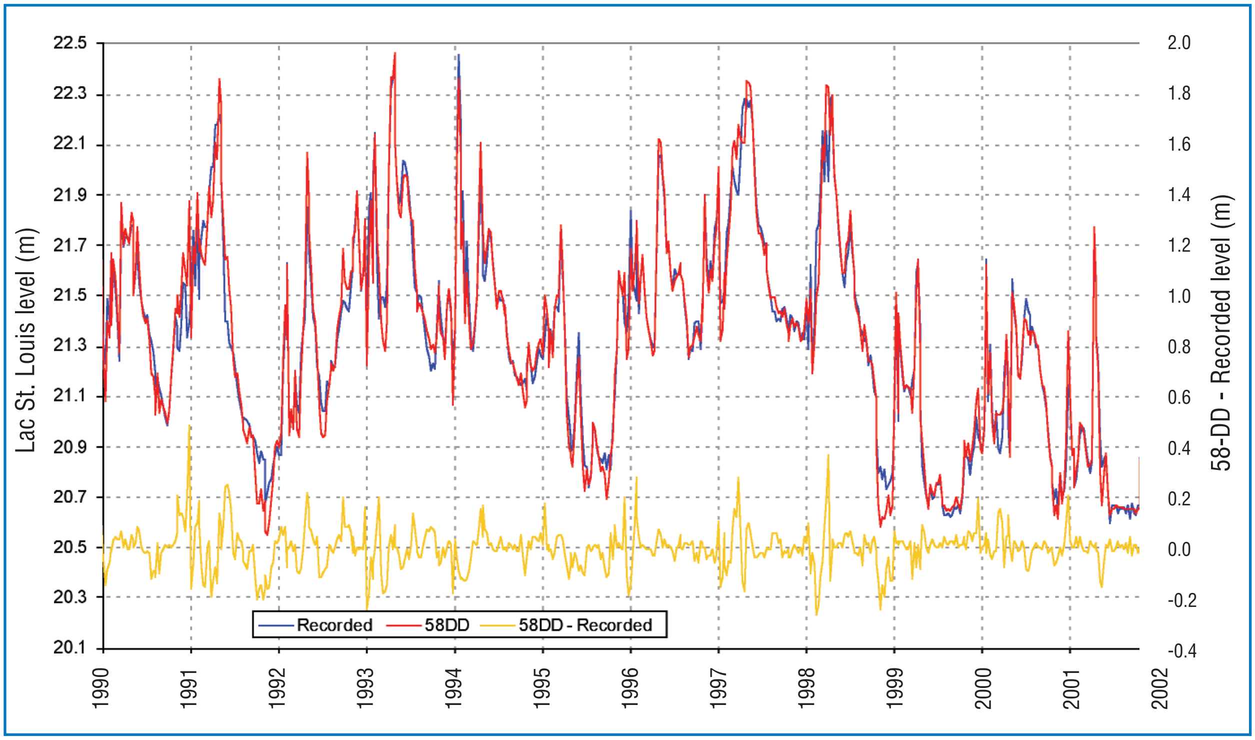


***Figure B-5A:* Lac St. Louis at Pointe Claire level 58-DD Simulated vs. Recorded 1990-2001**

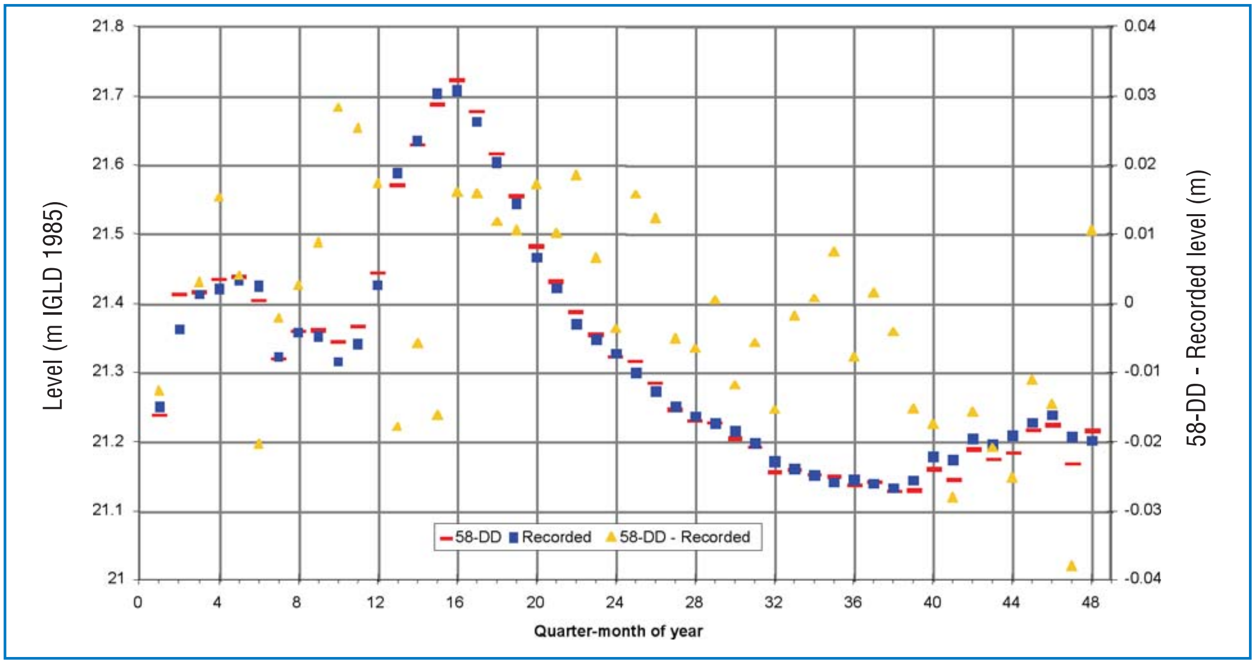


Figure B-6: Lac Saint Louis at Pointe Claire Average Quarterly-Monthly Level 58-DD vs. Recorded

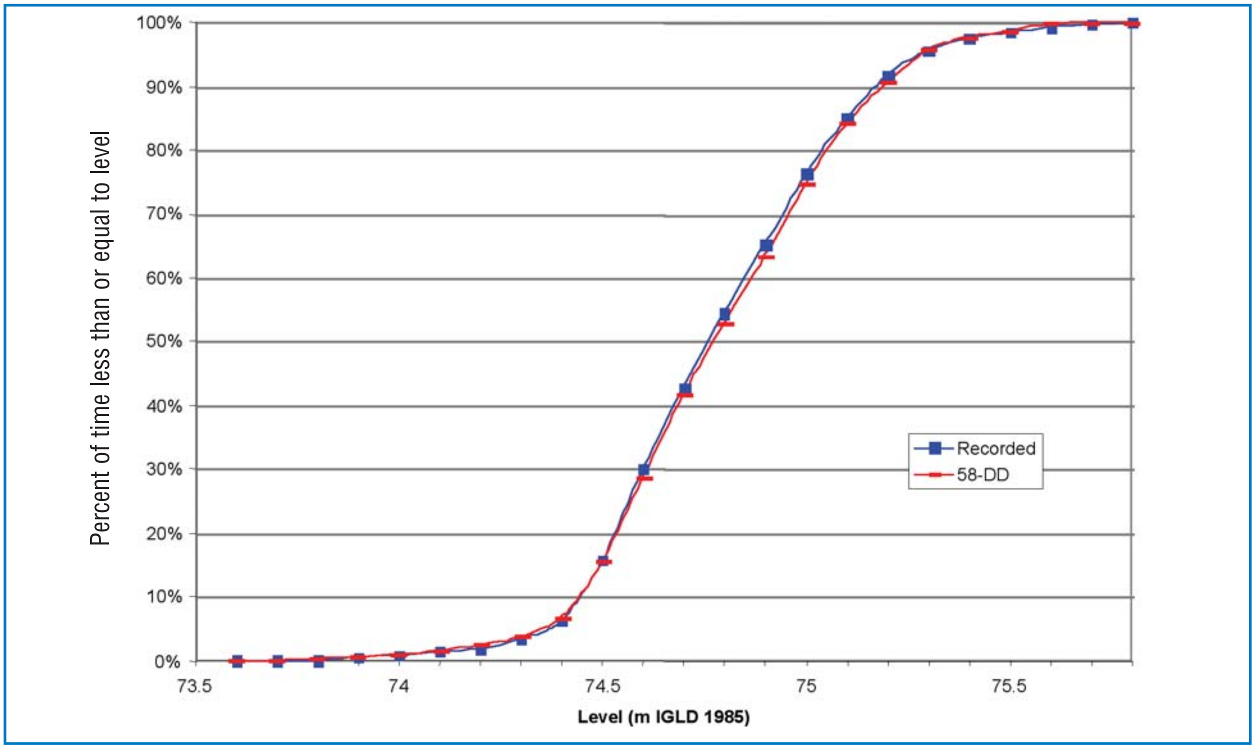


Figure B-7: Cumulative Frequency of Lake Ontario Levels 58-DD vs. Recorded All Year 1960-2001

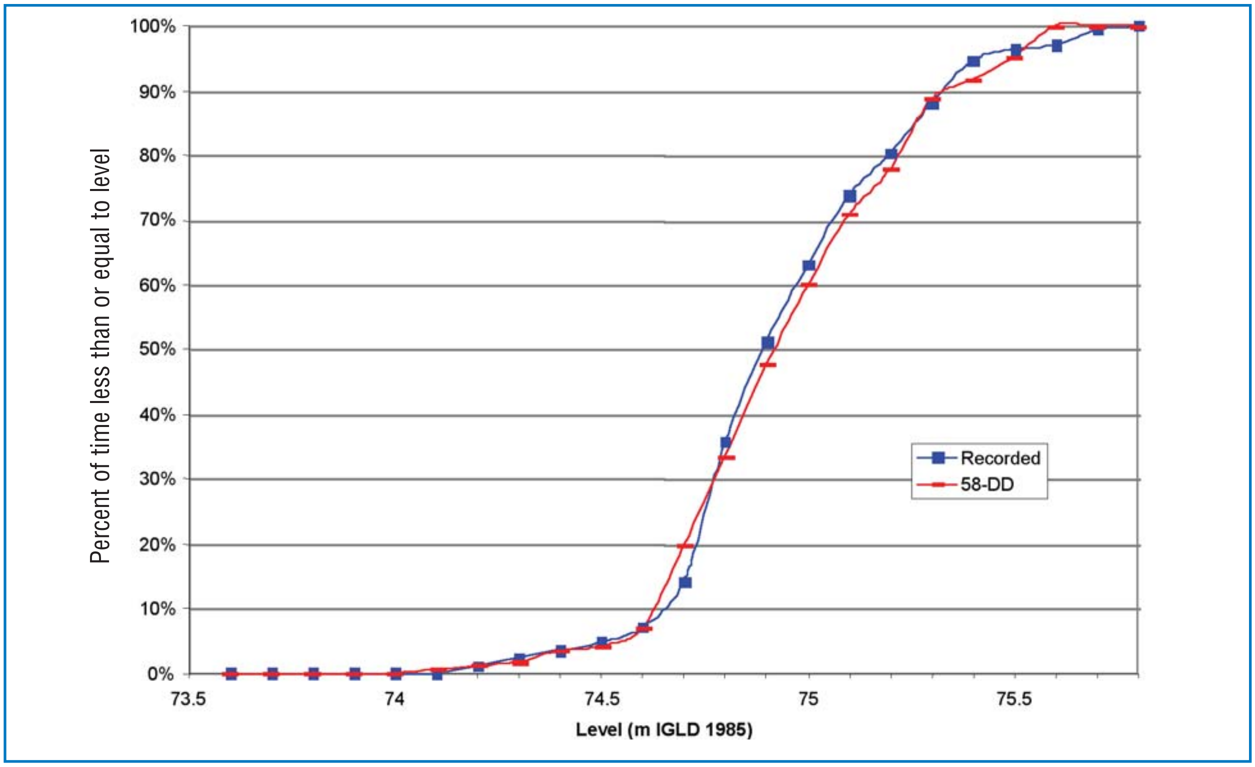


Figure B-8:* *Cumulative Frequency of Lake Ontario Levels 58-DD vs. Recorded April 1960-2001

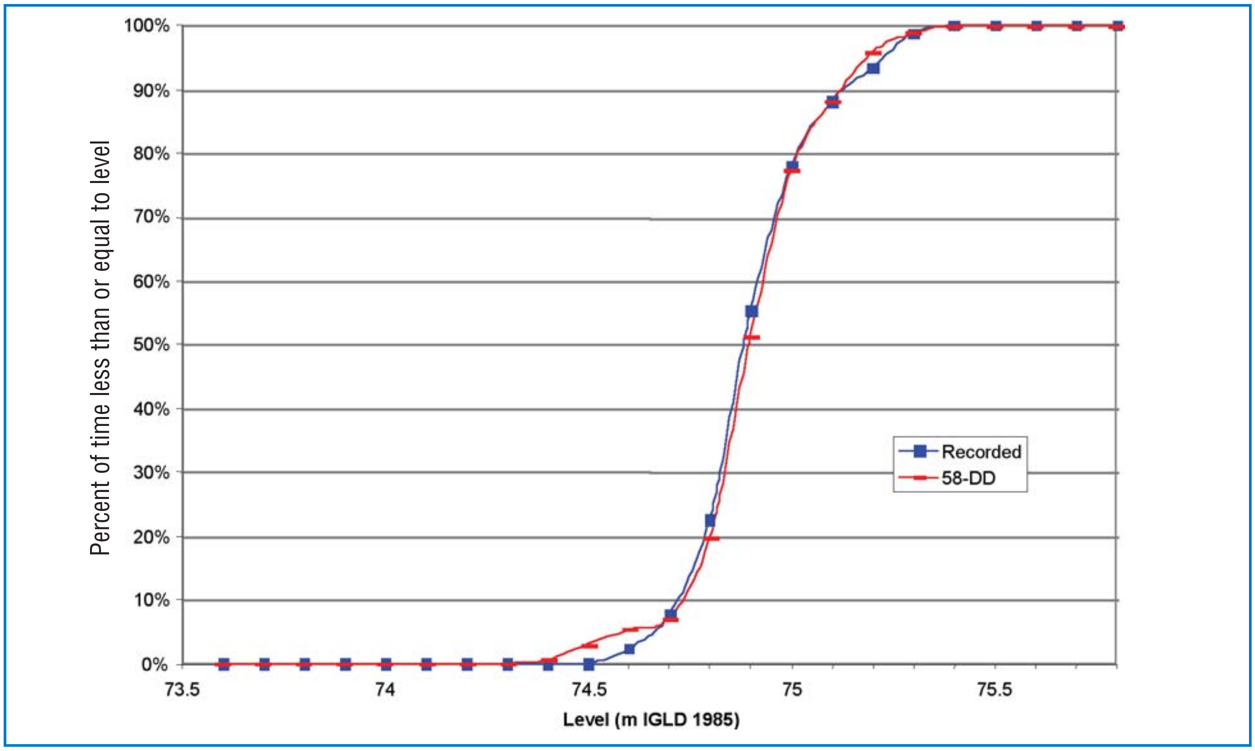


Figure B-9:* *Cumulative Frequency of Lake Ontario Levels 58-DD vs. Recorded August 1960-2001

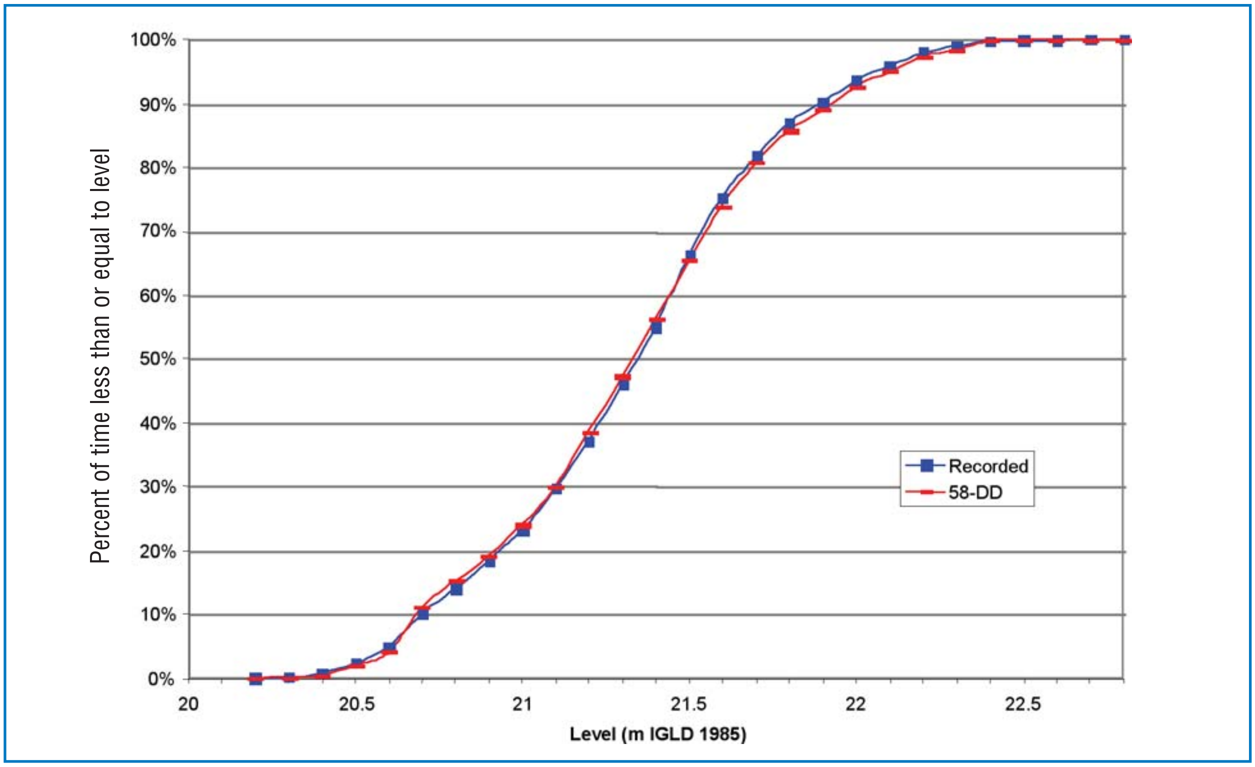


Figure B-10: ***Cumulative Frequency of Lac St. Louis Levels 58-DD vs. Recorded All Year 1960-2001***

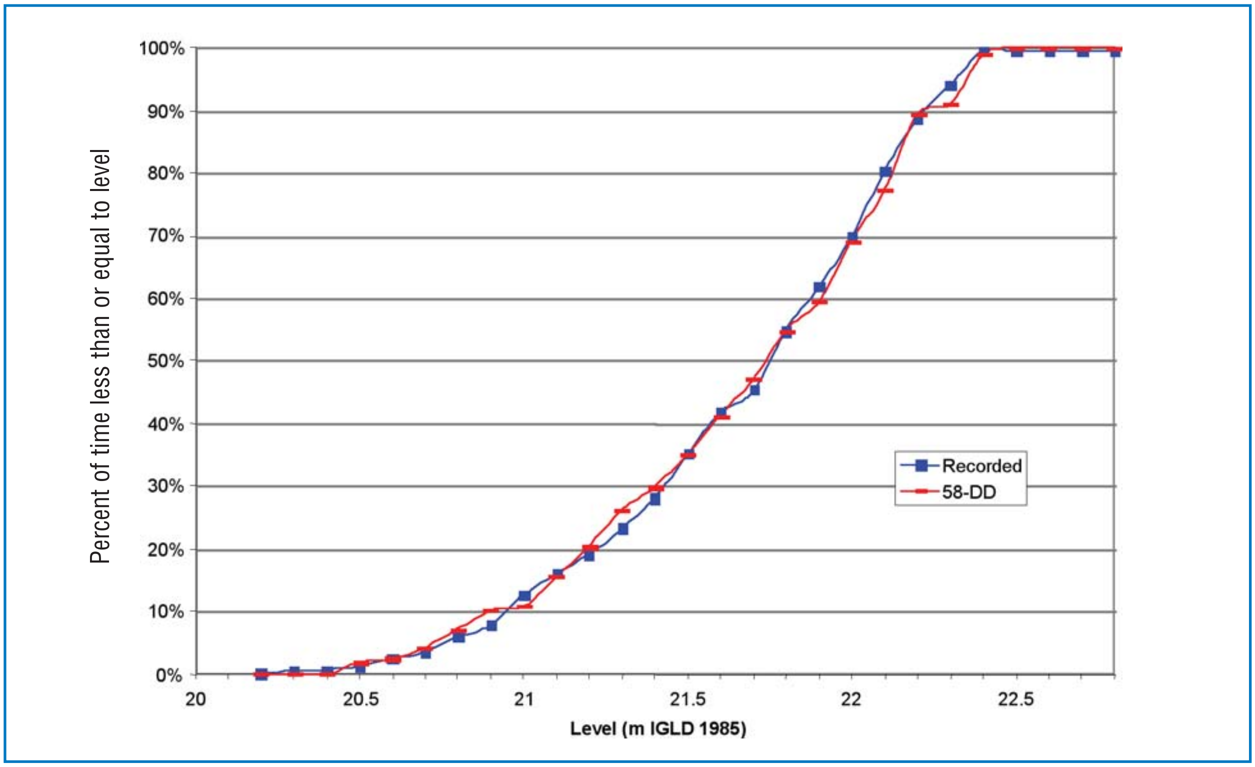


Figure B-11: ***Cumulative Frequency of Lac St. Louis Levels 58-DD vs. Recorded April 1960-2001***

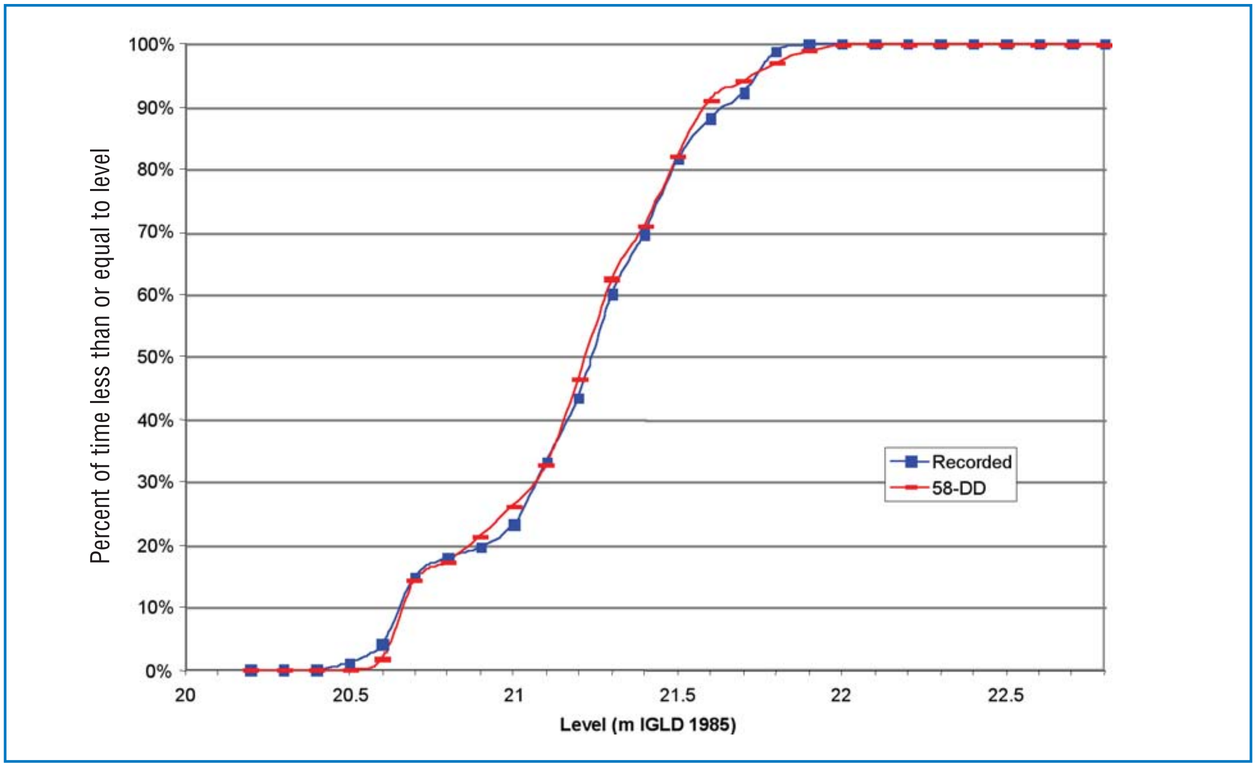


Figure B-12: Cumulative Frequency of Lac St. Souis Levels 58-DD vs. Recorded August 1960-2001

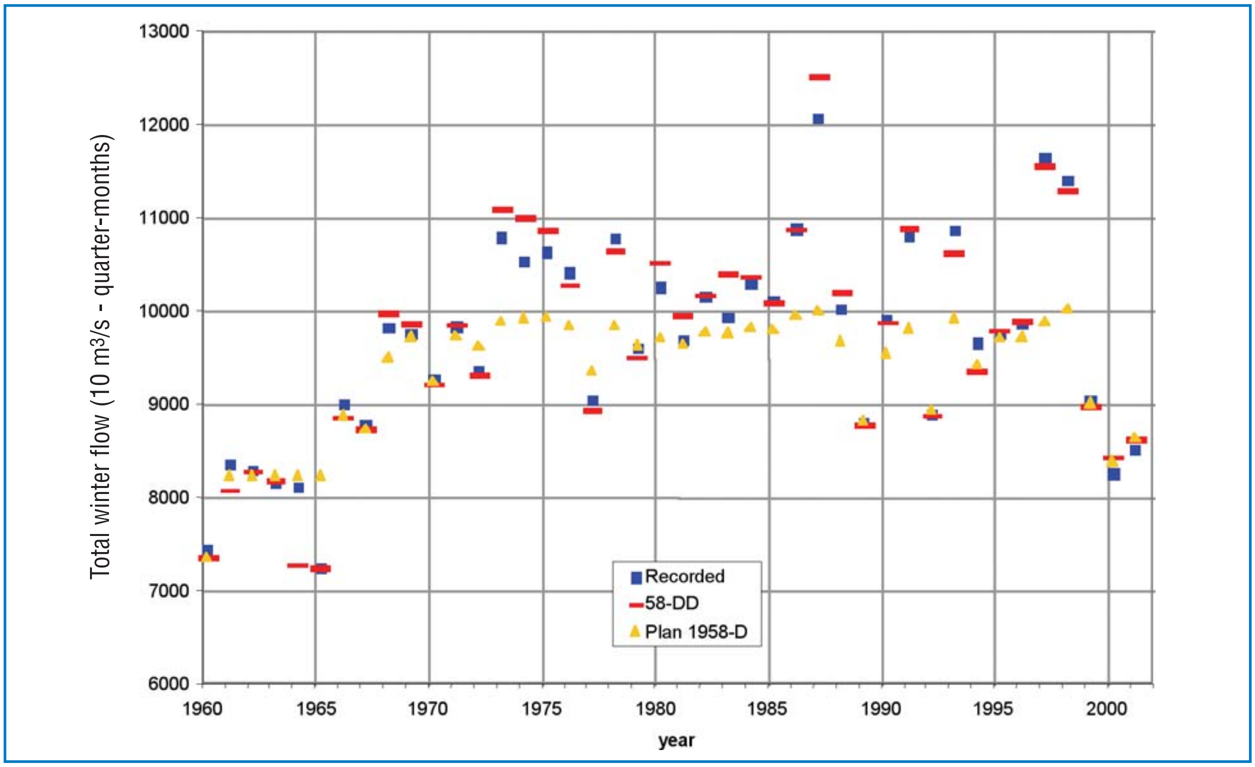


Figure B-13: Total Winter Flows 58-DD vs. Recorded and Plan 1958-D 1960-2001

Comparing the frequencies shown in Figures B-7 through B-12, it can be seen that the overall distribution of levels through the year on Lake Ontario produced by 58-DD is similar to the recorded distribution. The frequencies of extreme low and high levels are almost identical in 58-DD to the recorded case. In August, 58-DD results slightly more levels from 74.4 to 74.6 m (244.09 to 244.75 ft) on Lake Ontario, and slightly fewer levels below 20.6 m (67.59 ft) on Lake St. Louis than were recorded in the 1960-2001 period. This may be the result of the simulation of the Board of Control's strategy in recent years that attempts to keep the level of Lac St. Louis above 20.6 m (67.59 ft) in the Seaway season.

As mentioned above, the inflexible, date-specific, maximum winter flow limits of Plan 1958-D result in frequent deviations from Plan 1958-D-specified flows in the winter due to the variability of ice conditions in the River from year to year. Actual winter flows were found to be among the most difficult to simulate due to a lack of data on the factors governing flow under ice conditions. A method similar to that developed for use in Plan 1998 (ISLRBC, 1997) was used in 58-DD to estimate maximum winter flows with deviations. This method uses a simple indicator of the ice formation status in the Beauharnois Canal and the international section, and a coefficient to estimate the roughness of the ice cover in the international section, to aid in setting maximum winter flows. Figure B-13 compares the 58-DD and recorded total winter flows (10 m^3/s-quarter-months or 350 m^3/s-quarter-months) in each year from 1960 to 2001. From this figure it can be seen that 58-DD estimates the total winter flow quite well, particularly in the last decade.

Discussion

The levels and flows resulting from 58-DD can only be approximations of actual historical flow decisions made by the Board of Control. This is due to the evolving and often subjective decision factors that are taken into consideration by the Board. The Board of Control has changed the way it deviates from Plan 1958-D over time as the needs of the interests have changed, as its understanding of the variability of the hydrology of the Lake Ontario–St. Lawrence River has developed, and as the values of the Board have shifted with the turnover in its membership. Thus, a simulator of flow-release decisions based solely on a few physical hydrologic inputs cannot be expected to exactly replicate each quarter-monthly decision. In this light, 58-DD is considered an adequate approximation of the existing flow regulation method.

References

International St. Lawrence River Board of Control (ISLRBC), July 1963. *Regulation of Lake Ontario: Plan 1958-D*. Report to the International Joint Commission, Ottawa and Washington.

International St. Lawrence River Board of Control (ISLRBC), June 1997. *An Updated Regulation Plan for the Lake Ontario-St. Lawrence River System*. Report to the International Joint Commission, Ottawa and Washington.

Levels Reference Study Board, March 1993. *Levels Reference Study: Great Lakes - St. Lawrence River Basin*. Main report. Report to the International Joint Commission, Ottawa and Washington.

Plan 1958-DD - Appendix

Detailed description of changes to Plan 1958-D in 58-DD

The following is the logic of the changes made to simulate Plan 1958-E with deviations.

Note: qm = quarter-month
Conversion from metric to Imperial units: 1 m^3/s = 35.31467 ft^3/s; 1 metre = 3.28084 feet

Reduce flow to store water on Lake Ontario in spring-summer

From mid-March (qm 11) to the end of August (qm 32)

If the accumulated deviations are less than -1,800 m^3/s-qm (roughly 6 cm stored on Lake Ontario) AND the Lake Ontario level is more than 5 cm below the target level, then reduce the adjusted rule curve flow by 300 m^3/s.

The target level, which is the average Lake Ontario level for the period 1900-2001, is defined in Table B-1 below.

Table B-1: Target Lake Ontario beginning-of-quarter-month level (m, IGLD 1985)

qm	level (m)	qm	level (m)
1	74.54	25	75.03
2	74.55	26	75.02
3	74.56	27	75.00
4	74.57	28	74.98
5	74.58	29	74.96
6	74.58	30	74.92
7	74.58	31	74.90
8	74.59	32	74.86
9	74.61	33	74.82
10	74.63	34	74.79
11	74.65	35	74.76
12	74.70	36	74.72
13	74.75	37	74.69
14	74.83	38	74.66
15	74.87	39	74.63
16	74.92	40	74.61
17	74.96	41	74.58
18	74.98	42	74.56
19	75.00	43	74.55
20	75.03	44	74.54
21	75.04	45	74.54
22	75.04	46	74.54
23	75.04	47	74.54
24	75.04	48	74.54

Use Plan 1998 J limit

The J limit specifies the allowable flow change from one period to the next.

If Lake Ontario level > 75.20 m then allow J increase to be 1420 m^3/s.
Otherwise J increase is 570 m^3/s.

J decrease remains at 570 m^3/s.

(Recall that another limit may take precedence over the J limit. The "J increase" is a maximum limit and the "J decrease" is a minimum limit. If a maximum limit is less than a minimum limit then the maximum limit governs; e.g., flow reduction due to max limit for ice formation.)

Plan 1998 P limit with further modifications

Modify the Lac St. Louis outflow limit to reduce flooding.

If Lake Ontario is below 75.2 m:

From 1st qm of February to 3rd qm of April then:

limit the Lake Ontario outflow such that it plus the forecast (perfect in 58-DD) difference between the L. St. Louis and L. Ontario flows is less than the L. St. Louis flood flow of 11500 m^3/s

Qont = 11500 - StlOnt

(corresponds to 22.1 m alert level computed using the Pointe Claire relationship) or the original Plan 1958-D P limit, whichever is less.

For the rest of year:

limit outflow such that flow plus forecast (perfect in 58-DD) difference between L St. Louis and Lake Ontario flows is less than the L. St. Louis flood flow of 11500 m^3/s

If Lake Ontario level is above 75.2 m, but below 75.45 m:
then use 12400 m^3/s (corresponds to 22.33 m flood level).

If Lake Ontario level is above 75.45 m:
then revert back to original P limit or the 12400 m^3/s, whichever is greater.

Plan 1998 I limit modified

Replace winter L LIMIT of Plan 1958-D by a new I limit calculated on the basis of Long Sault level (seasonal to account for shipping and ice condition).

1. If ice is forming at Beauharnois or was forming at Beauharnois in the previous period (thus assumed to be forming in the international reach) then limit maximum flow to 6230 m^3/s.

2. IF qm = 48 OR qm < 13 THEN assume no Seaway navigation and the governing maximum flow is based on the Long Sault threshold levels and the supplies (adjusted supply indicator).

```
SELECT CASE adjusted supply indicator
    CASE IS < 0
        Long Sault target level = 72.2 m
    CASE 0 TO 100
        Long Sault target level = 72.0 m
    CASE ELSE
        Long Sault target level = 71.8 m
    END SELECT
```

Revise to prevent excessively low downstream levels with very low Lake Ontario levels for stochastic and climate change cases.

```
    IF L. Ontario level <= 73.60 m THEN
    Long Sault target level = Long Sault target level - 0.2 m
```

Calculate flow to produce the Long Sault target level with the forecast ice roughness factor. The following equation calculates the limiting flow, LSq (m^3/s), for a given Kingston level and Long Sault Dam level (LSlev) and roughness "n."

LSq = 22.9896(Kingston level - 62.4)2.2381 ((Kingston level – LSlev)/n)0.387

3. Limit the maximum flow with ice to be no more than 9430 m^3/s, the maximum flow that was achieved with ice present (occurred in 1987).

4. In the period after the last ice in the international section each winter, a maximum flow of 9500 m^3/s is allowed, and in the following period, a maximum of 10000 m^3/s is used. These limits were added in consideration of the possibility of ice conditions remaining in the Beauharnois and Coteau channels after the ice leaves the international section.

Modified maximum outflow L limits relative to Plan 1958-D during the navigation season

Applies for assumed Seaway season from April 1 to December 3rd qm.

Use same L limits as in 1958-D if the L. Ontario level is below 75.13 m. Then, as in Plan 1998:

If Lake Ontario level between 75.13 m and 75.44 m then
    L limit = 8780 m^3/s + linear increase to 9910 m^3/s at 75.44 m

In Plan 1998, If above 75.44 m then
    L limit = 9910 m^3/s

But, modified for more extreme cases,
The 75.7-m level is an estimate of the threshold to go to extreme flow conditions that could temporarily stop Seaway traffic. This is the maximum qm flow that has occurred in navigation season.

Supersede the L limit if needed to keep Long Sault level above Seaway minimum. Use 72.6 m at Long Sault as limit since this is based on the beginning-of-period Lake Ontario level. To deal with very low levels, if the Lake Ontario level is below chart datum (74.20 m) then allow the LS level to be equally below the 72.6-m limit in an effort to provide enough water downstream.

```
IF Lake Ontario level >= 74.20 m THEN
     lsMintarget = 72.6 m
ELSE
     lsMintarget = 72.6 m - (74.2 m - Lake Ontario level)
END IF
```

maxLS = LSq(Kingston level, lsN, lsMintarget)

IF the maximum flow to keep Long Sault above 72.6 m < normal L limit then set the L limit to this flow.

Modified P limit*

A revised P* limit is used to keep the Lac St. Louis outflow above 6,800 m^3/s (a Lac St. Louis level of about 20.64 m) if the Lake Ontario level is above 74.30 m. If the Lake Ontario level is above 74.20 m but less than 74.30 m, then keep the L St. Louis flow above 6400 m^3/s (20.5 m). If the L. Ontario level is above 73.80 m but less than 74.20 m then keep the L. St. Louis flow above 6100 m^3/s (20.4 m). If the L. Ontario level is less than 73.80 m, then keep the L. St. Louis flow above 5770 m^3/s (20.3 m). In addition, if the Lake Ontario level is more than 35 cm below its target level (see Table B-1 above), then these target L. St. Louis outflows are reduced by 200 m^3/s.

The M limit is set to the P* limit if the Lake Ontario level is less than 74.20 m.

These rules apply throughout the year.

The Lac St. Louis minus Lake Ontario outflow is defined as stlont in the following:

```
SELECT CASE Lake Ontario level
     CASE IS > 74.30
          MINPSTAR = 6800 - stlont
               IF devlev <= -0.35 THEN
                 MINPSTAR = MINPSTAR - 200
               END IF
     CASE 74.20 TO 74.30
          MINPSTAR = 6400 - stlont
               IF devlev <= -0.35 THEN
                 MINPSTAR = MINPSTAR - 200
               END IF
     CASE 73.80 TO 74.20
          MINPSTAR = 6100 – stlont
               MINM = MINPSTAR    force M limit to equal P* if Lake Ontario less than 74.2
     CASE 73.60 TO 73.80
          MINPSTAR = 5770 - stlont
          MINM = MINPSTAR      force M limit to equal P* if Lake Ontario less than 74.2
     CASE IS < 73.60
          MINPSTAR = 5200 – stlont
          MINM = MINPSTAR    force M lim to equal P* if Lake Ontario less than 74.2
     END SELECT
```

If the Lake Ontario level is greater than 74.40 m, then do not allow P* limit to be less than the existing P* limit of 1958-D during the period from qm 12 to qm 47.

```
IF qm > 11 AND qm < 48 THEN
    IF Lake Ontario level > 74.40 THEN
      MINPSTAR = Max(MINPSTAR, pstar58d)
    END IF
END IF
```

Selected flow limit

The selected maximum limit is the least of the various maximum limits (L, I, P, J+) and the minimum limit is the largest of the minimum limits (P*, M, J-). As in 1958-D, if a maximum limit is less than a minimum limit, then the maximum limit governs.

Accumulating and zeroing simulated deviations

In 58-DD, the difference between the 58-DD-specified flow and the Plan 1958-D flow is tracked and accumulated. These accumulated deviations are equivalent to a difference in the Lake Ontario levels that would result between 58-DD-simulated flows and the Plan 1958-D flows. The rules of 58-DD use the simulated 58-DD Lake Ontario level, while the Plan 1958-D rules are applied with the Lake Ontario level computed as though no deviations had occurred. As arises in actual operations, if the deviations become too great (i.e., the difference between the actual Lake Ontario level and the computed Plan 1958-D level becomes so large that the Plan-1958-D computed flows are no longer realistic for the given conditions), then the accumulated deviations are reset to zero. This is equivalent to resetting the Plan 1958-D-computed Lake Ontario level to the actual level. This has occurred eight times in actual practice since 1963.

In 58-DD, the deviations account is reset under the following conditions:

If the accumulated deviations are greater than +10000 m^3/s-qm in July or August, then the accumulated deviations are reset to zero.

If the accumulated deviations are less than -7000 m^3/s-qm at the end of March, then the accumulated deviations are reset to zero.

```
SELECT CASE accdev
    CASE IS > 10000
        IF month >= 7 AND month < 9 THEN
          accdev = 0
          clev = Lake Ontario level
        END IF
    CASE IS < -7000
        IF month = 3 AND qm = 4 THEN
          accdev = 0
          clev = Lake Ontario level
        END IF
    END SELECT
```

Where "clev" is the Plan 1958-D-computed level.

Lake Ontario level precision

The 58-DD simulator applies the same degree of precision as actual operations, in which the Lake Ontario level is determined to the nearest centimetre prior to being entered into the computation. However, to more accurately track the Lake Ontario level and to avoid problems related to lack of precision with different software at 2 decimals, the level is computed to a precision of 6 decimal metres. Each time step, this 6-decimal precision level is rounded to 2 decimals prior to entering into the plan rules to preserve consistency with operations.

Candidate Regulation Plan Descriptions

Plan A+
Plan B+
Plan D+

Plan A+: Balanced Economics

Plan A+ development took place in two phases. First, an optimization model was used to generate a family of rule curves for determining the release based on the current Lake Ontario level. Applying these rule curves alone produced some undesirable results, so the plan was modified by the addition of adjustments and limits based on forecasts and other conditions in the system.

Phase I: Optimization

The optimization model minimized expected deviations from target levels for Lake Ontario, Lac St. Louis, Montreal Harbor, and Sorel, and from target flows for the release. All of these targets varied through the year and were derived from relevant performance indicators or other similar sources. A graph of each set of targets appears at the end of this document.

The optimization minimized the likely deviation from these desired targets given uncertain future inflows. The model used a probabilistic approach to account for the uncertainty of these future inflows. Historical Lake Ontario inflows (net total supply (NTS) from 1900 to 2000) were divided evenly into five categories (very dry to very wet), according to total annual inflows. It is assumed that those inflows would be closely correlated with annual precipitation, hence a good indication of wet/dry years.

For each flow range, a representative year was chosen: the year in which total inflows were the closest to the average total annual inflows for that category. All the inflows and ice factors that are associated with this flow range then come from the chosen representative year: very dry – 1933, dry – 1937, moderate – 1903, wet – 1954, very wet – 1993.

A transition matrix was built to define the probability of being in any particular flow category (e.g., wet, very wet, etc.) for the upcoming year, given the flow category over the previous year. These transition probabilities were determined using the 101 years of historical inflow data and are shown in Table B-2 below.

Table B-2: Transition matrix of probability of occurrence of specific weather conditions

Past yr \ Next yr	VERY DRY	DRY	MODERATE	WET	VERY WET
VERY DRY	0.57	0.33	0.10	0	0
DRY	0.32	0.33	0.25	0.10	0
MODERATE	0.05	0.22	0.11	0.41	0.21
WET	0.06	0.12	0.38	0.28	0.16
VERY WET	0	0	0.16	0.21	0.63

These probabilities represent the probabilities of occurrence of a specific weather condition (very dry, dry, moderate, etc.) for one year following a year characterized by the same or another specific weather condition. For instance, if 2004 was a very wet year, there is a high probability (63% chance) that 2005 will turn out to be very wet as well, but only a 21% chance that 2005 will turn out to be a moderate year.

The inflow category (e.g., wet, dry etc.) for the past year is designated using the current Lake Ontario level. The rational behind this is that, even though Lake Ontario levels are highly regulated, a series of wet years may produce higher lake levels than average, while a prolonged drought may produce lower lake levels than average. The corresponding past flow ranges and Lake Ontario ranges are shown in Table B-3 below:

Table B-3: Lake Ontario levels and corresponding past weather condition

Lake Ontario Level	Past Weather Condition
below 74 m	very dry
between 74 m and 74.5 m	dry
between 74.5 m and 75 m	moderate
between 75 m and 75.5 m	wet
above 75.5 m	very wet

Note: 1 metre = 3.28084 feet

If, at the beginning of a given period, Lake Ontario is at 75.3 m (247.05 ft), the past year (last 48 quarter months) is then considered to have been wet. Then the transition probability matrix can be applied to determine the likelihood of next year being very dry, dry, etc.

The optimization model is run for 48 periods (each quarter-month of the year) and for each of the five defined discrete lake levels to produce 48 different release rule curves, one for each quarter-month. A matrix and graph of all the rule curves appear at the end of this document.

Phase II: Adjustments and Limits

In order to improve the performance of Plan A$^+$, various limits and adjustments are applied to the base rule curve release each quarter-month.

Step 1 – NTS adjustments: Several adjustments can be made based on NTS coming into Lake Ontario. A 10-quarter-month moving average of NTS is tracked and used as an indicator of wet or dry conditions. An annual NTS forecast is also used to identify wet conditions. Table B-4 shows the adjustments made based on the NTS moving average.

Table B-4: Adjustments made based on NTS moving average

Condition	Adjustment
10-quarter-month moving average NTS > 9,750 m^3/s (344,300 ft^3/s) **AND** Current Lake Ontario level > 75.4 m (247.38 ft)	Increase base rule curve release by 25%
10-quarter-month moving average NTS < 7,500 m^3/s (264,900 ft^3/s)	Decrease base rule curve release by 5%
10-quarter-month moving average NTS < 5,750 m^3/s (203,000 ft^3/s)	Decrease base rule curve release by 20%

If none of the three NTS moving average conditions listed above apply, then adjustments are applied based on the annual NTS forecast as shown in Table B-5.

Table B-5: Adjustments based on the annual NTS forecast

Condition	Adjustment
Annual NTS forecast > 7,700 m^3/s (271,900 ft^3/s)	Increase base rule curve releases by 10%

The three adjustments based on the moving average NTS take precedence; hence, if one of these adjustments is triggered, the annual NTS forecast adjustment is not applied.

Step 2 – Flow smoothing: Since each quarter-month has its own rule curve, Plan A^+ can produce releases that vary somewhat erratically from quarter-month to quarter-month. In order to prevent this, a simple smoothing rule is applied which slows down the rate at which Plan A^+ can vary releases. This rule averages the last two releases and the current release produced in Step 1 above, giving the Step-1 release double weight.

New Releases = [2 x (Step-1 Release) + (Release @ t-1) + (Release @ t-2)]/4

Where: Step-1 Release = the release adjusted for NTS moving average and forecast,
Release @ t-1 = the final release made in the previous quarter-month,
Release @ t-1 = the final release made 2 quarter-months ago.

This rule is only applied if the current Lake Ontario level is ≤ 75.55 m (247.87 ft). If the Lake is higher than 75.55 m (247.87 ft), then the smoothing rule is not applied so that releases can be increased fast enough to avoid flooding.

Step 3 – J limit: A J limit is also applied. This limits flow changes from quarter-month to quarter-month based on the current Lake Ontario level.

Table B-6: J-Limit based on Lake Ontario level

Lake Ontario Level	Plan A^+ J Limit
> 75.5 meters (247.7 ft)	2100 m^3/s (74,200 ft^3/s)
≤ 75.5 meters (247.7 ft)	700 m^3/s (24,700 ft^3/s)

Note that because the rules are applied after the J limit, two other factors can result in violation of the J limit: 1) flow reductions for ice conditions, and 2) flow reductions to avoid flooding downstream.

Step 4 – Downstream flood prevention: Adjustments to the release are made to prevent downstream flooding. For simulation purposes, these adjustments are applied using the freshet perfect forecast indicator developed by David Fay. The release is limited to keep Lake St. Louis from rising above certain levels, depending on the Lake Ontario level as shown in Table B-7.

Table B-7: Adjustments to prevent downstream flooding

Lake Ontario Levels	Lac St Louis Limit
< 75.4 meters (247.38 ft)	22.3 meters (73.16 ft)
≥ 75.4 (247.38) and < 75.5 meters (247.7 ft)	22.4 meters (73.49 ft)
≥ 75.5 (247.7) and < 75.6 meters (248.03 ft)	22.6 meters (74.15 ft)
≥ 75.6 (248.03) and < 75.7 meters (248.36 ft)	22.7 meters (74.48 ft)
≥ 75.7 meters (248.36 ft)	22.8 meters (74.80 ft)

Step 5 – Ice limit: Exactly the same ice limits that were used for Plan 1998 are applied in Plan A+. During the non-navigation season, the maximum allowable release is that which will keep Long Sault at 71.8 m (235.56 ft) or higher. In addition, during ice formation, the maximum allowable release is 6,250 m^3/s (220,700 ft^3/s). The Ice Limit release applied is the minimum of the two.

Step 6 – Minimum allowable release: Finally, an absolute lower limit of 4,000 m^3/s (141,300 ft^3/s) is applied.

Target Levels/Releases for the Optimization Model

Target levels and releases

The target levels outlined in Figures B-14 to B-17 come from the PIAG_Yr4_Draft_17 PowerPoint file, which outlines all the existing suggested criteria. For a given period, the target maximum level is the minimum of the various maxima, the target minimum level being the maximum of the various minima. (For purposes of conversion from metric to Imperial units, 1 metre = 3.28084 ft and 1 m^3/s = 35.31467 ft^3/s).

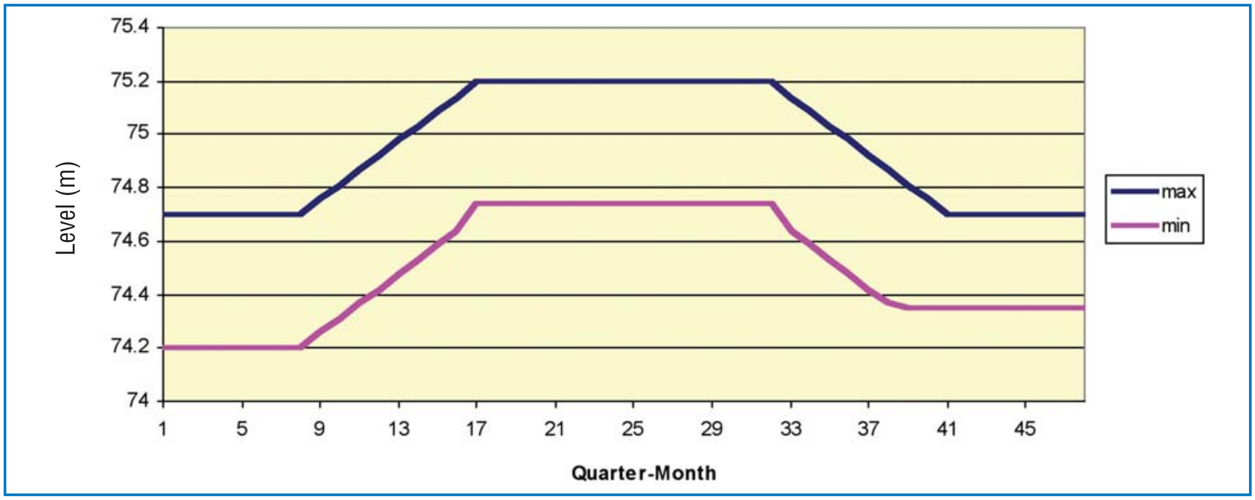


Figure B-14: Lake Ontario target levels

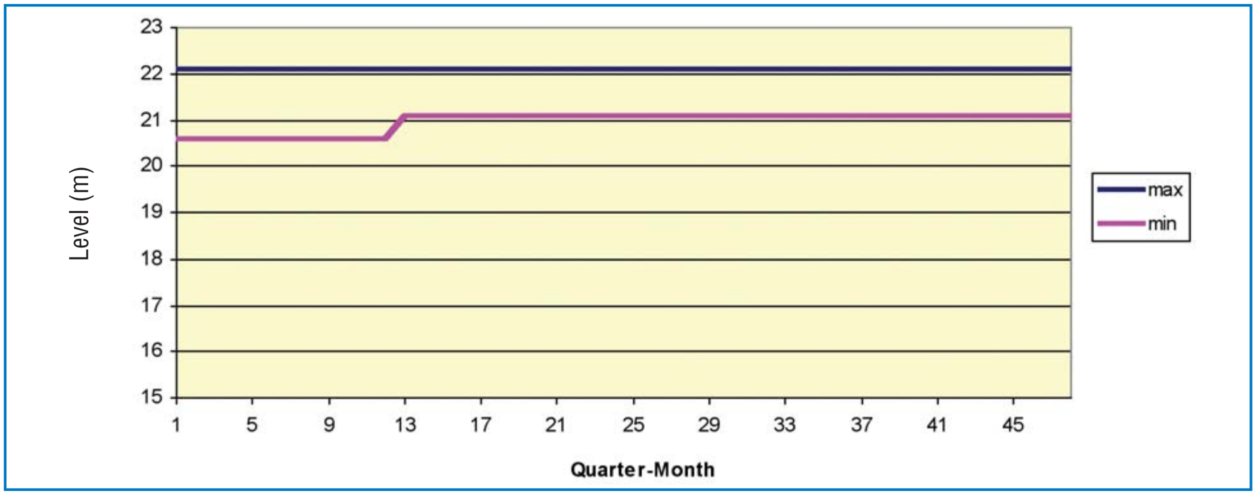


Figure B-15: Lac St. Louis at Pointe Claire target levels

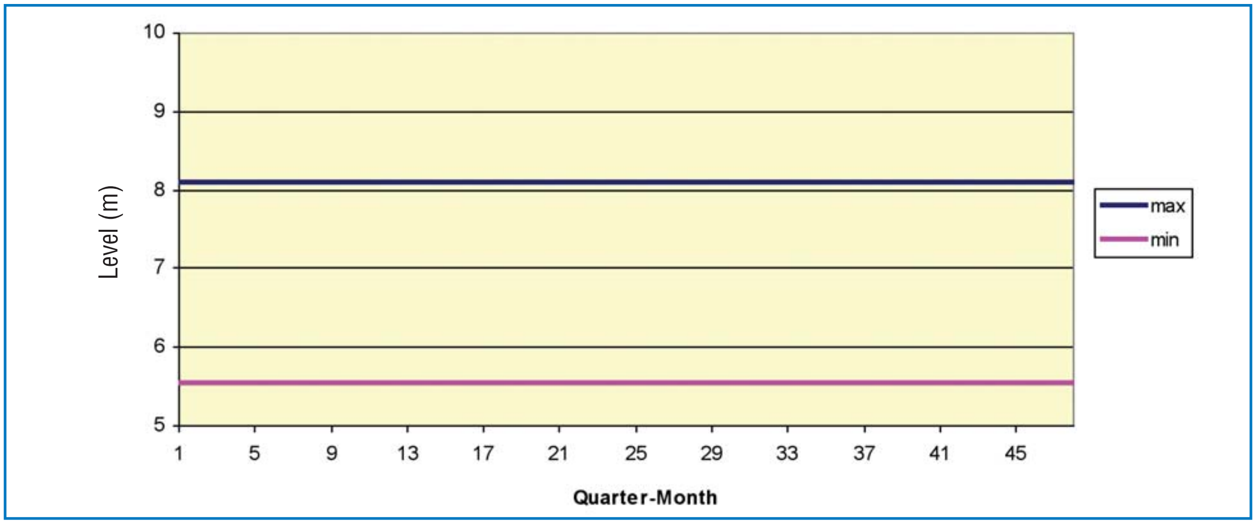


Figure B-16: Montreal Harbour target levels

The target maximum release and target minimum release have been adjusted such that hydropower is produced most efficiently during the summer (high electricity price):

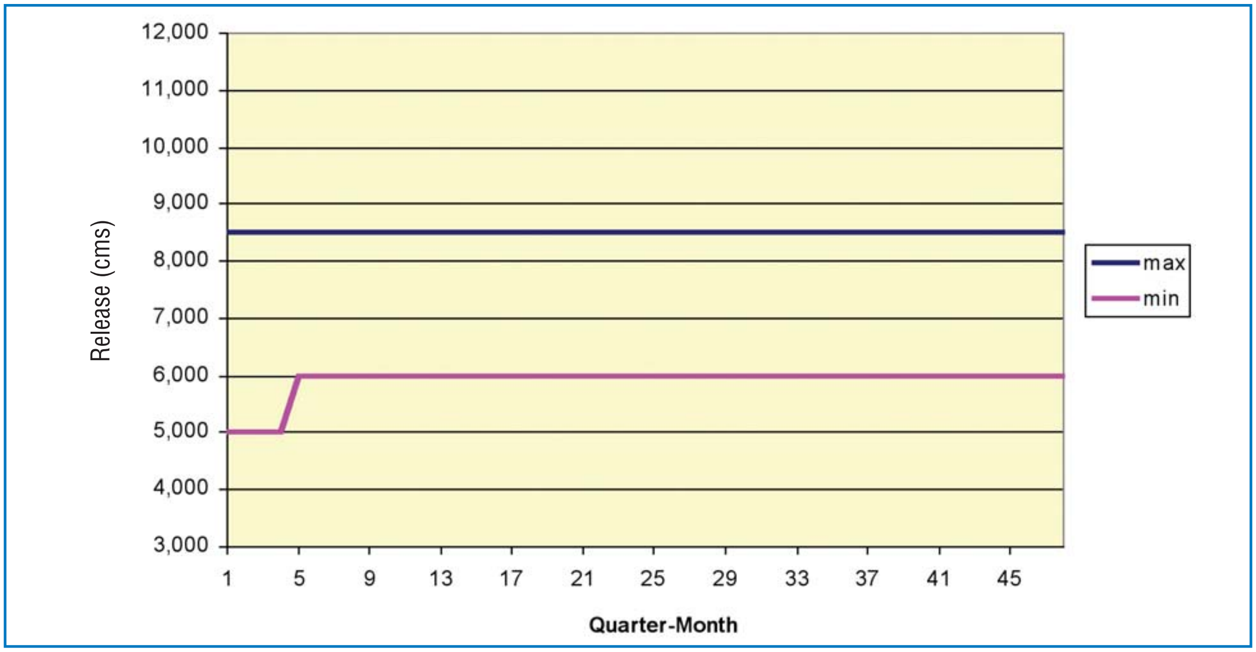


Figure B-17: Hydropower target releases

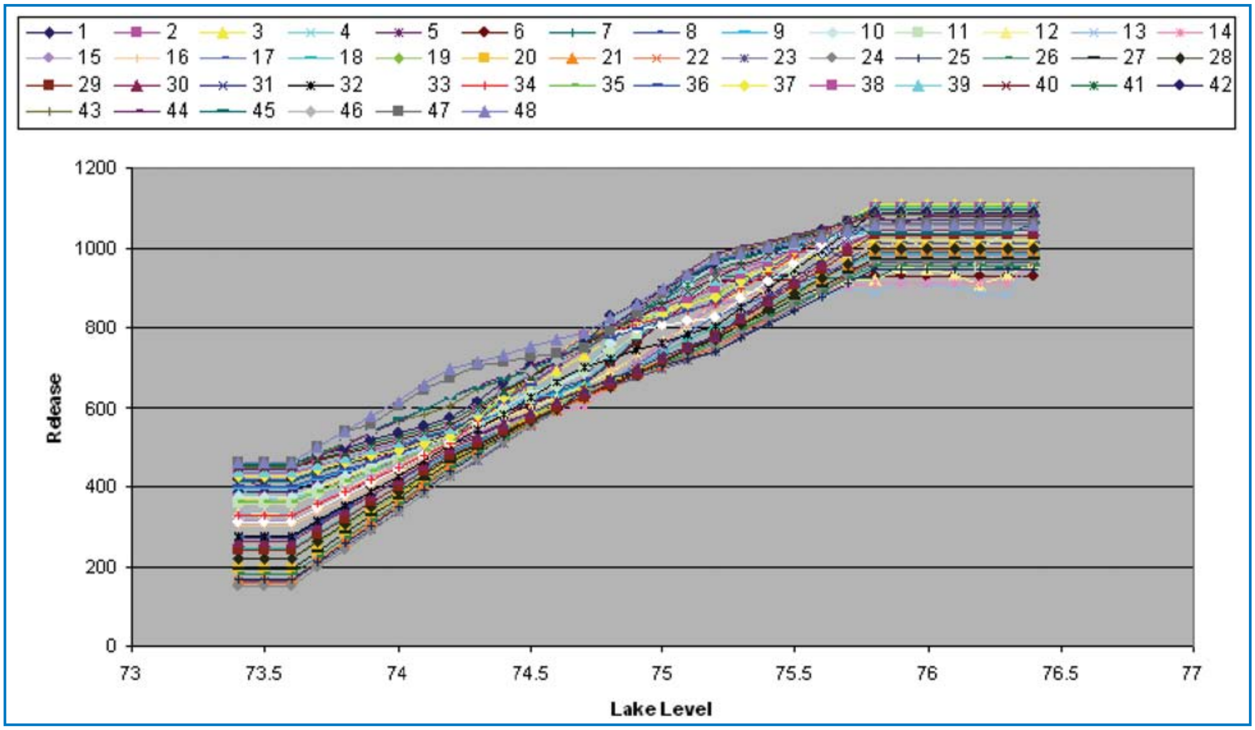


Figure B-18: ***Plan A+ rule curves by quarter-month***

Plan B+: Balanced Environmental Plan

Objectives

Plan B+ strives to return the Lake Ontario-St. Lawrence River System to a more natural hydrologic regime, similar to conditions before lake regulation, while limiting impacts to other interests. The goals of the plan are as follows:

- to maintain more natural seasonal levels and flow hydrographs on the Lake and River;
- to provide stable lake releases;
- to obtain the inter-annual highs and lows required for healthy vegetation habitats;
- to enhance the diversity, productivity, and sustainability of species sensitive to water level fluctuations;
- to minimize lake and river flooding and erosion;
- to minimize impacts to recreational boating.

The plan uses short-term and long-term forecasts of water supplies in conjunction with the pre-project stage-discharge relationship to determine lake releases. Flow limits are applied to ensure minimum river flows, stable river ice development, acceptable navigation conditions, safe operating conditions for control structures, and controlled week-to-week changes in flows. In addition, two rules are included to reduce the risk of flooding on the Lake and River. A framework for a deviation policy is also proposed for use by the Control Board.

Approach

Rule curves

Lake releases are primarily a function of a sliding rule curve, based on the pre-project stage-discharge relationship, that adjusts to long-term supply conditions. Essentially, as water supply forecasts trend above normal, lake releases are increased. As forecasts trend below normal, lake releases are decreased.

For supplies above normal, the lake release is determined as follows:

$$outflow_t = preproject\ release + \left[\frac{F\_NTS - A\_NTS_{avg}}{A\_NTS_{\max} - A\_NTS_{avg}}\right]^{P_1} x(C_1)$$

For supplies below normal, the lake release is determined as follows:

$$outflow_t = preproject\ release - \left[\frac{A\_NTS_{avg} - F\_NTS}{A\_NTS_{avg} - A\_NTS_{\min}}\right]^{P_2} x(C_2)$$

where F_NTS is the forecast annual net total supply, and A_NTS represents the maximum, minimum and average statistics of the annual net total supply forecast. The constants C1 and C2 determine the rate of flow adjustment of the pre-project release. The exponents P1 and P2 serve to accelerate or decelerate the rate of flow adjustment. Calibrated values of C1 and C2 are 2.200 m^3/s (77,700 ft^3/s) and 400 m^3/s (14,100 ft^3/s), respectively. Similarly, the values of P1 and P2 are 0.9 and 1.0, respectively.

Variability of releases from quarter-month to quarter-month is smoothed by taking the average of short-term forecasts of releases t quarter-months into the future, as follows:

$$outflow = \frac{\sum_{t=1}^{t=nforecasts} outlow_t}{nforecasts}$$

This averaging also has the effect of accelerating releases during periods of rising lake levels (spring), and decelerating releases during periods of falling lake levels (fall). Sensitivity analysis and assessment of forecast skill indicates that forecasts four quarter-months into the future are optimal.

The pre-project relationship is that developed by Caldwell and Fay (2002), with the term for differential crustal movement fixed to simulate conditions in the year 2010.

Flow limits

Flow limits, adopted from Plan 1998 with some modifications, are used:

- M limit – minimum flows for power and downstream navigation interests. If the lake level should decline below 74.2 m (243.44 ft), the hydropower limits are waived and minimum flows are determined by downstream river needs.
- L limit – maximum flow limits to maintain adequate levels and velocities for International Section river navigation. The L limit is waived and maximum releases are limited to 11,500 m^3/s (406,200 ft^3/s) if the Lake should rise above 75.7 m (248.36 ft).
- I limit – maximum flows for ice formation and stability or maximum flow estimated to produce a level at Long Sault Dam of 71.8 m (235.56 ft).
- J limit – maximum change in flow from one period to the next unless another limit takes precedence. Flows are permitted to change by 700 m^3/s (24,700 ft^3/s). If the Lake is above 75.2 m (246.72 ft), and no ice is forming, the flow may change by up to 1,420 m^3/s (50,100 ft^3/s).

Other rules

Plan B+ has two additional rules to reduce the risk of flooding upstream and downstream. The first rule strives to lower Lake Ontario to 74.8 m (245.41 ft) by January 1 whenever the Lake Ontario level is above 75 m (246.06 ft) at the beginning of September. This rule reduces the risk of Lake Ontario and St. Lawrence River flooding in the following spring and summer by making storage available for reduced flows during the Ottawa River freshet. It also provides some benefit (relative to Plan E) to the lower river muskrats by reducing winter den flooding. To accommodate recreational boaters through the U.S. Labor Day weekend, this rule also ensures that flows in the first week of September do not exceed those of the last week of August. The second rule determines Lake Ontario releases to limit flooding at Montreal based on the forecast level at Pointe Claire. It is a three-tier rule that attempts to balance upstream and downstream flooding damages. If Lake Ontario is below 75 m (246.06 ft), lake releases are constrained to keep levels at Pointe Claire below the alert level of 22.1 m (72.51 ft). If Lake Ontario is at or above 75 m (246.06 ft), but below 75.2 m (246.72 ft), flows are limited to keep Pointe Claire below the action level of 22.33 m (73.26 ft). Above 75.2 m (246.72 ft), lake releases are limited to keep Pointe Claire below 22.5 m (73.82 ft). This rule uses a 1-quarter-month forecast of Ottawa River and local tributary inflows.

Plan B+ also has two rules to ensure the integrity of control structures. One rule limits flows through the Hydro-Québec Coteau structure to ensure its safe operation. Given a perfect forecast of Lake St. Francis local inflows and the maximum capacity of Beauharnois, Lake Ontario releases are reduced to limit flows through the structure to 2500 m^3/s (88,300 ft^3/s) during ice conditions, and 4,000 m^3/s (141,300 ft^3/s) otherwise. The second rule ensures that flows maintain a level of 75.6 m (248.03 ft) or less at the Iroquois Dam to prevent overtopping and loss of Lake St. Lawrence level control. This rule also assumes perfect knowledge of flow conditions when invoked and supersedes all other constraints.

Application of Plan B+

Assumptions

Plan B+ uses imperfect forecasts of Lake Erie inflows, Lake Ontario net basin supplies, annual net total supplies, and Ottawa River and local tributary flows. Perfect knowledge of ice formation is assumed. The water supply forecasts are based on time-series analysis of the historical data as contained in the “DataWarehouse.xls” file available from the “ijcstudy/pfeg/” ftp site. Overall, the error associated with the statistical forecasts was found to be similar to that of forecasts in use operationally. Because the operational methods generally rely upon hydrometeorological data not available for either the historical time series or the stochastic time series, actual forecasts could not be used.

To partially account for the foreknowledge embedded in the basis of comparison plan, 1958-DD, the “perfect” or “naïve” forecast indicator of the Ottawa freshet is used for the historical scenario. When indicated, perfect forecasts of the Ottawa River and local tributary flows are used in place of statistical forecasts. Statistical forecasts were used exclusively for the stochastic time series simulations.

Procedure

1. 1. For each of the next four quarter-months, forecast the Lake Ontario annual net total supply, the quarter-monthly Lake Erie inflow and Lake Ontario net basin supply, the Ottawa River and local tributary flows to Lac St. Louis, and ice roughness.
2. For each of the next four quarter-months, sequentially route supplies and determine forecasts of lake outflows using the sliding rule curve.
3. Average the next four forecast releases to determine the lake release.
4. If the current time period is within quarter-months 33 to 48, and Lake Ontario was at or above 75 m (246.06 ft) on September 1 (end of quarter-month 32), then increase the basic rule curve by the amount needed to achieve 74.8 m (245.41 ft) by January 1 (end of quarter-month 48), not exceeding quarter-month 32 flows in quarter-month 33.

5. Apply the M, L, I and J limits. If the plan flow is outside the maximum of the minimum limits and the minimum of the maximum limits, the appropriate limit becomes the plan flow.
6. Check to see if the plan release needs to be reduced to limit flows through the Hydro-Québec Coteau control structure for safe operation.
7. If the 1-qm forecast of Pointe Claire indicates the gauge may rise above the target flood stage corresponding to the beginning-of-period Lake Ontario level, reduce flows by the amount necessary to prevent flooding.
8. Check to ensure the level of 75.6 m (248.03 ft) at the Iroquois Dam is not exceeded. Release the flow necessary to maintain 75.6 m (248.03 ft).

Operationalizing Plan B+

Implementation

Making Plan B+ operational requires modifying the plan's computer program from a quarter-monthly to a weekly computational time step. Procedures for operational forecasts for Lake Erie inflow, Lake Ontario net basin supply, and Ottawa River and tributary flows need to be determined and put in place. Because the plan is calibrated to the statistical annual net total supply forecast and is a function of the past 48 quarter-months' supplies, this forecast procedure can be carried forward into the operational plan. The operational plan would need to be tested and coordinated between U.S. and Canadian Regulation Representatives. A trial period before transition to the new plan would be advisable.

Ideally a long-term monitoring plan would be put in place to measure environmental improvements. The monitoring plan would include observation and reporting of start and end dates of species reproductive periods to the Control Board to avoid adverse impacts such as flooding or stranding of nests.

Deviation policy

Because this plan is dependent upon forecasts and has flow limitations, criteria and policies for deviating from the plan need to be developed as guidance for the Control Board. Deviation policies and criteria should be developed for the following circumstances:

- within-week conditions
  - Montreal Harbor navigation needs
  - emergency response
  - hydropower maintenance
- short-term conditions
  - river ice development and management
  - management of lake releases during Ottawa River freshets
  - short-duration, high impact meteorological events (ice storms, tropical storm precipitation, etc.)
  - accommodation of start and end dates of species reproductive periods
  - meeting plan intent of Jan 1 Lake Ontario levels of 74.8 m (245.41 ft)
- long-term conditions
  - extended droughts that exceed requirements for healthy vegetation habitats
  - extended high supplies where recommended plan flows significantly exceed the fixed flow limitations

Development of a deviation policy lends flexibility and responsiveness to the regulation plan while maintaining its long-term objectives of environmental sustainability.

References

Caldwell, R. and Fay, D. (2002) *Lake Ontario Pre-project Outlet Hydraulic Relationship Final Report*. Hydrology & Hydraulics TWG, IJC Lake Ontario-St. Lawrence River Study.

Plan D⁺: Blended Benefits

Objectives

Plan D⁺ is an incremental evolution of a benefit-balancing plan combined with short-term forecasting of contributing water supplies. The intent of this plan is to increase the net economic and environmental benefits of regulation relative to Plan 1958-DD without disproportionate loss to any interest on Lake Ontario, or the upper and lower St. Lawrence River. Emphasis is placed on achieving no significant economic or environmental losses in any sector relative to Plan 1958-D with deviations, while providing overall economic and environmental benefits.

Approach

Benefit balancing considers the major interests in the system from Lake Ontario downstream to Lac St. Pierre, including the following (in no particular order):

- municipal, industrial and domestic water supply;
- ecosystem;
- riparian property;
- recreational boating;
- Seaway navigation (Lake Ontario, and St. Lawrence River from Ogdensburg to Lac St. Louis);
- Ontario Power Generation and New York Power Authority;
- Hydro-Québec;
- Port of Montreal navigation.

Mathematical relationships relating one or more interest preferences to water levels or flows, and a flow-fluctuation relationship, are used seasonally in a quasi-optimization approach to determine Lake Ontario quarter-monthly (or weekly) releases. These relationships are shown in Figures B-19A to B-28. Releases are constrained by ice formation and ice roughness factors and multi-stage minimum and maximum flow limits that vary with the hydrologic supply conditions.

The parameters, target levels and scaling factors of the relationships for the non-environment interests were adjusted iteratively to better serve that interest. In addition, logic was added to Plan D⁺ to cause the target Lake Ontario level to be lower in the growing season for up to two consecutive years if there has not been two consecutive years with peak summertime Lake Ontario levels below 74.7 m (245.08 ft) in the previous 20 years, and if the outflows from Lake Erie were low enough that levels below 74.7 m (245.08 ft) are a good possibility. This addition periodically provides some needed variation to the growing-season Lake Ontario levels for the ecosystem. (This is described in more detail following the Lake Ontario level score curve.)

Short-term (next quarter-month or week) forecasts of Lake Ontario net basin supply, Lake Erie outflow, Ottawa River and local tributary flows to Lac St. Louis, and ice roughness and cover are utilized in the quasi-optimization process to determine system water levels for a range of trial flows. The forecasts are based on time-series models, with the exception of ice roughness and cover, which uses either a “naive” forecast (i.e., assumes the prior quarter-month values for the coming quarter-month) or a 1-quarter-month ahead foreknowledge assumption to reflect operational adjustments within the week.

The September 2005 version of Plan D⁺ incorporates maximum outflow assumptions under ice conditions that are more conservative and more consistent with those used in Plan 1958-DD and Plan 1998 than those used in the earlier benefits plans.

Plan D+ uses the short-term time series forecasts of Lake Ontario net basin supply and Lake Erie outflow and time-series forecasts of Ottawa River and local flows to Lac St. Louis. To allow a fair comparison with Plan 1958-DD simulation results, these plans assume the same one quarter-month ahead foreknowledge (i.e. "perfect" forecast) of Lac St. Louis inflows as 1958-DD during periods in which 1958-DD produces high Lac St. Louis levels. In actual operations, within-week adjustments should be made during these high-level periods, as has been done in the past under Plan 1958-D with deviations.

Compared with earlier versions, Plan D+ includes a small increase in the summer target average Lake Ontario level in order to increase benefits to hydropower, recreational boating and navigation without harming coastal interests. Target levels in the stormier fall, winter and spring seasons were either reduced or not increased relative to those of earlier versions of the benefits plans. The parameters of the relationship that makes use of this target level were also adjusted relative to the earlier generation plans. The scoring relationships for flooding of the lower St. Lawrence River were revised from earlier versions based on the performance indicators developed for the Lake Ontario–St. Lawrence River study.

Steps in the plan

To determine the Lake Ontario release for the coming quarter-month (or week), the following steps are taken:

1. Forecast the water supplies to Lake Ontario, Ottawa River and local flows to Lac St. Louis, the annual net total supplies, and the ice roughness and cover for the coming quarter-month (or week) period.
2. Calculate the smallest trial Lake Ontario release (typically, the present flow minus 400 m^3/s (14,100 ft/s) or the minimum flow limit (this may be lower to assist ice formation or in more extreme level conditions). (See examples.)
3. Using the trial flow, the forecast hydrology, and initial Lake Ontario water level, calculate the trial water levels for Lake Ontario and downstream river levels using known stage-storage and stage-discharge relationships.
4. Calculate the benefit score for each relationship for this trial flow.
5. Sum the individual benefit scores to determine the total score for the trial flow.
6. If the trial flow is less than the maximum flow (typically, the present flow plus 400 m^3/s (14,100 ft/s) or the minimum flow limit (this may be more in extreme level conditions), increase the trial flow by 10 m^3/s (350 ft/s) to obtain the next trial flow and repeat steps 2 through 6.
7. From the set of trial flows and their corresponding individual benefits scores, pick the flow having the highest overall benefit score.

Benefit score curves

The following are the benefit score relationships, or curves, used within Plan D+ to determine the release for the coming period. These curves were initially developed to reflect the relationships between levels or flows and benefits to several of the uses of the system, but some were later modified by trial and error to produce better overall results with respect to the more rigorous performance indicators used in the study evaluation process. Since beneficial water levels for one use often overlap those for another, a separate curve does not exist for each and every use or interest or location.

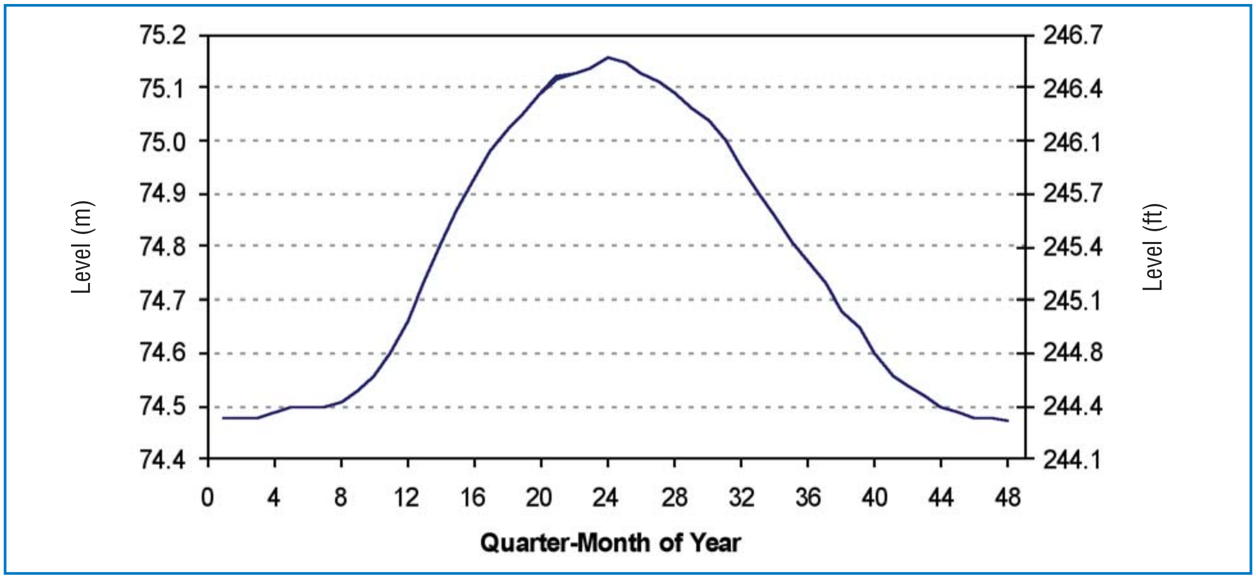


Figure B-19A: Lake Ontario normal target level

The expected level of Lake Ontario in the coming period is estimated by a water balance (i.e., present level + (forecast supply – trial outflow)). This expected level varies depending on the trial outflow. Referring to Figures B-19A and 19B, if the expected Lake Ontario level in the coming period equals the target level in Figure B-19A—or, in the case of a year in which the environmental shift applies, if it equals the target level in Figure B-19A minus the amount of shift—then the Lake Ontario level score is 35. As the expected Lake Ontario level in the coming period deviates from the target level, then the score diminishes as shown in Figure B-19B.

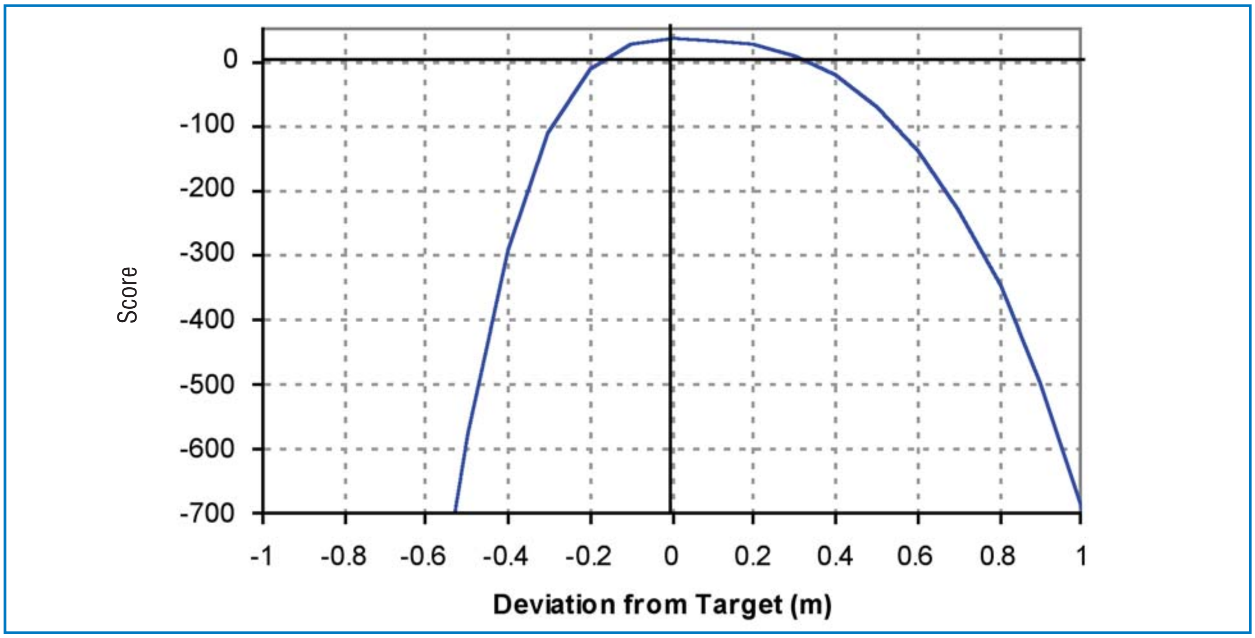


Figure B-19B: Lake Ontario score for deviation from target level

The further away from the target level the poorer the score, with the score for levels below the target decreasing faster than for levels above the target. For example, if the expected level is 0.20 m below the target level, then the Lake Ontario level score is about -12.0. If the expected level is 0.20 m (0.66 ft) above the target level, then the Lake Ontario level score is about 27.0. As can be seen from Figure B-19B, the score decreases exponentially as the expected level deviates further from the target level.

In the development of Plan D+, both the normal target level and the deviation scoring curves were adjusted many times in consideration of several different interests both on the Lake and the River, including the ecosystem, until this final set of curves was achieved.

In order to periodically provide lower Lake Ontario water levels in the growing season, Plan D+ checks how many years it has been since the peak annual Lake Ontario level was below 74.70 m (245.08 ft), which is the peak growing season level that the Environmental Technical Work Group has suggested is needed periodically to maintain adequate wetland habitat diversity. If it has been more than 20 years since the last peak annual Lake Ontario level lower than 74.70 m (245.08 ft), then the plan at the end of February checks whether the Lake Erie outflow (averaged over the past 2 months to smooth out weekly fluctuations due to wind and ice) is in the "right zone" for there to be a good chance that supplies are apt to produce a peak Lake Ontario level less than 74.70 m (245.08 ft) in the coming spring-summer period. If the Lake Erie flows are too high (outside the right zone), then it is unlikely that the Lake Ontario level can be maintained below 74.70 m (245.08 ft) in the growing season, and it makes no sense to try to reduce the level due to the impact on the other objectives. If the Lake Erie flow is too low, then it is likely that the peak Lake Ontario level will be less than 74.70 m (245.08 ft) anyway, and it would be counter-productive to try to drive the level even lower. If it has been more than 20 years since the last annual Lake Ontario peak below 74.70 m (245.08 ft) and the Lake Erie outflow is in the right zone at the end of February, then the plan shifts the Lake Ontario target levels down by 0.35 m (1.15 ft) from March through the end of July, after which the target level is gradually returned to its usual value over the next four months. A gradual, rather than a rapid return to the normal target Lake Ontario level is made in order to avoid causing a large reduction in the release that would result in a sudden drop of levels downstream and a rise in Lake St. Lawrence. The shift is not applied throughout the year since this would exacerbate low levels on the Lake and the lower river late in the year, with no benefit to the environment. At the end of the year, the plan checks whether the peak Lake Ontario level in the growing season was indeed below 74.70 m (245.08 ft); if so, it again checks whether the Lake Erie flows are in the right zone at the end of the following February. If both of these conditions are met, then the second year shift is applied, with Lake Ontario target levels shifted down, this time by 0.20 m (0.66 ft), but again for the same March-July period, and then gradually returned to their usual values over the next four months. This second year of lower peak growing season level is again provided to better meet the stated wetland habitat diversity needs. Whether or not the shift was applied, once the peak annual Lake Ontario level has been lower than the 74.70-m (245.08-ft) level for two years in a row, the year counter is reset and the low shift will not occur again until both the 20-year and the right Erie outflow conditions occur.

To provide better levels for Lake Ontario recreational boating, the scores shown in Figure B-20 are applied from the second quarter-month of April to mid October. Outside this period, a score equal to 6/35 of the Lake-Ontario-deviation-from-target-level score produced using Figures B-19A and B-19B is added.

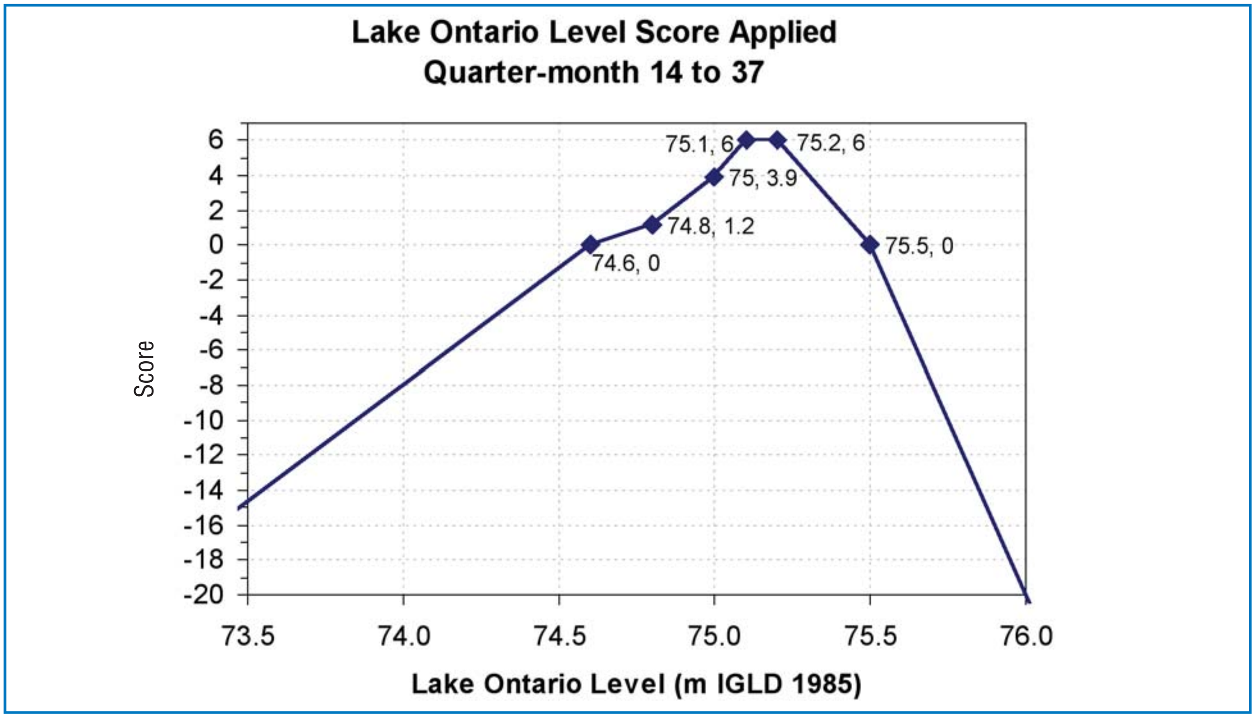


Figure B-20: ***Lake Ontario score added in recreational boating season (2nd quarter-month of April to mid October) (1 metre = 3.28084 ft)***

The benefit score for the Seaway is the least score obtained from a number of relationships for different locations along the Seaway route from Lake Ontario to Lac St. Louis. These scores reflect the levels preferred along the route by ships using the Seaway. During low-level periods at the various locations in the system, this score also attempts to maintain a balance in low level for all uses. Also included in this set are scoring relationships that are based on the gradient between key points on the upper river. The gradients are a measure of the current in the River, and the score is reduced as the gradients become too high for safe navigation. Only the lowest score from the relationships in Figures B-21A to B-21K is included in the optimization. Note that as the plan iterates through the different trial flows, the curve with the lowest scoring relationship may switch from one to another. The scores from these relationships are used during the period when the Seaway operates, which is assumed to be quarter-month 13 through 48 inclusive. Outside this period, a score equal to 3/35 of the Lake-Ontario-deviation-from-target-level score produced using Figures B-19A and B-19B is added. (For purposes of conversion in all subsequent figures, 1 metre = 3.28084 ft and 1 m^3/s = 35.31467 ft^3/s).

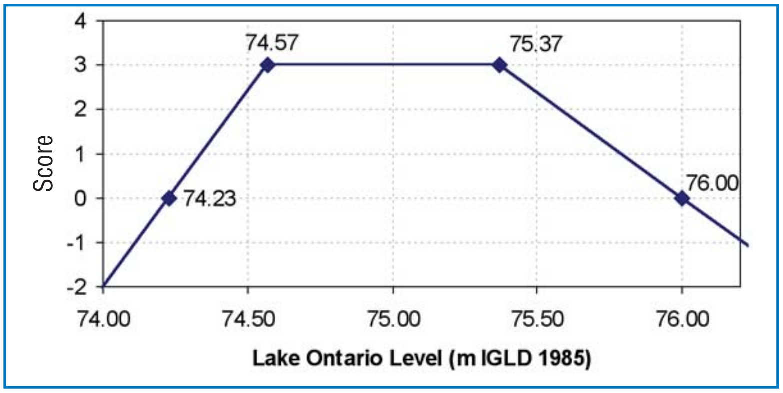


Figure B-21A: ***Lake Ontario level Seaway navigation score***

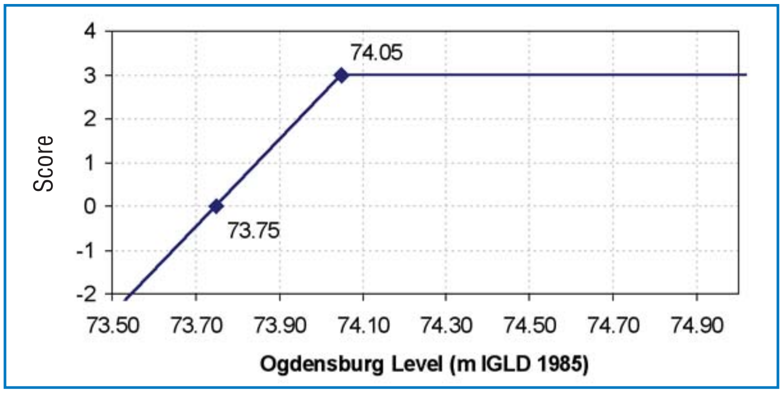


Figure B-21B: Ogdensburg level Seaway navigation score

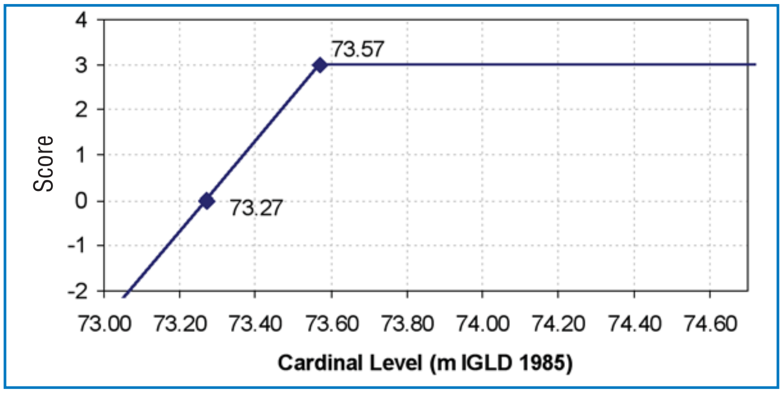


Figure B-21C: Cardinal headwater level Seaway navigation score

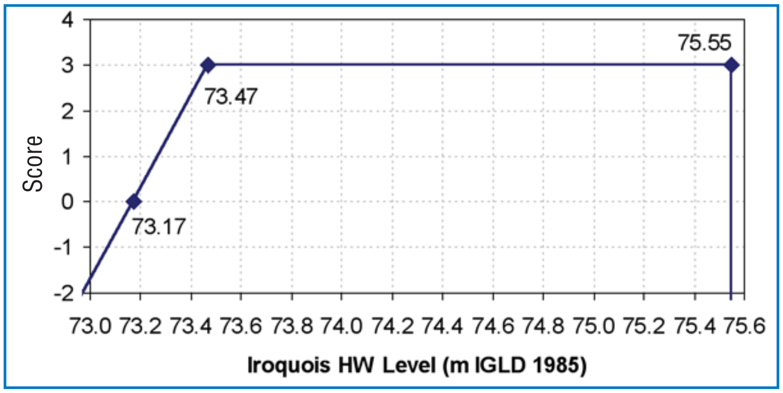


Figure B-21D: Iroquois headwater level Seaway navigation score

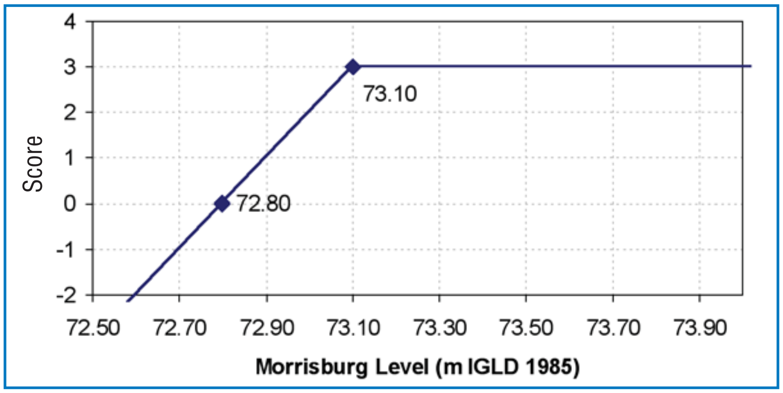


Figure B-21E: Morrisburg level Seaway navigation score

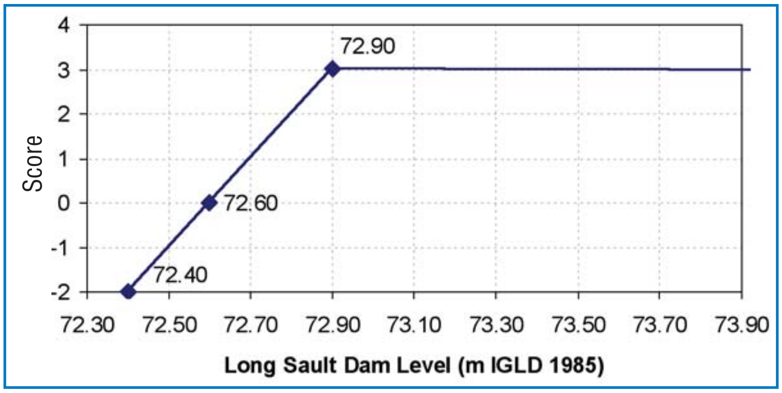


Figure B-21F: Long Sault Dam level Seaway navigation score

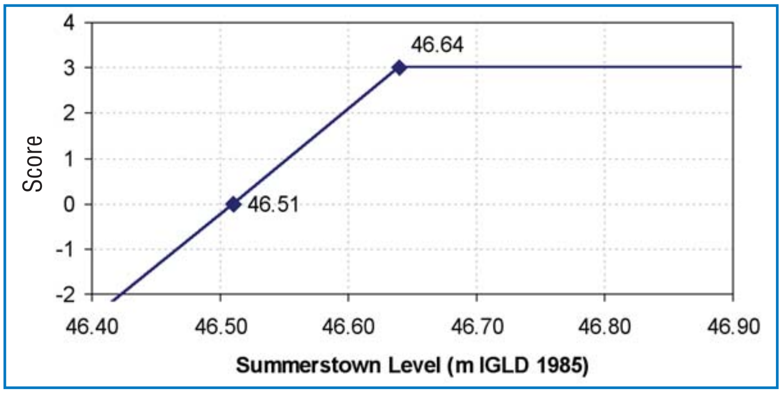


Figure B-21G: Summerstown level Seaway navigation score

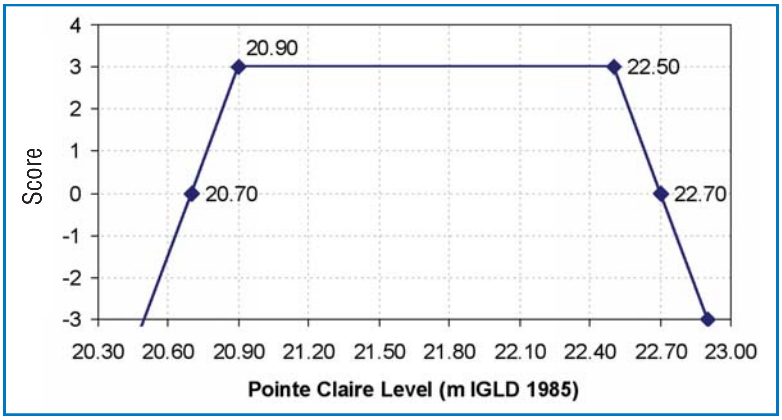


Figure B-21H: Pointe Claire level Seaway navigation score

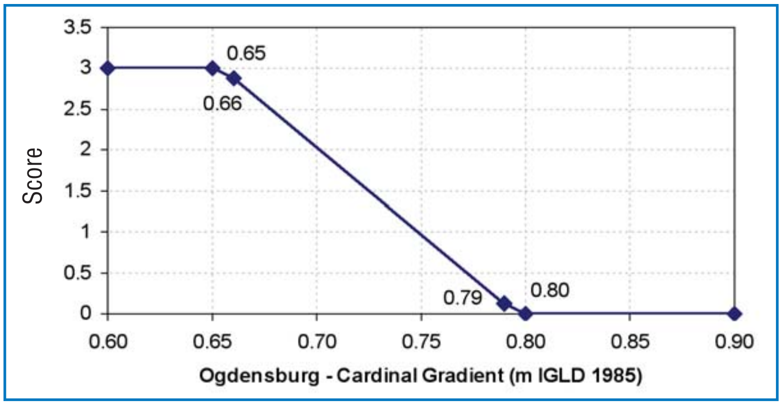


Figure B-21I: Ogdensburg–Cardinal gradient Seaway navigation score

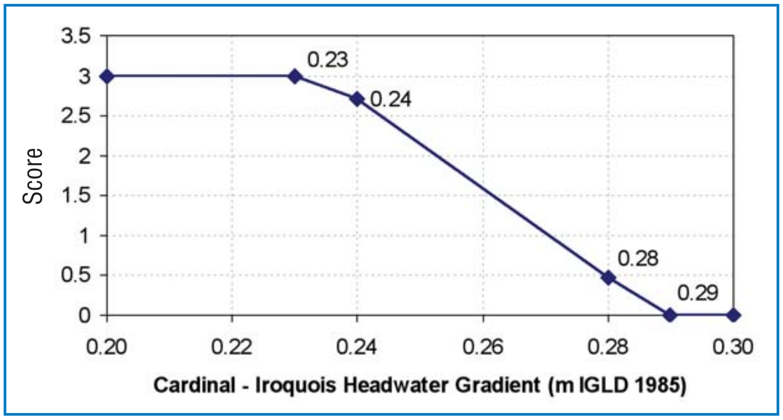


Figure B-21J: Cardinal–Iroquois headwater gradient Seaway navigation score

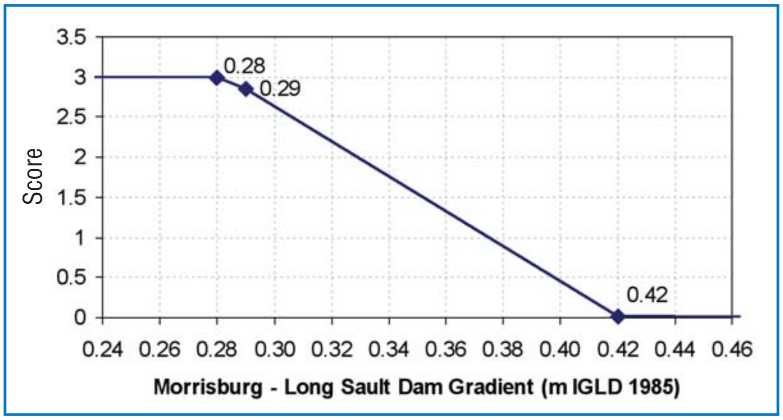


Figure B-21K: Morrisburg–Long Sault Dam gradient Seaway navigation score

Figure B-22 shows the benefit score curve used to limit the severity and frequency of very low levels on Lake St. Lawrence. It uses the expected level at Long Sault Dam to represent the Lake St. Lawrence level. This score has a large range due to the sensitivity of Lake St. Lawrence levels to Lake Ontario outflows and river ice restrictions, and the impact on municipal water supplies of low Lake St. Lawrence levels. The score from this curve is included throughout the year.

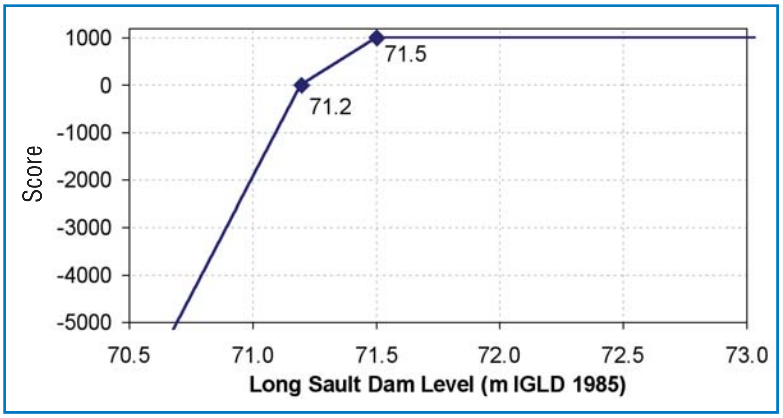


Figure B-22: Score for level at Long Sault Dam

Figure B-23 shows the three benefit score curves for flow that are used with the selected curve, depending on the ice status upstream of the Moses-Saunders Dam. If there is no ice (i.e., open water condition) upstream of the Moses-Saunders Dam, then the score given by the green curve applies. If the ice cover is forming in the international section of the River upstream of the dam, then the score shown in the lighter blue curve applies; this essentially limits the flow to less than 6,230 m^3/s (220,000 ft^3/s) in order to form a smooth, stable ice cover and prevent ice jams on the River. Once the ice cover has formed on the upper river, flows are limited according to the dark blue curve.

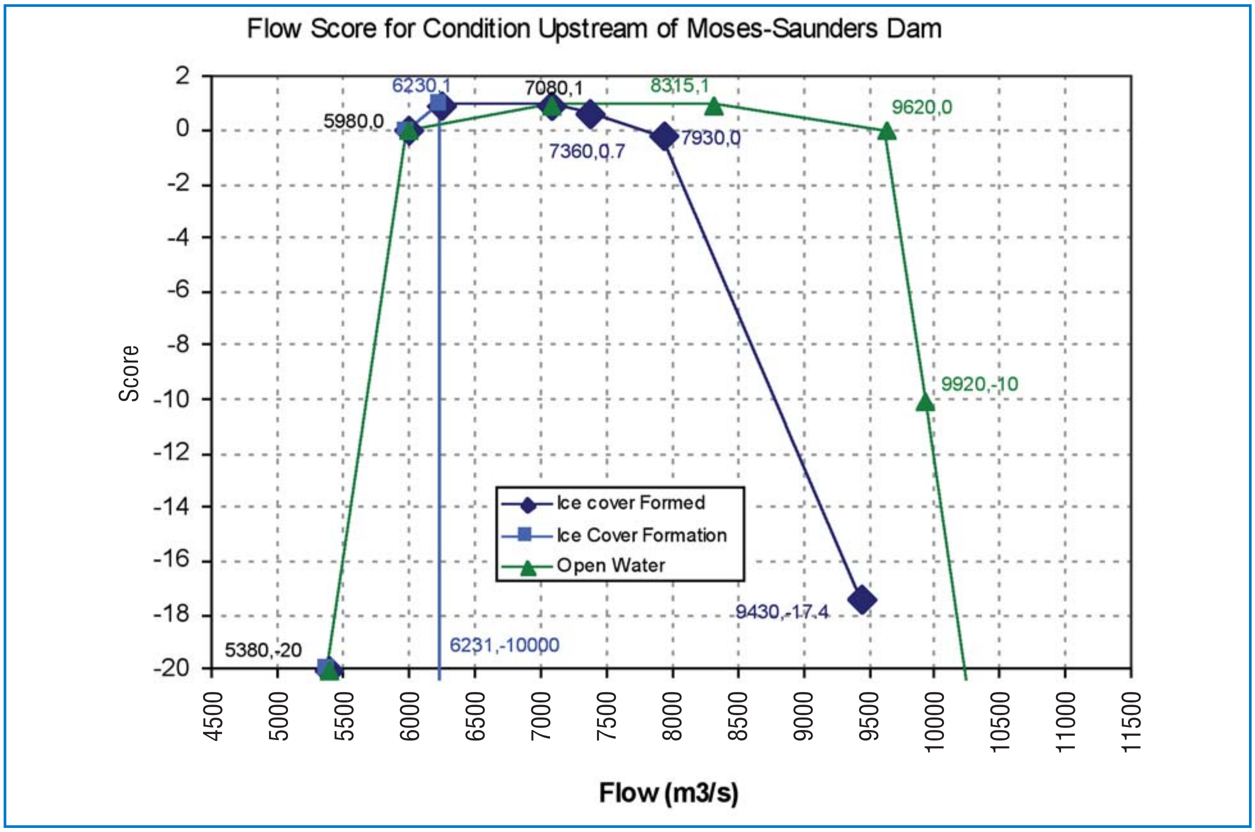


Figure B-23: ***Lake Ontario flow score for different conditions on the St. Lawrence River upstream of Moses-Saunders Dam***

Figures B-24A and B-24B shows the benefit score curves that are used depending on the ice status in the Beauharnois Canal. The flow referred to is the Lake Ontario outflow that is being determined by the plan. If the ice cover is forming on the canal, then the score shown in Figure B-24A applies; this tends to limit the frequency of occurrence of Lake Ontario outflows above 6,100 m^3/s (215,400 ft^3/s) in order to form a smooth, stable ice cover and prevent ice jams on both the Beauharnois Canal and the Coteau channel. Once the ice cover in the Beauharnois Canal has formed, or if there is no ice (i.e., open water condition), then the curve shown in Figure B-24B applies. During the ice break-up period on the lower river, which typically occurs within the two quarter-months after the last ice on the River upstream of Moses-Saunders, the maximum Lake Ontario flows are limited to 9,500 m^3/s (335,500 ft^3/s) and 10,000 m^3/s (353,100 ft^3/s) in the first and second quarter-month after upper river ice disappears, respectively.

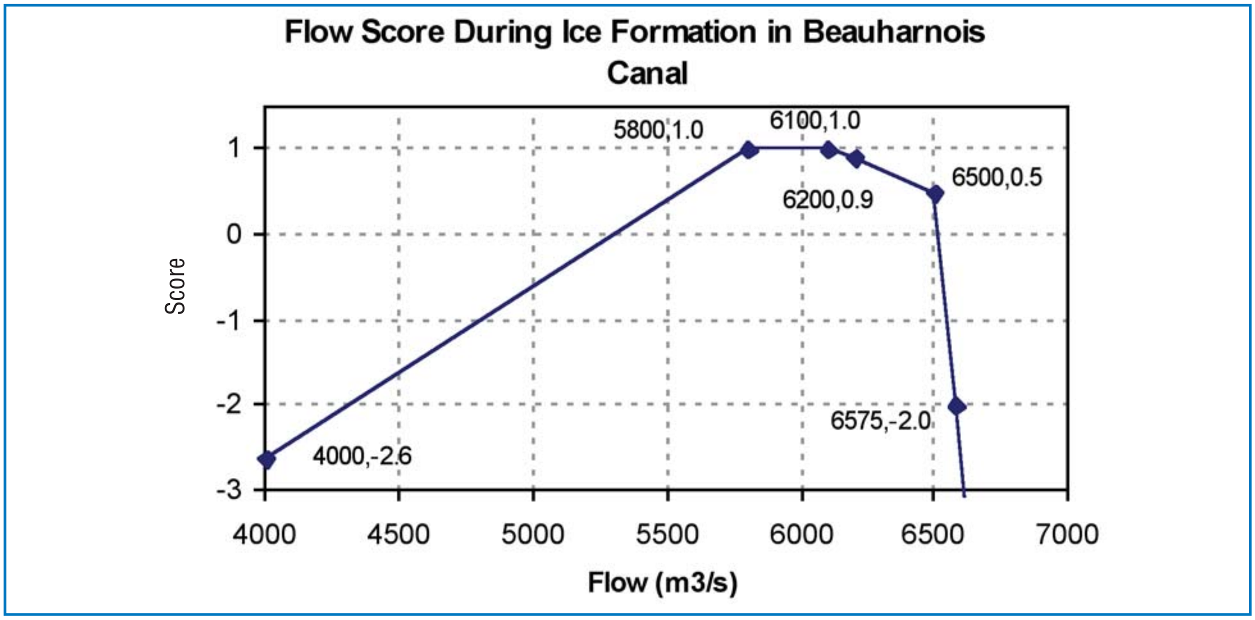


Figure B-24A: Lake Ontario flow score during ice formation on the Beauharnois Canal

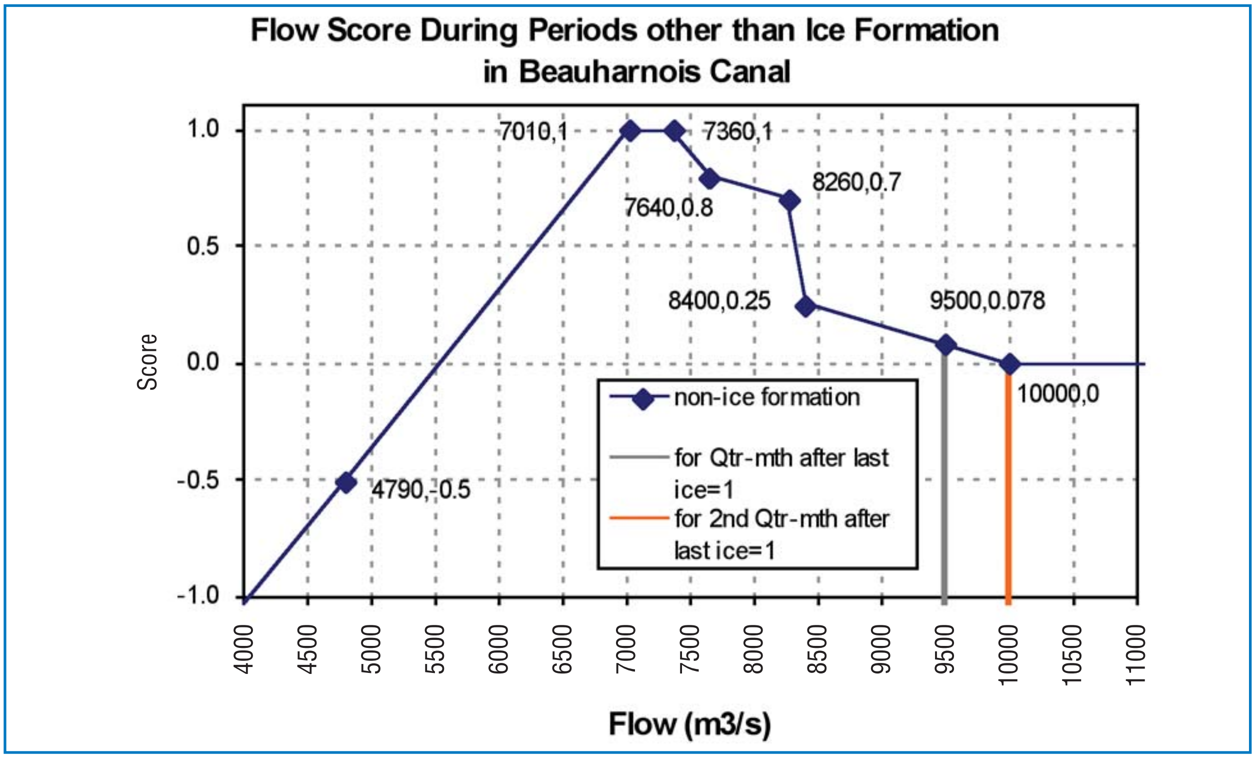


Figure B-24B: Lake Ontario flow score for conditions other than ice formation on the Beauharnois Canal

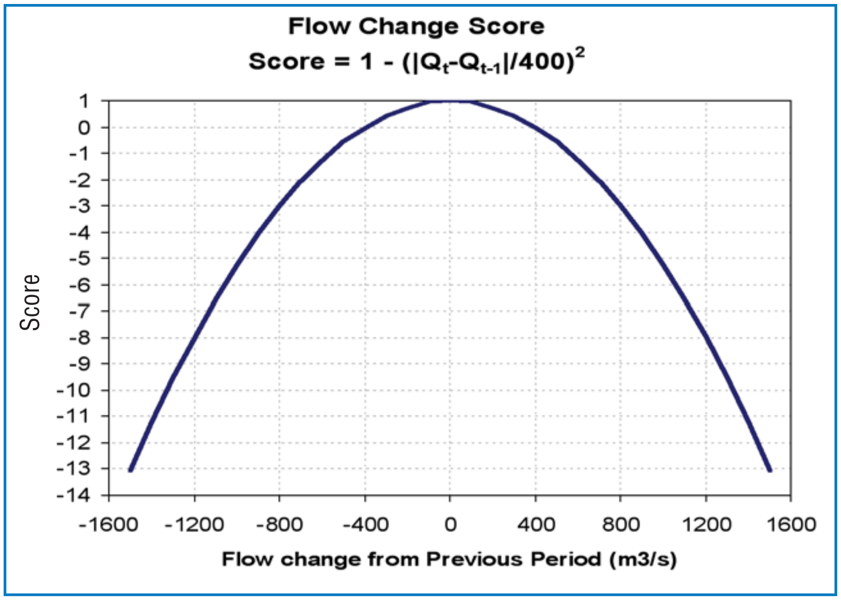


***Figure B-25:* Score based on the change in flow from one period to the next**

Figure B-25 shows the score applied to the change in flow from one period to the next. If the trial flow is the same as the previous period's flow, then the score is 1. As the absolute difference from the previous flow increases, the score is reduced according to the relationship shown in the figure. This tends to reduce the flow change from period to period. The score is included throughout the year, with the following exceptions: if it is a period of ice formation, if the level at Pointe Claire is above 21.9 m (71.85 ft), or if the projected Lake Ontario level is more than 0.25 m (0.82 ft) above the target Lake Ontario level.

Four benefit scores curves are included that are based on the expected level in the coming period at Pointe Claire, given the trial flow. The score from one of the three curves, as shown in Figure B-26, is applied depending on the time of year. These curves reflect different seasonal benefits from the Lac St. Louis levels. In addition, during the mid-April to mid-October period, the score shown in Figure B-27 is also included.

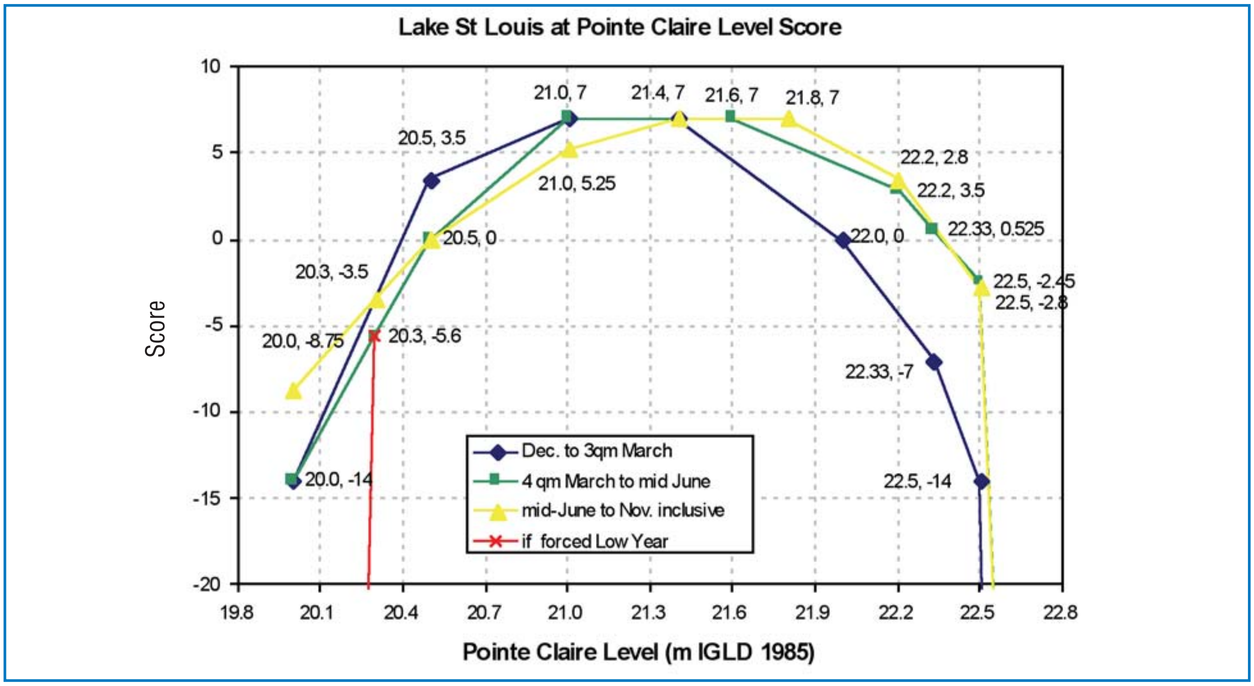


***Figure B-26:* Lac St. Louis at Pointe Claire level score**

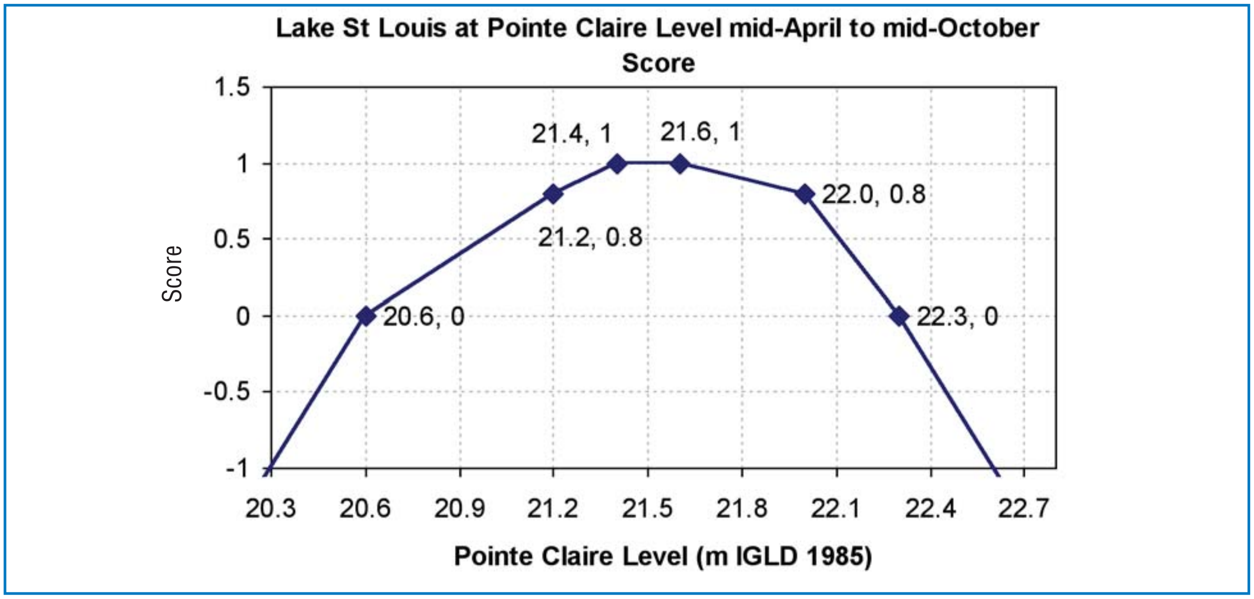


Figure B-27: ***Lac St. Louis at Pointe Claire level score***

A score based on the expected level of the St. Lawrence River at Montreal, as shown in Figure B-28, is also included. This curve applies throughout the year and tends to limit the frequency of occurrence of levels above 8.7 m (28.54 ft) or below 5.56 m (18.24 ft) at Montreal (Jetty 1 gauge).

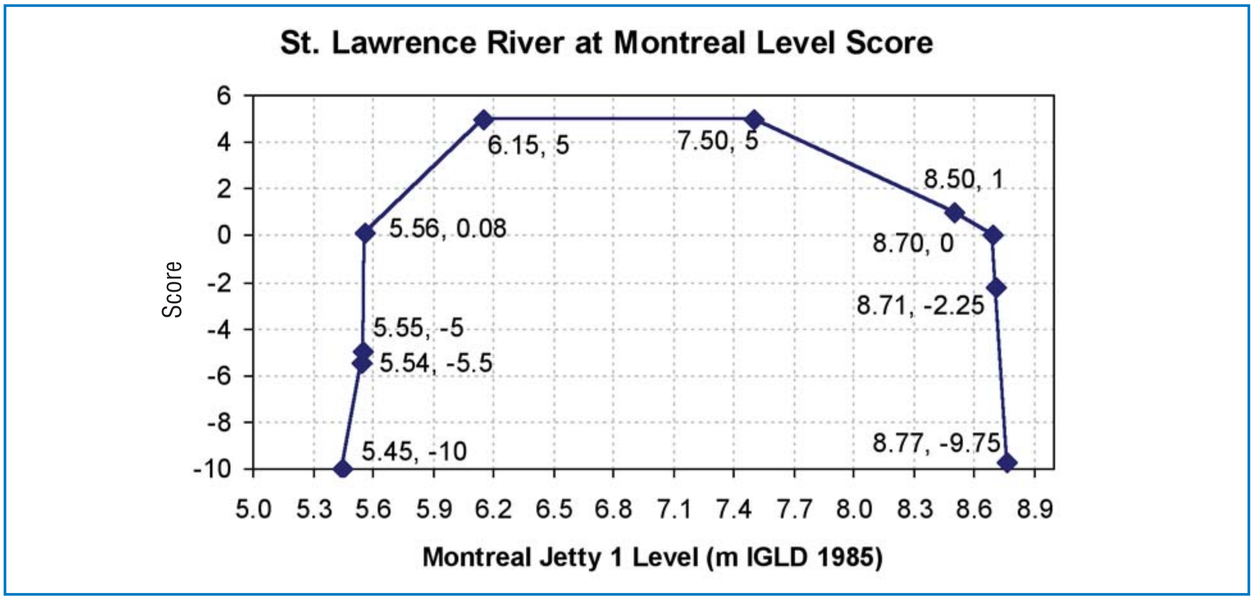


Figure B-28: ***St. Lawrence River at Montreal score***

Flow Constraints

In addition to the tendency of the above-described curves (especially those in Figures B-23 to B-25) to limit the Lake Ontario outflows, a number of further constraints are imposed on the flows.

The absolute maximum outflow is limited to no more than 9,910 m^3/s (350,000 ft^3/s) if the Lake Ontario level is less than 0.78 m (2.56 ft) above the target level. If the Lake Ontario level is more than 0.78 m (2.56 ft) above the target, then the maximum outflow averaged over the period is allowed to be as high as 10,700 m^3/s (377,900 ft^3/s) for periods from quarter-month 13 to 47 inclusive, and 11,500 m^3/s (406,100 ft^3/s) for periods outside this range. These flow limits were based on experience in the 1990s with high flows and Seaway navigation operation. The maximum Lake Ontario outflow at which the Seaway has maintained operation has been 9,910 m^3/s (350,000 ft^3/s). Under very high Lake Ontario levels in the past, the Seaway has operated on alternate days, when the flow was reduced to 9,910 m^3/s (350,000 ft^3/s), with the other day having higher flows. The figure of 10,700 m^3/s (377,900 ft^3/s) approximates half the weekly period at an outflow of 9,910 m^3/s (350,000 ft^3/s) and the other half at an outflow of 11,500 m^3/s (406,100 ft^3/s). A flow of 11,500 m^3/s (406,100 ft^3/s) is considered the maximum practical outflow from Lake Ontario, with the downstream Lake St. Francis outlet control structures operating at capacity.

The minimum outflow limits in Plan D^+ are as shown in Figure B-29 if the Lake Ontario level is not more than 0.48 m (1.57 ft) below the target level. However, if the Lake Ontario level is more than 0.48 m (1.57 ft) below the target level, then the minimum flow limit is reduced by the following amount in m^3/s:

$$1300 \times (\text{deviation} - 0.48)/0.18$$

where, deviation is the amount, in metres, below the target Lake Ontario level. For example, if the Lake Ontario level is 0.57 m (1.87 ft) below the target level for the particular period, then the minimum flow for that period will be 650 m^3/s (23,000 ft^3/s) less than the value given for that period in Figure B-29.

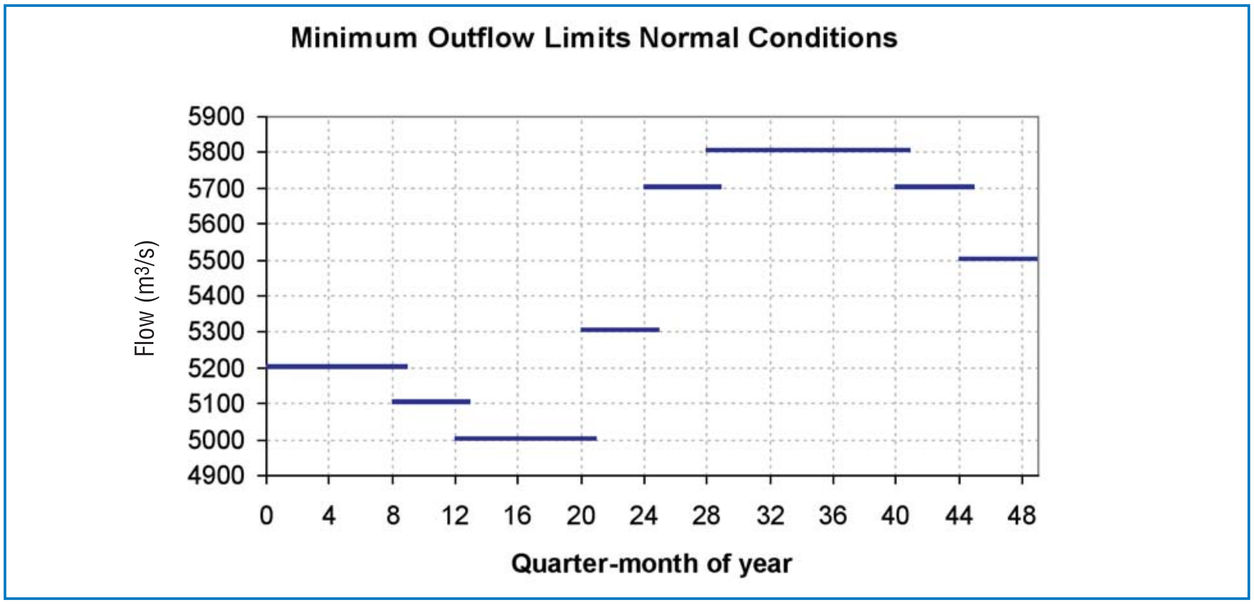


Figure B-29.: Minimum Lake Ontario outflow limits for normal conditions

Examples

Example 1: Calculating the flow for the second quarter-month of 1947.

The Lake Ontario outflow in the first quarter-month of 1947 is 6,480 m^3/s (228,800 ft^3/s) and the level at end of the first quarter-month is 74.39 m (244.06 ft). The forecast net total supply (NTS) for the second quarter-month is 6,824 m^3/s (241,000 ft^3/s), and the ice cover is considered to be formed in the Beauharnois Canal and upstream of the Moses-Saunders Dam. The Lake Ontario target level for quarter-month two is 74.48 m (244.36 ft).

For the second quarter-month, the lowest trial flow is 6,080 (= 6480 - 400) m^3/s (214,700 ft^3/s). For this trial Lake Ontario flow of 6,080 m^3/s (214,700 ft^3/s), the beginning-of-quarter-month Lake Ontario level of 74.39 m (244.06 ft), forecast NTS of 6,824 m^3/s (241,000 ft^3/s), the program calculates the trial Lake Ontario end-of-quarter-month level for qm two (74.39 + (6,824 - 6,080)/29,700 = 74.42 m)(244.16 ft), the downstream water levels using forecast tributary flows and roughness, and each benefit score. For the first trial flow of 6,080 m^3/s (214,700 ft^3/s), the individual benefit scores are as follows:

Lake Ontario Score for Deviation from Target Level:	32.98
Lake Ontario Score added in Recreational Boating Season:	5.65
Seaway Navigation Score:	2.83
Flow Score for River Upstream of Moses-Saunders Dam:	0.40
Flow Change Score:	0.00
Lac St. Louis at Pointe Claire Level Score:	6.22
Lake St Lawrence Level Score:	1,000.00
Lake Ontario Flow Score for Conditions on the Beauharnois Canal:	0.37
St. Lawrence River at Montreal Score:	0.90
Lac St. Louis at Pointe Claire Level Score Add Boating Season:	0.00

The total score for this trial flow of 6,080 m^3/s (214,700 ft^3/s) is the sum of individual scores, or 1,049.35.

Plan D^+ then checks to see whether the trial flow is greater than high end of the trial flow range, which in this case is 6,880 (= 6.480 + 400) m^3/s (243,000 ft^3/s). If it is not, the flow is incremented by 10 m^3/s (350 ft^3/s), which makes the next trial flow in this case 6090 (6080 + 10) m^3/s (215,050 ft^3/s). The plan repeats the above-mentioned calculations, and obtains the individual scores for this trial flow of 6,090 m^3/s (215,050 ft^3/s) for the 2nd quarter-month of 1947:

Lake Ontario Score for Deviation from Target Level:	32.95
Lake Ontario Score added in Recreational Boating Season:	5.65
Seaway Navigation Score:	2.82
Flow Score for River Upstream of Moses-Saunders Dam:	0.44
Flow Change Score:	0.00
Lac St. Louis at Pointe Claire Level Score:	6.24
Lake St Lawrence Level Score:	1,000.00
Lake Ontario Flow Score for Conditions on the Beauharnois Canal:	0.38
St. Lawrence River at Montreal Score:	0.94
Lac St. Louis at Pointe Claire Level Score Add Boating Season:	0.00

The total score for this trial flow of 6090 m^3/s (215,050 ft^3/s) is 1,049.42.

This procedure is repeated until the trial flow equals 6,880 (6,480 + 400) m^3/s (243,000 ft^3/s). The plan then checks which trial flow (from 6,080 to 6,880 m^3/s or roughly 214,700 to 243,000 ft^3/s) results in the highest total score. The trial flow with the highest score is 6,410 m^3/s (226,400 ft^3/s) with a total score of 1,050.83. The forecast Lake Ontario level with this score is 74.40 m (244.09 ft). The individual scores for a flow of 6,410 m^3/s (226,400 ft^3/s) in this case are:

Lake Ontario Score for Deviation from Target Level:	31.86
Lake Ontario Score added in Recreational Boating Season:	5.46
Seaway Navigation Score:	2.73
Flow Score for River Upstream of Moses-Saunders Dam:	1.00
Flow Change Score:	0.00
Lac St. Louis at Pointe Claire Level Score:	7.00
Lake St Lawrence Level Score:	1,000.00
Lake Ontario Flow Score for Conditions on the Beauharnois Canal:	0.59
St. Lawrence River at Montreal Score:	2.19
Lac St. Louis at Pointe Claire Level Score Add Boating Season:	0.00

For the second quarter-month of 1947, the Lake Ontario flow is 6,410 m^3/s (226,400 ft^3/s).

Under certain conditions, such as the transition from open water to ice formation conditions, the lowest trial flow is permitted to be as much as 6,000 m^3/s (212,000 ft^3/s) lower than the previous quarter-month flow (rather than only 400 m^3/s (14,100 ft^3/s) lower) to allow the flow to be reduced for ice formation. If the levels in the lower river are high (above 22.0 m (72.18 ft) at Pointe Claire), the highest trial flow can be as much as 1,500 m^3/s (53,000 ft^3/s) higher than the previous quarter-month flow (rather than only 400 m^3/s or 14,100 ft^3/s higher) to allow the flow to rebound after being reduced for the Ottawa River freshet. The following example explains this situation.

Example 2: Calculating the flow for quarter-month 19 of 1947.

The Lake Ontario outflow in the 18th quarter-month of 1947 is 7,080 m^3/s (250,000 ft^3/s) and the level at end of the 18th quarter-month is 75.27 m (246.95 ft). The forecast net total supply (NTS) for quarter-month 19 is 8,533 m^3/s (301,300 ft^3/s) and open water conditions exist in the Beauharnois Canal and upstream of the Moses-Saunders Dam. The Lac St. Louis level at quarter-month 18 is 22.06 m (72.38 ft). The Lake Ontario target level for quarter-month 19 is 75.05 m (246.23 ft).

Since the previous Lac St. Louis level was over 22 meters (72.18 ft), for quarter-month 19 the plan determines the initial trial flow to be 5,000 m^3/s (176,600 ft^3/s). This is the maximum of the previous flow minus 3,500 m^3/s (7,080 - 3,500 = 3,580 m^3/s or 126,400 ft^3/s) and the minimum flow constraint for quarter-month 19, which is 5,000 m^3/s (176,600 ft^3/s), as shown in Figure B-29. The high end of the trial flow range is determined to be 8,580 (= 7,080 + 1,500) m^3/s (303,000 ft^3/s).

The scores for the trial flows from 5,000 m^3/s to 8,580 m^3/s (176,600 to 303,000 ft^3/s) in increments of 10 m^3/s (350 ft^3/s) for quarter-month 19 are determined. The highest total score occurs for the trial flow of 7,660 m^3/s (270,500 ft^3/s). The total score for this flow is 1,033.32, with the individual scores shown below.

Lake Ontario Score for Deviation from Target Level:	20.30
Lake Ontario Score added in Recreational Boating Season:	4.01
Seaway Navigation Score:	3.00
Flow Score for River Upstream of Moses-Saunders Dam:	1.03
Flow Change Score:	0.00
Lac St. Louis at Pointe Claire Level Score:	2.80
Lake St Lawrence Level Score:	1,000.00
Lake Ontario Flow Score for Conditions on the Beauharnois Canal:	0.80
St. Lawrence River at Montreal Score:	1.11
Lac St. Louis at Pointe Claire Level Score Add Boating Season:	0.27

Operationalizing Plan D+

Implementation

The computer program for Plan D+ can easily be converted from a quarter-monthly to a weekly operational time step. Procedures for operational forecasts for Lake Erie inflow, Lake Ontario net basin supply, and Ottawa River and tributary flows need to be determined and put in place. Because the plan is calibrated to the statistical annual net total supply forecast and is a function of the past 48 quarter-months' supplies, this forecast procedure can be carried forward into the operational plan. The operational plan would need to be tested and coordinated between the U.S. and Canadian Regulation Representatives. A trial period before transition to the new plan would be advisable.

Within-week flow adjustments

As in the case of all the candidate plans, this plan is dependent upon forecasts and minimum and maximum flow limitations. It has been recognized by the Study Board that, in some circumstances, adjustments will need to be made within the week due to the difficulty of accurately forecasting changing ice conditions and Ottawa River and downstream tributary flows. These adjustments are to be made consistent with the intent of the plan. For Plan D+, explicit relationships can be developed from the results of the 50,000-year stochastic simulation to guide these within-week adjustments.

Reference and Interest Specific Regulation Plan Descriptions

Plan E – Natural Flow Plan
Plan 1958-D
Plan 1998
OntRip3
RecBoat

Plan E – Natural Flow Plan

Background

Plan E attempts to replicate pre-project or natural flow conditions as closely as possible. It was developed on the basis of pre-project releases. Prior to regulation, Lake Ontario outflows were limited by the hydraulic capacity of the St. Lawrence River channel. Rock sills at the head of the Galop Rapids (in the vicinity of Galop and Adam Islands) formed the natural constraint. Originally, these two islands divided the rapids into three channels: the Canadian Galop Rapids, the Gut, and the American Galop Rapids. This section was modified to facilitate navigation in the late 19th and early 20th centuries by dredging (of the Canadian Galop Rapids) and construction of a submerged weir (Gut Dam). This weir had been removed by January of 1953. In its Orders of Approval for the Regulation of Lake Ontario, the International Joint Commission (IJC) defined the pre-project outlet conditions as those existing between 1953 and 1955, after the removal of the Gut Dam, but prior to the beginning of the St. Lawrence hydropower project. These conditions create a state hydraulically similar to the natural state of the channel prior to 1900 (ILOBOE, 1958).

In its natural state, the river fell approximately 1.5 m in 1.6 km (5 ft in 1 mi) within the Galop Rapids (CCGLBHHD, 1958). From Lake Ontario to the head of the Galop Rapids, the fall was 0.6 m (2 ft) over a distance of 112 km (70 mi). Below the rapids, the River fell 4 m (13 ft) over the next 16 km (10 mi) to the head of Rapide Plat (rapids that formerly existed adjacent to Ogden Island). The channel constriction at the Galop Rapids was sufficient to create a backwater effect, and flow at these rapids reached speeds in excess of what is (hydraulically) defined as "critical velocity." In other words, water levels upstream of the rapids were independent of levels and flows below the rapids. Hence, a stage-discharge relationship could be defined that was dependent only upon upstream level conditions.

Such a stage-discharge relationship was developed for the International St. Lawrence River Board of Control (ISLRBC) in the 1950s to estimate pre-project outflows and was reviewed and redeveloped by Caldwell and Fay in 2002. Determination of pre-project flows in the winter must take into consideration flow retardation due to ice conditions. Ice retards (i.e., reduces) the outflow in the St. Lawrence River and generally results in a temporary increase in water levels upstream of the ice formation. The stage-discharge relationship includes terms to account for ice retardation effects upstream of the Galop Rapids. Because the land and channel bottom at Galop were slowly rising relative to the land and lake bottom of Lake Ontario, under natural unregulated conditions the water level of Lake Ontario was gradually rising over time (all else being equal). A term is included in the pre-project stage-discharge equation to account for this gradual rise in the elevation at Galop relative to the Lake Ontario level.

Since pre-project outflows may be estimated using a stage-discharge relationship, the effects on lake levels can be obtained and used in determining pre-project levels. The Lake Ontario outflow and level regime that would exist under unregulated conditions can be simulated by the use of this pre-project stage-discharge equation.

Plan E

The release for this plan is calculated according to the pre-project Lake Ontario stage-discharge relationship developed by Caldwell and Fay (2002). The term that accounts for differential crustal movement in the equation has been fixed to simulate conditions as they would be in the year 2010. The historical pre-project winter ice retardation effects are included in the determination of the pre-project flow.

As with all regulation plans, Plan E would function with the modern channel and structures in place in the international section of the River. During winter ice formation, the plan invokes rules to limit the maximum release in the winter in order to form and maintain a stable ice cover on the River and prevent ice jams. These ice limits are similar to those established for Plan 1998 and identified in the plan formulation guidelines (Fay, 2005) and used for the candidate plans. The ice limits as specified are flexible and respond to the state of ice conditions in the River. The ice limits apply whenever an ice cover is forming or has established in the Beauharnois Canal and/or the international section of the River. An ice status indicator is used to determine if the ice limits apply for the period. The ice limit maximum outflow is 6,230 m^3/s (220,000 ft^3/s) if an ice cover is forming in the period in the Beauharnois Canal and/or the international section of the River. Once the ice cover has formed, then the ice limit maximum outflow is the flow estimated to produce a level at Long Sault Dam of 71.8 meters (235.57 ft^3/s). In addition, to prevent large flow changes from breaking up the ice cover and potentially causing an ice jam, a week-to-week flow fluctuation limit is imposed if there is an ice cover on the River. Plan E also has an overall maximum outflow limit of 11,500 m^3/s (406,000 ft^3/s) that applies at all times to protect the integrity of the control structures at Beauharnois and Coteau.

This plan assumes a perfect forecast of the coming quarter-month's supply to Lake Ontario, but does not use any forecast of inflows to Lac St. Louis.

References:

Caldwell, R. and Fay, D. (2002) *Lake Ontario Pre-project Outlet Hydraulic Relationship Final Report*. Hydrology & Hydraulics TWG, IJC Lake Ontario-St. Lawrence River Study.

Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (CCGLBHHD). December 1958. Lake Ontario Outflows 1860-1954.

International Lake Ontario Board of Engineers (ILOBE). October 1958. Effects on Lake Ontario Water Levels of the Gut Dam and Channel Changes in the Galop Rapids Reach of the St. Lawrence River.

Plan 1958-D

Regulation of Lake Ontario outflows began in April 1960. The first plan used to regulate outflows was titled Plan 1958-A (ISLRBC, 1958). Shortcomings of Plan 1958-A in terms of meeting the low-flow requirements of downstream navigation in 1960 led to the development of Plan 1958-C (ISLRBC, 1961), which was put into operation in January 1962. Further study in 1962 and 1963 led to a revision of that plan with the stated objective of improving water levels in Montreal Harbor without reducing the minimum winter flows of Plan 1958-C. This study resulted in Plan 1958-D, which is fully described in the report *Regulation of Lake Ontario: Plan 1958-D* (ISLRBC, 1963) by the International St. Lawrence River Board of Control. Plan 1958-D went into operation in October of 1963.

Plan 1958-D provides a method of calculating Lake Ontario outflows for each quarter-monthly or weekly period. The rules determine a release based on Lake Ontario levels, recent supplies to the Lake, water supplies entering the River between the regulation dam and Lac St. Louis, and time of year, then reduce or increase that release if it violates one of a set of release limits designed to prevent the worst impacts. The rules are applied in the following order in each quarter-month:

- calculate the total supply to Lake Ontario in the previous period;
- calculate the weighted supply for the previous period;
- calculate the supply indicator for the previous period by subtracting the weighted normal supply from the weighted supply for the period;
- with the supply indicator and the current lake level, one of two sets of rule curves (depending on the season) is used to give basic rule curve flow;
- the seasonal adjustment, computed from the deviation of Lake Ontario level from the plan target, is then added to the basic rule curve flow to give the seasonally adjusted flow;
- flow limits are then applied to ensure the computed outflow is within the following limits:
  - M limit - minimum flows for power and downstream navigation interests;
  - L limit - maximums to maintain adequate levels and velocities for navigation in the international section of the River;
  - I limit - maximum limit for ice formation and for maintenance of adequate levels in the international section of the River, applied in the last two quarters of December;
  - P limit - maximum limit to minimize downstream flooding;
  - P*limit - minimum downstream flow limits for navigation;
  - J limit - maximum change in flow from one period to the next, unless another limit takes precedence.

Many of these limits vary with the time of year, and some vary with the hydrologic conditions within the system. The interaction of the various elements of the plan is important and the structure of a single component of the plan should not be taken out of the context of the plan as a whole.

In general, the least of the maximum limits and the largest of the minimum limits are applied. Occasionally, the largest minimum limit will be larger than the smallest maximum limit, creating a conflict that must be resolved by an additional rule. For example, the calculated M limit for one period may be 5,950 m^3/s (210,000 ft^3/s) and the calculated L limit may be 5,800 m^3/s (205,000 ft^3/s). In effect, these limits demand that the release be at least 5,950 m^3/s (210,000 ft^3/s) but no more than 5,800 m^3/s (205,000 ft^3/s). In such cases, the minimum limit applies.

References

International St. Lawrence River Board of Control (1958) *Regulation of Lake Ontario, Plan 1958-A*, Report to the International Joint Commission, 14 May 1958.

International St. Lawrence River Board of Control (1961) *Regulation of Lake Ontario, Plan 1958-C*, Report to the International Joint Commission, 5 October 1961.

International St. Lawrence River Board of Control (1963) *Regulation of Lake Ontario, Plan 1958-D*, Report to the International Joint Commission, July 1963.

Plan 1998

Plan 1998 is the revised version of Plan 1958-D. In 1998, the International St. Lawrence River Board of Control recommended that it replace Plan 1958-D, but the IJC elected not to accept that recommendation because the evaluation of the plan had not addressed environmental concerns or the needs of recreational boaters. Plan 1998 is a further modification of Plan 35P, which was developed as part of the Levels Reference Study.

Plan 1998 was designed to improve the performance of the regulation plan with reference to the existing IJC Orders of Approval for Lake Ontario regulation and in consideration of the preferences of the interests affected by regulation of the Lake's outflows. The revisions to Plan 1958-D were developed on the basis of information acquired through more than 30 years of experience in the regulation of Lake Ontario outflows under a variety of supply conditions, the results of previous studies, and recent expressions of preferences from the interest groups. These interests include those on Lake Ontario and the St. Lawrence River extending downstream to Lac St. Pierre.

Differences between Plan 1958-D and Plan 1998

1. Plan 1998 is based on a greater range of water supply conditions. Plan 1958-D and its predecessors were all designed to satisfy the criteria specified in the 1956 IJC Orders of Approval as tested using the historical water supplies to Lake Ontario for the period 1860-1954. This was the same supply period used in the design of the hydropower/Seaway project and in the development of the IJC criteria. Subsequent to 1954, water supplies more extreme than those in the 1860-1954 period have occurred, causing conditions to exceed some of the criteria of the Orders of Approval. Plan 1998 was designed on the basis of data for the period from 1900 to 1989. This led to changes in the weighted supply and the supply indicator calculations, the seasonal adjustment and adjustments to the P and P* limits.

2. The M limits of Plan 1998 were developed by modifying those of Plan 1958-D in conjunction with the P* limits based on an examination of the actual flows during periods of low supply since regulation began.

3. The L limits of Plan 1958-D are the set of maximum outflows that were designed in conjunction with channel excavations in the international section of the River to "provide stipulated limiting depths and velocities for navigation and stipulated maximum velocities for formation of an ice cover" (ISLRBC 1963). In Plan 1998, the maximum outflow limits for navigation have been separated from the limits for ice formation. L limits in Plan 1998 refer only to the maximum outflows at which Seaway navigation can continue in the international section during the Seaway operating season. The L limits for navigation of Plan 1998 are the same as those of Plan 1958-D at and below Lake Ontario levels of 75.13 m (246.50 ft). Actual operations during periods in which Lake Ontario levels were above 75.13 m (246.50 ft) have shown that Seaway navigation can continue to operate at flows above the 8,780-m ^{3}/s (310,000-ft^3/s) maximum of the Plan 1958-D L limits. Based on this experience, Plan 1998 L limits extend linearly from 8,780 m^3/s (310,000 ft^3/s) at a Lake Ontario level of 75.13 m (246.50 ft), to 9,910 m^3/s (350,000 ft^3/s) at a Lake Ontario level of 75.44 m (247.50 ft). At Lake Ontario levels above 75.44 m (247.50 ft) the L limit of Plan 1998 specifies a maximum flow of 9,910 m^3/s (350,000 ft^3/s). This high flow was estimated to be the maximum at which navigation of the international section would safely continue. The discharge of such high flows only occurs at high Lake Ontario levels, which is consistent with the direction given in Criterion (k) to operate the system to benefit riparians in times of extreme high supplies.

4. The "I" limits, or ice limits, set maximum outflows for ice conditions in Plan 1998. The "I" limits may also be applied to limit flows under open water conditions outside the Seaway operating season. They replace the "I" limits of Plan 1958-D and the winter L limits of that plan. In Plan 1958-D, the I and L limits that apply during the winter assume that the formation of the ice cover on the St. Lawrence River downstream of Cornwall/Massena always occurs in the last half of December and that ice is forming throughout January in the international section. Plan 1958-D also imposes L limits based on the assumption that an established ice cover always exists throughout February and March. These assumptions are based on the anticipated typical conditions. In reality, the timing of ice cover formation and the duration of the ice-covered period can vary considerably. The I limits of Plan 1998 are flexible and respond to the state of ice conditions in the River. The Plan 1998 I limits apply whenever an ice cover is forming or has established in the Beauharnois Canal and/or the international section of the River. They also apply in open-water conditions prior to the start and after the close of the Seaway navigation season. An ice status indicator and a navigation status indicator are used in Plan 1998 to determine whether the I limits apply for the period. The Plan 1998 I limit maximum outflow is 6,250 m^3/s (220,700 ft^3/s) if an ice cover is forming in either the Beauharnois Canal and/or the international section of the River in the period. If ice cover formation is not occurring (i.e., either ice cover is established or open water conditions exist), then the I limit maximum outflow is the flow estimated to produce a level at Long Sault Dam of 71.8 m (235.56 ft).

References

International St. Lawrence River Board of Control (1963) *Regulation of Lake Ontario, Plan 1958-D*, Report to the International Joint Commission, July 1963.

OntRip3: Plan Designed for Coastal Property Owners

Objectives

Plan OntRip3 is a plan developed specifically to minimize flood and erosion damages to shore property, while also taking into consideration the other interests in the Lake Ontario–St. Lawrence system, to try to attain a riparian-focused plan with overall net benefits. (Although OntRip3 did reduce coastal damages compared to Plan 58-DD, it did not meet the goal of doing so without increased overall losses.)

Approach

The OntRip3 plan is based on the benefits-balancing approach used to develop Plan D^+. It considers the same major interests in the system from Lake Ontario downstream to Lac St. Pierre that are listed in the Plan D^+ description found in this document. The reader is directed to review that description to obtain an understanding of the methodology applied in OntRip3. OntRip3 also uses the same forecast procedures and outflow constraints as Plan D^+. OntRip3 uses the same benefits scoring relationships as Plan D^+, with the important exceptions of the Lake Ontario target level and the score for deviations in level from the target level. In addition, OntRip3 does not include the feature, contained in Plan D^+, that occasionally shifts the Lake Ontario target level to try to induce inter-annual fluctuations in the growing season level.

Benefit Score Curves

With the exception of the Lake Ontario target level, OntRip3 uses the same benefit scoring relationships, or curves, as used within Plan D^+. Only the relationships that differ from Plan D^+ are included here. The other relationships are described in the Plan D^+ section. The Lake Ontario target level used in OntRip3 is shown in Figure B-30 along with the normal target level used in Plan D^+. The OntRip3 target level is lower and has a somewhat different seasonal variation than the Plan D^+ target level.

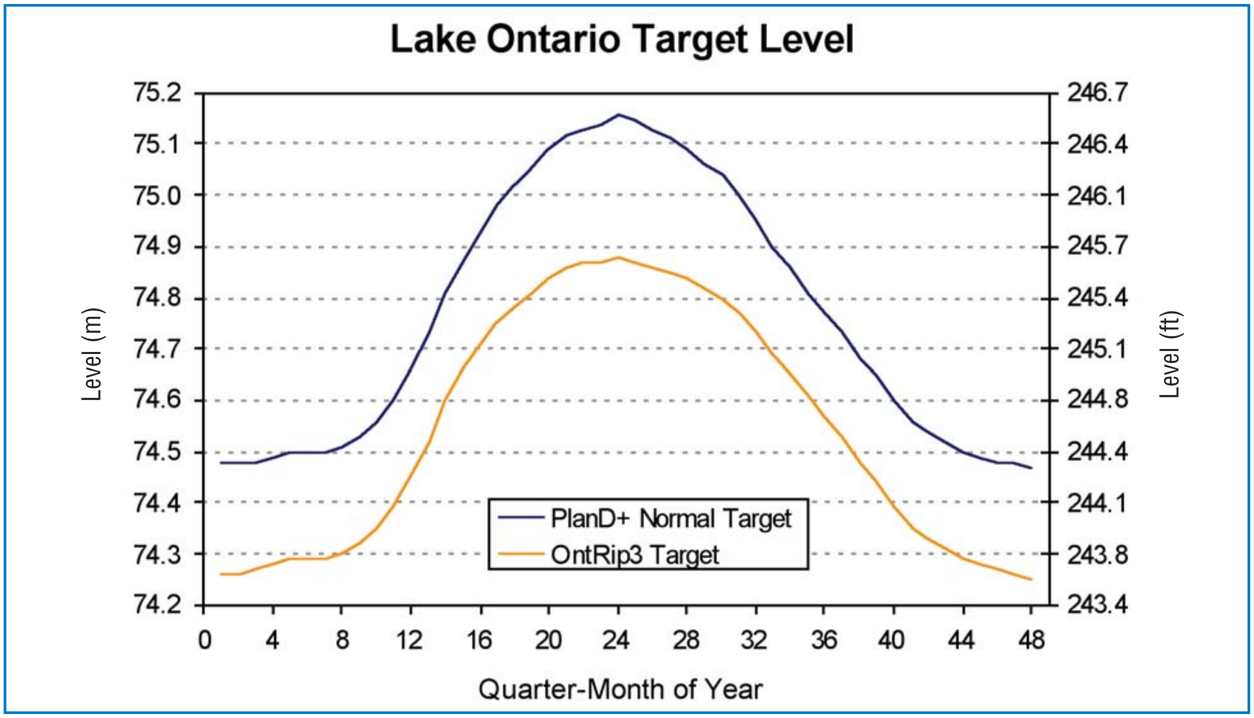


Figure B-30: OntRip3 Lake Ontario target level and Plan D^+ normal target level

Figure B-31 compares the scoring relationships applied by the two plans as the Lake Ontario level deviates from their respective target levels. It can be seen that the score decreases more sharply for levels below the target level in the OntRip3 plan than in Plan D+ , while for levels above the target level the score does not diminish quite as quickly. In combination with the lower target level of OntRip3 shown Figure B-30, this tends to keep the Lake Ontario level lower, but not too low, and reduces the inter-annual lake level fluctuations with OntRip3 relative to the other regulation plans.

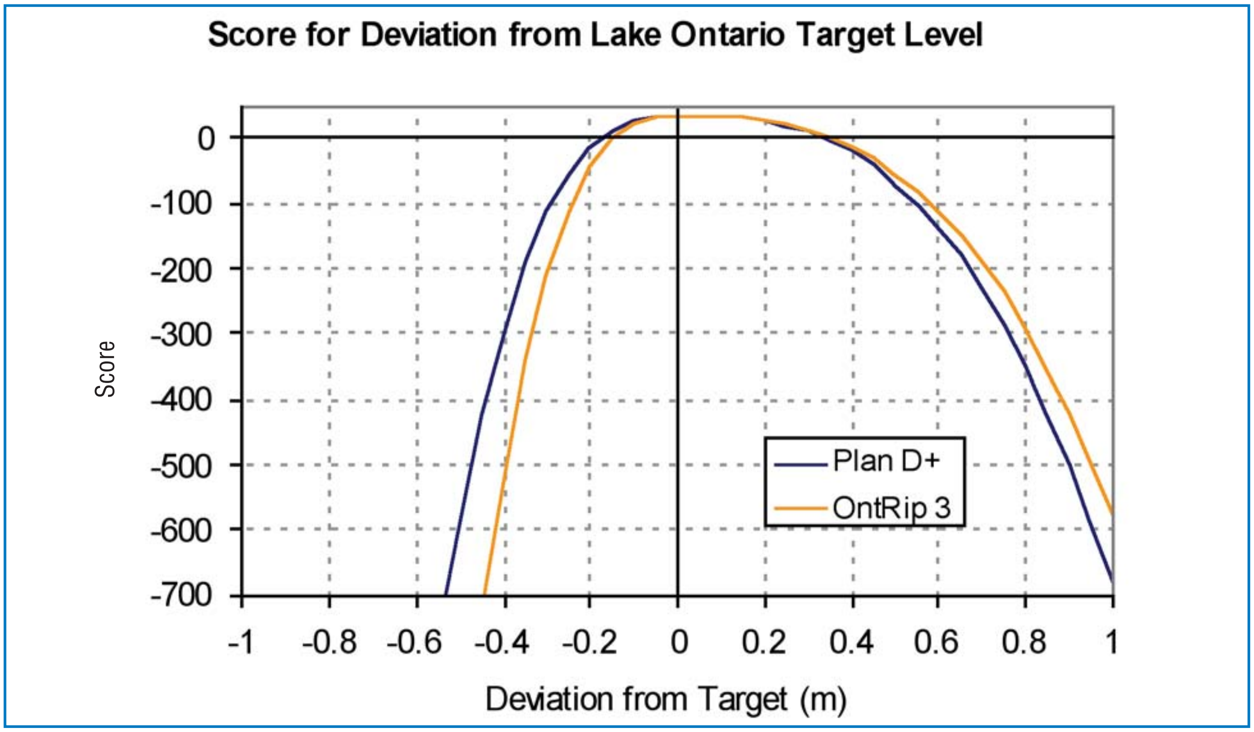


Figure B-31: Lake Ontario score for deviation from target level

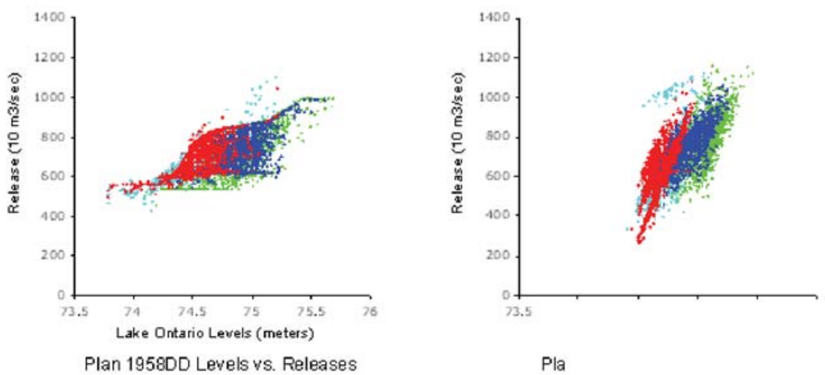
RecBoat: Plan Designed for Recreational Boaters

RecBoat was created to estimate how much boating conditions could be improved by a new regulation plan. RecBoat is not a balanced plan, and was designed only to maximize recreational boating benefits, not to avoid disproportionate losses. The design approach taken was to conserve water on Lake Ontario so that water would be available for Lake and River boating during long droughts.

The apparent conflict between Lake and River boating—water must be let out of Lake Ontario to make the River deeper—is rarely a problem. In fact, unless there is a drought, the release needed to create good boating conditions on the River will not draw Lake Ontario down too low for boaters. Making sure that the River gets no more water than it needs for good boating helps store enough water on Lake Ontario and the River during droughts.

Experimentation with different combinations showed that, over the long term, the best basic strategy for a plan that was good for boaters throughout the system was to try to maintain just enough depth to avoid impacts in Lac St. Louis during the boating season, but to lower that target elevation when water was in short supply or during the off season. During high water supplies, allowing Lake Ontario to rise higher does add more stored water for subsequent droughts, but also creates problems for boaters while the water is high. Experimentation showed that even if the only concern was recreational boating, it did not make sense to allow Lake Ontario to rise too high; even one extra metre of water would be dissipated over a long drought and it would cause damages as long as it persisted.

As the following graphs of release versus Lake Ontario levels show in Figure B-32, Lake Ontario elevations vary less and releases vary more than the levels and releases of Plan 1958-DD (1 m = 3.28084 ft and 1 m^3/s = 35.31467 ft^3/s).



Spring
Summer
Fall
Winter

	Plan 1958DD Ontario x	Plan 1958DD Release y		Plan RecBoat Ontario x	Plan RecBoat Release y
Max	75.69	1103	Max	75.47	1159.00
Min	73.78	426	Min	74.41	265.00
Mean	74.74	705	Mean	74.86	705.58
Median	74.72	696	Median	74.83	701.00
StdDev	0.29	98	Std Dev	0.19	133.39

Figure B-32: ***Plan releases versus Lake Ontario water levels for Plan 1958-DD and Plan RecBoat***

Experimental variations

In simpler problems, a simple optimization can solve for the independent variables driving the dependent variable to be maximized. In terms of the dependent variable to be maximized here, there are many possible choices, but the most obvious is total net recreational boating benefits. "Total" means the benefits for all reaches are considered together, and "net" means the benefit is measured in terms of the change relative to Plan 1958-DD benefits. The independent variables are the water levels at eight different gauges, which, in turn, are functions of some or all of the following: net total water supplies to Lake Ontario, release from Lake Ontario, tides, channel roughness and tributary flows. Many of these variables would have to be perfectly forecast in order to maximize benefits, and the optimization would have to consider all possible release patterns over at least the next five to ten years, which appears to be the approximate length of long-term substantial deviations from normal water supplies (long droughts and long wet periods).

Experimentation and reflection can provide a reasonable approximation to an optimization. In this case, experimentation involved the following steps:

- Each quarter-month, a set of forecasts was used to determine how large a release would be needed to provide Lac St. Louis levels of 21.32 m (about 70 ft). This is the shallowest level for which there are no problems for boaters. That was the release made. The experiment brought Lake Ontario very low during long droughts when less water was coming into the Lake, and more water was needed in the release to supplement lower river tributary flows.
- The target elevation at Lac St. Louis was reduced, and staged targets were introduced. This improved dry condition benefits but led to high boating damages from occasional very high Lake Ontario levels.
- An upper and lower bound for Lake Ontario was defined, and releases were made to meet the target level at Lac St. Louis and to keep the Lake within those limits. This tended to eliminate water that could be used during droughts.
- The upper limit was buffered with a forecast, so that if the forecast were for drier weather, the Lake was allowed to violate the upper limit. The option of using the M (minimum release) and J (week-to-week variation in release) limits from Plan 1998 was introduced. An off-season target for Lac St. Louis was defined.

Iterations of the experimental plans were named by the parameters as shown in Figure B-33.

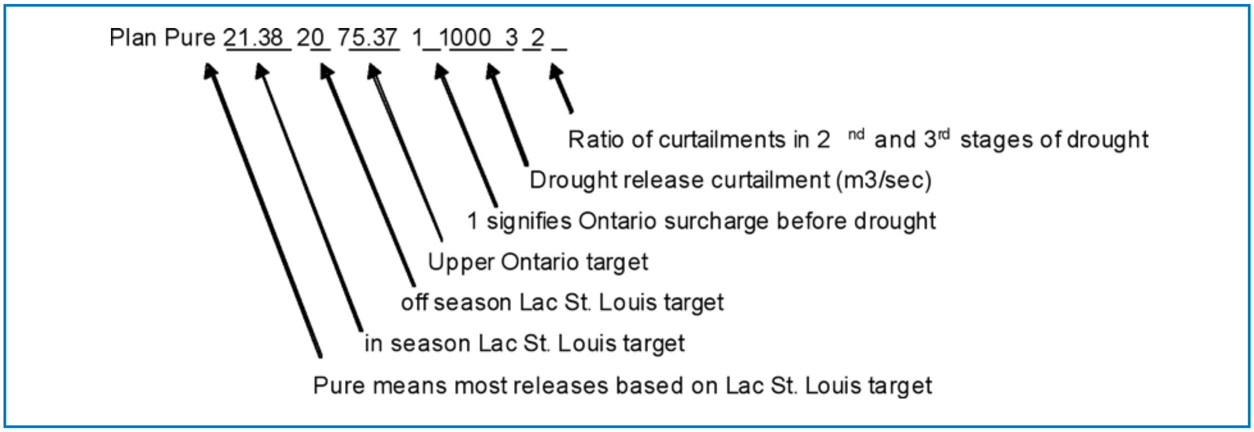


Figure B-33: Naming convention for iterations of experimental plans

Impacts were graphed in every reach and for every year and compared with impacts for that reach or year under Plan 1958-DD. Overall comparisons of graphs and numbers overall and comparisons in segments helped show why a change in input parameters was or was not improving matters.

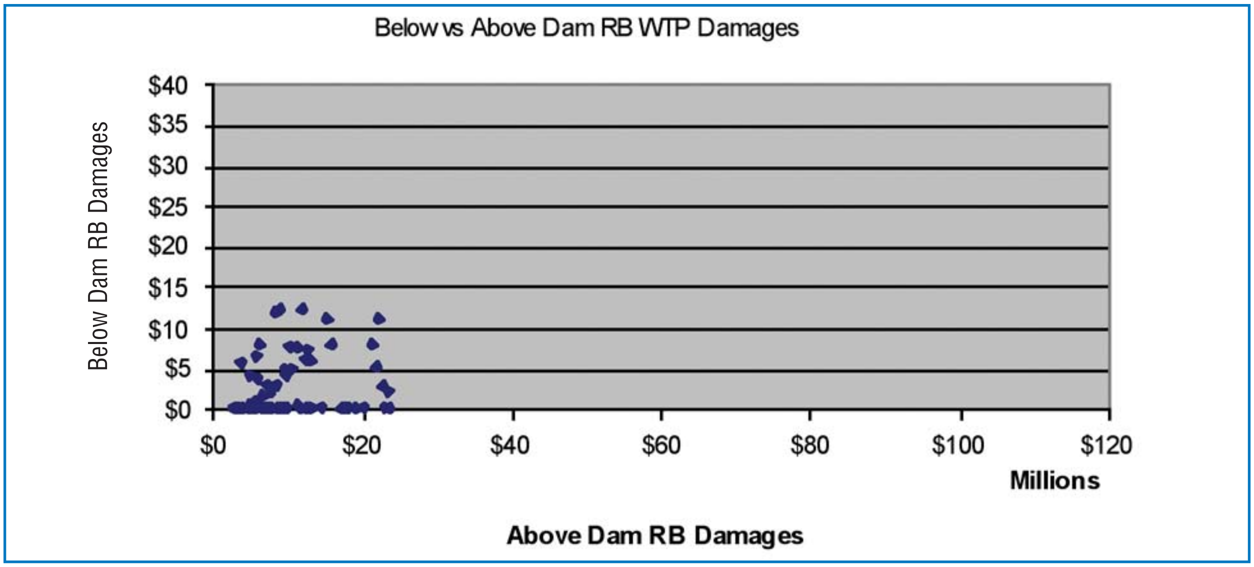


Figure B-34:* *Below versus above dam recreational boating willingness to pay damages

Figure B-34 above shows an x-y plot of above-dam versus below-dam damages for Plan Pure 21.38 20 75.37 1 1000 3 2. Each point represents a one-year average. The average annual above-dam damage for this plan is $8.6 million, while the below-dam damage is $2.24 million ($3.28 std. dev.)

Several versions of RecBoat were able to achieve average benefits of several millions of dollars per year over Plan 1958-DD, but always with far greater losses to hydropower, especially Hydro-Québec generation. Losses to Hydro-Québec occurred in 90% of the years in the historical analysis, primarily because releases were measured out to avoid pushing Lac St. Louis above 21 m (68.9 ft), and because releases were reduced substantially in winter, when power generation is very valuable for heating.

C. Summary Tables of Plan Results

The following set of summary tables provides results from all regulation plans described in the main report. The tables cover results for all candidate plans, interest-specific and reference plans under the historical time series. They include the economic results for the candidate plans for the 50,000-year stochastic sequence. Environmental results are not available for the full stochastic as the Integrated Ecological Response Model component of the Shared Vision Model could not be adapted to run the full 50,000-year sequence. Economic and environmental results for the candidate plans under four separate 101-year extreme centuries selected from the 50,000-year stochastic series (S1 through S4) and economic results for the candidate plans under four separate 101-year climate change time series based on different supply series (C1-C4) are also included.

The programmed Plan 1958-DD was run through all of the time-series sequences to provide the baseline against which all plans would be compared. To allow this comparison, all economic damages related to 1958-DD were set to equal zero; in this way, any increase in damages was considered a negative benefit and any decrease in damages was considered a positive benefit. All economic results, with the exception of Table C-1, are shown relative to Plan 1958-DD.

Plan 1958-DD – Absolute Damages

While all damages were set to zero for comparison purposes, this does not mean there are zero damages under Plan 1958-DD. For example, shoreline erosion damages are an ongoing phenomenon and occur with every regulation plan. The table below shows the gross values of the economic performance indicators measured when Plan 1958-DD was evaluated for the historical time series and the stochastic time series. The purpose of the table is to show how and why the values differ between historical and stochastic evaluations; the gross numbers shown may or may not have meaning. For example, while the difference between the hydropower performance indicator for any two plans does represent the societal value of the marginal difference in energy production, the gross number for Plan 1958-DD hydropower does not represent anything real by itself. The gross performance indicators for coastal damages, on the other hand, do represent our best estimates of the actual costs stakeholders will bear in addressing those impacts under Plan 1958-DD.

Table C-1: Average annual damages for Plan 1958-DD under the historical[2] and 50,000 year stochastic[3] sequence

Performance Indicator	1958-DD Historic[2]	1958-DD 50,000 yr Stochastic[3]
COASTAL	**$21.74**	**$26.07**
Lake Ontario	*$13.28*	*$18.15*
Shore Protection Maintenance[4]	$12.22	$15.48
Erosion (unprotected developed parcels)[4]	$1.06	$2.50
Flooding	$0.00	$0.17
Upper St. Lawrence River	*$0.00*	*$0.01*
Flooding	$0.00	$0.01
St. Lawrence	*$8.46*	*$7.91*
Flooding	$1.41	$0.98
Shore Protection Maintenance[5]	$7.05	$6.935
COMMERCIAL NAVIGATION	**$194.37**	**$193.31**
Lake Ontario	$29.22	$29.22
Seaway	$108.80	$107.93
Montreal down	$56.35	$56.17
HYDROPOWER[1]	**$348.90**	**$345.04**
NYPA-OPG	$249.81	$246.89
Hydro Quebec	$99.09	$98.15
RECREATIONAL BOATING	**$16.75**	**$15.83**
Above Dam	*$8.61*	*$8.00*
Lake Ontario	$4.69	$4.33
Alex Bay	$3.83	$3.60
Ogdensburg	$0.02	$0.02
Lake St. Lawrence	$0.07	$0.05
Below Dam	*$8.14*	*$7.83*
Lac St. Louis	$3.29	$3.24
Montreal	$3.76	$3.56
Lac St. Pierre	$1.09	$1.02
M&I	**$0.50**	**$0.00**
SL One-time infrastructure costs	$0.31	$0.00
LSL Water Quality Investments	$0.20	$0.00

Notes to Table C-1:

1. Results are absolute average annual values (US$M) with all numbers representing costs (damages) except the hydropower numbers, which measure the value to society of the electricity produced (i.e., economic surplus of the electricity produced at the hydroelectric plants on the St. Lawrence and Niagara rivers that are affected by Lake Ontario levels and flows).
2. Historical sequence represents supplies from 1900 to 2000.
3. The 50,000-year stochastic is a statistically generated sequence based on historical supplies (actually 49,995 years).
4. Coastal Erosion and Shore Protection on Lake Ontario are discounted damages for all stochastic supply sequences but regular (non-discounted) damages for all other supply sequences.
5. Lower St. Lawrence River shore protection is based on the average of four 101-year stochastic simulations and the historical supply sequence since the St. Lawrence River Model component of the Shared Vision Model could not be adapted to run the full 50,000-year stochastic series.

Historical Time Series (1900-2000)

Economic Results for Candidate Plans (Plus Plan E)

Table C-2: Economic results for candidate plans by interest and region based on THE historical supply sequence

Average Annual Net Benefits ($M)	Plan A+	Plan B+	Plan D+	Plan E[3]
Total	**$7.52**	**$6.48**	**$6.52**	**-$12.30**
COASTAL	**-$0.62**	**-$1.11**	**$0.32**	**-$25.96**
Lake Ontario	*-$0.36*	*-$0.60*	*$0.25*	*-$23.12*
Shore Protection Maintenance	-$0.23	-$0.49	$0.27	-$12.98
Erosion to Unprotected Developed Parcels	-$0.13	-$0.10	-$0.02	-$0.29
Flooding	-$0.01	-$0.01	-$0.01	-$9.85
Upper St. Lawrence River	*$0.00*	*$0.00*	*$0.00*	*-$1.56*
Flooding	$0.00	$0.00	$0.00	-$1.56
St. Lawrence	*-$0.25*	*-$0.51*	*$0.07*	*-$1.27*
Flooding	-$0.22	-$0.47	-$0.02	-$1.21
Shore Protection Maintenance	-$0.03	-$0.04	$0.09	-$0.07
COMMERCIAL NAVIGATION	**$0.41**	**$2.20**	**$2.31**	**$4.13**
Lake Ontario	-$0.04	-$0.02	-$0.01	-$0.01
Seaway	$0.53	$2.28	$2.35	$4.15
Montreal down	-$0.08	-$0.06	-$0.03	$0.00
HYDROPOWER	**$3.50**	**$5.97**	**$1.82**	**$14.16**
NYPA-OPG	$3.51	$4.16	$1.04	$10.23
Hydro Quebec	-$0.01	$1.81	$0.78	$3.93
RECREATIONAL BOATING	**$4.23**	**-$0.58**	**$2.04**	**-$4.64**
Above Dam	*$2.21*	*-$0.62*	*$0.52*	*-$5.91*
Lake Ontario	$1.29	-$0.64	$0.13	-$5.03
Alex Bay	$0.89	-$0.05	$0.32	-$0.86
Ogdensburg	$0.01	$0.00	$0.01	-$0.09
Lake St. Lawrence	$0.02	$0.06	$0.06	$0.07
Below Dam	*$2.02*	*$0.04*	*$1.53*	*$1.27*
Lac St. Louis	$1.13	$0.17	$0.77	$0.78
Montreal	$0.70	-$0.02	$0.58	$0.41
Lac St. Pierre	$0.19	-$0.10	$0.17	$0.08
M&I	**$0.00**	**$0.00**	**$0.00**	**$0.00**
SL One-time infrastructure costs	$0.00	$0.00	$0.00	$0.00
LSL Water Quality Investments	$0.00	$0.00	$0.00	$0.00

Notes to Table C-2:
1. Figures represent the average annual impact relative to Plan 1958-DD, in millions of U.S. dollars. **Blue** indicates a positive net benefit relative to 1958-DD and **red** indicates a negative net benefit relative to 1958-DD.
2. These are economic results based on the historical supply series (representing 1900-2000). No discount rate is applied.
3. Plan E is shown for comparison purposes only to represent the natural flow condition. Plan E is not a candidate plan.

Economic Results (Historical) for Interest-Specific and Reference Plans

Table C-3: Economic results by interest and region for the interest-specific and reference plans based on the historical supply sequence

	RecBoat	OntRip3	1998	1958-D
Total	**-$20.55**	**-$8.07**	**-$0.03**	**-$40.91**
COASTAL	**-$1.77**	**$0.94**	**-$0.80**	**-$46.66**
Lake Ontario	*$0.74*	*$0.95*	*-$0.98*	*-$43.07*
Shore Protection Maintenance	$0.90	$0.77	-$0.97	-$20.04
Erosion to Unprotected Developed Parcels	-$0.16	$0.18	$0.00	-$0.12
Flooding	$0.00	$0.00	-$0.02	-$22.91
Upper St. Lawrence River	*$0.00*	*$0.00*	*$0.00*	*-$2.73*
Flooding	$0.00	$0.00	$0.00	-$2.73
St. Lawrence	*-$2.51*	*-$0.01*	*$0.18*	*-$0.85*
Flooding	-$2.46	-$0.08	$0.09	-$0.82
Shore Protection Maintenance	-$0.05	$0.07	$0.09	-$0.04
COMMERCIAL NAVIGATION	**-$3.91**	**$0.48**	**-$0.03**	**$2.97**
Lake Ontario	-$0.22	-$0.05	-$0.01	-$0.01
Seaway	-$3.04	$0.54	$0.01	$3.01
Montreal down	-$0.65	$0.00	-$0.03	-$0.03
HYDROPOWER	**-$18.72**	**-$3.90**	**-$0.45**	**$5.09**
NYPA-OPG	-$3.78	-$5.24	$0.02	$3.54
Hydro Quebec	-$14.94	$1.34	-$0.47	$1.55
RECREATIONAL BOATING	**$3.90**	**-$5.59**	**$1.05**	**-$2.51**
Above Dam	*$2.46*	*-$6.66*	*$1.02*	*-$2.82*
Lake Ontario	$2.14	-$4.57	$0.69	-$2.15
Alex Bay	$0.35	-$2.07	$0.30	-$0.67
Ogdensburg	$0.02	-$0.02	$0.01	-$0.06
Lake St. Lawrence	-$0.04	$0.01	$0.03	$0.06
Below Dam	*$1.44*	*$1.08*	*$0.04*	*$0.32*
Lac St. Louis	$0.80	$0.60	$0.10	$0.17
Montreal	$0.61	$0.39	-$0.03	$0.15
Lac St. Pierre	$0.03	$0.09	-$0.04	$0.00
M&I	**-$0.05**	**$0.00**	**$0.20**	**$0.20**
SL One-time infrastructure costs	-$0.05	$0.00	$0.00	$0.00
LSL Water Quality Investments	$0.00	$0.00	$0.20	$0.20

Notes to Table C-3:

1. Figures represent the average annual impact relative to Plan 1958-DD, in millions of U.S. dollars. **Blue** indicates a positive net benefit relative to 1958-DD and **red** indicates a negative net benefit relative to 1958-DD.
2. These are economic results based on the historical supply series (representing 1900-2000). No discount rate is applied.

Environmental Results (Historical) for Candidate Plans (Plus Plan E)

Table C-4: Environmental performance indicator results (ratios) for candidate plans based on the historical supply sequence

Environmental Performance Indicators	Plan A+	Plan B+	Plan D+	Plan E
Lake Ontario				
Wetland Meadow Marsh Community	1.02	1.44	1.17	1.56
Low Veg 18C - Spawning habitat supply	0.89	0.95	0.94	0.88
High Veg 24C - Spawning habitat supply	1.05	1.00	1.01	1.08
Low Veg 24C - Spawning habitat supply	1.00	1.02	1.00	1.11
Northern Pike – Young-of-year (YOY) recruitment	1.02	1.00	1.05	1.03
Largemouth Bass - YOY recruitment	0.94	0.98	0.97	0.96
Least Bittern (IXEX) - Reproductive index	0.88	1.04	0.95	1.13
Virginia Rail (RALI) - Reproductive index	0.96	1.11	0.99	1.15
Black Tern (CHNI) - Reproductive index	1.03	1.12	1.01	1.16
Yellow Rail (CONO) - Preferred breeding habitat	0.96	1.01	0.98	1.01
King Rail (RAEL) - Preferred breeding habitat	1.05	1.10	1.03	1.27
Upper River				
Low Veg 18C - Spawning habitat supply	1.01	1.01	1.01	1.04
High Veg 24C - Spawning habitat supply	1.03	1.01	1.02	1.02
Low Veg 24C - Spawning habitat supply	1.01	1.01	1.01	1.04
Northern Pike - YOY recruitment	1.05	1.03	1.01	1.06
Largemouth Bass - YOY recruitment	0.99	1.00	1.00	1.00
Northern Pike - YOY net productivity	4.02	2.08	1.17	4.08
Virginia Rail (RALI) - Reproductive index	1.16	1.27	1.31	1.33
Muskrat (ONZI) - House density in drowned river mouth wetlands	1.42	4.39	1.73	37.25
Lower River				
Golden Shiner - Suitable feeding habitat area	1.00	1.00	1.00	1.03
Wetlands Fish - Abundance index	0.87	0.90	0.84	0.97
Migratory Wildfowl - Habitat area	1.03	1.03	0.97	1.00
Least Bittern - Reproductive index	1.03	1.06	1.00	1.06
Virginia Rail (RALI) - Reproductive index	0.94	0.97	1.06	1.00
Migratory Wildfowl - Productivity	1.06	1.00	1.00	1.03
Black Tern (CHNI) - Reproductive index	0.84	0.77	1.00	0.77
Northern Pike (ESLU) - Reproductive area	0.97	0.94	0.94	0.94
Frog sp. - Reproductive habitat surface area	0.87	0.87	1.03	0.94
Eastern Sand Darter (AMPE) - Reproductive area	1.10	1.03	1.13	1.06
Spiny Softshell Turtle (APSP) - Reproductive habitat surface area	1.03	1.06	1.03	1.03
Bridle Shiner (NOBI) - Reproductive habitat surface area	1.00	0.97	1.00	1.03
Muskrat (ONZI) - Surviving houses	1.04	0.88	0.96	0.80
Percentage "good" scores for each plan	**9%**	**22%**	**16%**	**34%**
Overall Environmental Index	**1.06**	**1.35**	**1.10**	**4.04**

Notes to Table C-4:

1. Figures represent the impact relative to Plan-1958-DD expressed as ratios, where 1 represents no change from 58-DD, > 1.00 an improvement relative to 58-DD, and < 1.00 a deterioration relative to 58-DD.
2. Run using the historical supply sequence (1900-2000).
3. Aqua shading identifies species at risk.
4. Yellow shading indicates essentially no change from 1958-DD (within 10% difference). Anything above 1.10 is marked in **blue** and anything below 0.90 is marked in **red**.

Environmental Results (Historical) for Interest and Reference Plans

Table C-5: Environmental performance indicator results (ratios) for interest-specific and reference plans based on the historical supply sequence

Environmental Performance Indicators	RecBoat	OntRip3	1998	1958-D
Lake Ontario				
Wetland Meadow Marsh Community	0.41	1.02	1.09	1.24
Low Veg 18C - spawning habitat supply	1.03	1.05	1.00	0.96
High Veg 24C - spawning habitat supply	1.08	1.00	1.00	1.03
Low Veg 24C - spawning habitat supply	0.93	0.95	1.00	1.01
Northern Pike - YOY recruitment	1.01	1.02	1.02	1.00
Largemouth Bass - YOY recruitment	0.99	1.07	0.99	0.98
Least Bittern (IXEX) - reproductive index	0.21	0.68	1.03	1.01
Virginia Rail (RALI) - reproductive index	0.44	0.75	1.03	1.04
Black Tern (CHNI) - reproductive index	0.48	0.80	1.03	1.04
Yellow Rail (CONO) - preferred breeding habitat	0.92	1.04	1.00	1.00
King Rail (RAEL) - preferred breeding habitat	0.82	0.92	1.02	1.09
Upper River				
Low Veg 18C - spawning habitat supply	1.00	0.96	1.01	1.00
High Veg 24C - spawning habitat supply	1.00	1.00	1.01	1.00
Low Veg 24C - spawning habitat supply	0.99	1.01	1.00	1.00
Northern Pike - YOY recruitment	1.07	1.00	1.00	1.01
Largemouth Bass - YOY recruitment	1.04	1.04	1.00	0.99
Northern Pike - YOY net productivity	5.28	0.58	1.21	1.93
Virginia Rail (RALI) - reproductive index	0.99	0.92	1.12	1.33
Muskrat (ONZI) - house density in drowned river mouth wetlands	0.00	0.23	1.01	17.83
Lower River				
Golden Shiner - suitable feeding habitat area	1.00	1.06	0.94	0.81
Wetlands fish - abundance index	1.10	0.94	0.94	0.97
Migratory wildfowl - habitat area	1.10	0.97	1.00	1.00
Least Bittern - reproductive index	1.03	1.03	0.97	1.03
Virginia Rail (RALI) - reproductive index	1.03	1.03	1.00	1.06
Migratory wildfowl - productivity	1.10	1.00	1.00	1.03
Black Tern (CHNI) - reproductive index	0.74	1.00	0.90	1.03
Northern Pike (ESLU) - reproductive area	0.87	0.94	1.00	0.94
Frog sp. - reproductive habitat surface area	0.77	1.00	0.94	1.06
Eastern Sand Darter (AMPE) - reproductive area	0.94	1.10	1.03	1.13
Spiny Softshell Turtle (APSP) - reproductive habitat surface area	0.94	1.03	1.00	1.10
Bridle Shiner (NOBI) - reproductive habitat surface area	0.90	0.97	0.97	1.13
Muskrat (ONZI) - Surviving houses	0.20	1.00	1.00	1.20
Percentage "good" scores for each plan	**9%**	**6%**	**9%**	**22%**
Overall Environmental Index	**0.70**	**0.90**	**1.02**	**2.44**

Notes to Table C-5:

1. Figures represent the impact relative to Plan-1958-DD expressed as ratios, where 1 represents no change from 58-DD, > 1.00 an improvement relative to 58-DD, and < 1.00 a deterioration relative to 58-DD.
2. Run using the historical supply sequence (1900-2000).
3. Aqua shading identifies species at risk.
4. Yellow shading indicates essentially no change from 1958-DD (within 10% difference). Anything above 1.10 is marked in **blue** and anything below 0.90 is marked in **red**.

Stochastic Supply Sequences

Economic Results for Candidate Plans (50,000-year Stochastic)

Table C-6: Economic results for candidate plans by interest and region based on 50,000-year stochastic supply sequence

Average Annual Net Discounted Benefits	Plan A+	Plan B+	Plan D+	Plan E
Total	**$6.44**	**$4.63**	**$4.48**	**-$16.36**
COASTAL	**-$0.10**	**-$2.84**	**-$0.10**	**-$28.50**
Lake Ontario	*$0.46*	*-$2.52*	*-$0.23*	*-$27.16*
Shore Protection Maintenance[2]	$0.57	-$2.16	-$0.17	-$19.85
Erosion to Unprotected Developed Parcels[2]	-$0.23	-$0.17	$0.02	-$0.58
Flooding	$0.12	-$0.20	-$0.08	-$6.72
Upper St. Lawrence River	*$0.01*	*-$0.01*	*-$0.01*	*-$0.75*
Flooding	$0.01	-$0.01	-$0.01	-$0.75
Lower St. Lawrence River	*-$0.57*	*-$0.31*	*$0.14*	*-$0.59*
Flooding	-$0.51	-$0.22	$0.09	-$0.49
Shore Protection Maintenance[3]	-$0.06	-$0.09	$0.05	-$0.10
COMMERCIAL NAVIGATION	**$0.47**	**$2.13**	**$1.53**	**$3.21**
Lake Ontario	-$0.03	-$0.01	-$0.01	-$0.02
Seaway	$0.57	$2.16	$1.56	$3.21
Montreal down	-$0.07	-$0.02	-$0.02	$0.02
HYDROPOWER	**$2.26**	**$6.09**	**$1.64**	**$12.39**
NYPA-OPG (Energy$ + Peaking$)	$2.18	$3.87	$0.48	$8.57
Hydro Quebec (Energy $)	$0.08	$2.22	$1.16	$3.82
RECREATIONAL BOATING	**$3.81**	**-$0.74**	**$1.42**	**-$3.46**
Above Dam	*$1.20*	*-$1.42*	*-$0.36*	*-$5.31*
Lake Ontario	$0.70	-$1.18	-$0.44	-$4.93
Alex Bay	$0.47	-$0.29	$0.03	-$0.36
Ogdensburg	$0.01	$0.00	$0.01	-$0.07
Lake St. Lawrence	$0.01	$0.05	$0.05	$0.05
Below Dam	*$2.61*	*$0.68*	*$1.78*	*$1.85*
Lac St. Louis	$1.39	$0.49	$0.89	$1.03
Montreal	$0.93	$0.19	$0.68	$0.64
Lac St. Pierre	$0.29	$0.00	$0.21	$0.18
M&I	**$0.00**	**$0.00**	**$0.00**	**$0.00**
SL One-time Infrastructure Costs	$0.00	$0.00	$0.00	$0.00
LSL Water Quality Investments	$0.00	$0.00	$0.00	$0.00

Notes to Table C-6:
1. Figures represent the average annual impact relative to Plan 1958-DD, in millions of U.S. dollars. **Blue** indicates a positive net benefit and **red** indicates a negative net benefit relative to 1958-DD.
2. These are economic results based on the 50,000-year stochastic supply series, using a 4% discount rate over a 30-year period for coastal erosion and shore protection maintenance.
3. To keep the programming protocols the same as the 101-year historical-supply-based models, the 50,000-year sequence was shortened to 49,995 years, or 495 sequences of 101 years each.
4. The St. Lawrence River Model component of the Shared Vision Model could not be adapted to run the full 50,000-year stochastic series. The results presented represent an average of the historical sequence plus the four 101-year trial segments from the stochastic (S1, S2, S3 and S4 series).
5. The full stochastic runs were completed for the candidate plans and Plan E only. Plan E is shown for comparison purposes only to represent the natural flow condition. Plan E is not a candidate plan.

Four Extreme Stochastic Sequences (S1-S4)

Table C-7: Economic results for candidate plans by interest and region based on the extreme stochastic supply sequence S1—the century with the most severe Lake Ontario supply drought

S1 – Extremely Dry (Economic – Average Annual $M)

Average Annual Net Benefits ($M)	Plan A+	Plan B+	Plan D+	Plan E
Total	**$17.53**	**$2.62**	**$10.84**	**-$21.41**
COASTAL	**$0.46**	**-$1.26**	**$0.35**	**-$21.52**
Lake Ontario	*$0.76*	*-$0.98*	*$0.30*	*-$19.65*
Shore Protection Maintenance	$0.86	-$0.54	$0.27	-$10.06
Erosion to Unprotected Developed Parcels	-$0.12	-$0.05	$0.01	-$0.21
Flooding	$0.02	-$0.38	$0.02	-$9.38
Upper St. Lawrence River	*$0.00*	*$0.00*	*$0.00*	*-$1.41*
Flooding	$0.00	$0.00	$0.00	-$1.41
St. Lawrence	*-$0.31*	*-$0.28*	*$0.05*	*-$0.46*
Flooding	-$0.21	-$0.15	$0.02	-$0.25
Shore Protection Maintenance	-$0.10	-$0.13	$0.03	-$0.21
COMMERCIAL NAVIGATION	**$0.59**	**$1.79**	**$1.60**	**$3.06**
Lake Ontario	$0.02	-$0.01	$0.07	-$0.09
Seaway	$0.75	$1.99	$1.57	$3.25
Montreal down	-$0.18	-$0.18	-$0.04	-$0.11
HYDROPOWER	**$3.14**	**$4.12**	**$1.33**	**$7.86**
NYPA-OPG	$3.22	$2.33	$0.96	$4.98
Hydro Quebec	-$0.08	$1.78	$0.37	$2.88
RECREATIONAL BOATING	**$13.34**	**-$2.03**	**$7.56**	**-$10.81**
Above Dam	*$11.04*	*-$1.84*	*$6.47*	*-$11.81*
Lake Ontario	$8.89	-$1.50	$5.23	-$9.40
Alex Bay	$1.90	-$0.46	$0.99	-$2.28
Ogdensburg	$0.21	$0.04	$0.18	-$0.20
Lake St. Lawrence	$0.04	$0.08	$0.07	$0.08
Below Dam	*$2.30*	*-$0.19*	*$1.09*	*$1.00*
Lac St. Louis	$1.04	-$0.10	$0.40	$0.48
Montreal	$1.01	$0.05	$0.53	$0.46
Lac St. Pierre	$0.25	-$0.14	$0.16	$0.06
M&I	**$0.00**	**$0.00**	**$0.00**	**$0.00**
SL One-time infrastructure costs	$0.00	$0.00	$0.00	$0.00
LSL Water Quality Investments	$0.00	$0.00	$0.00	$0.00

Notes to Table C-7:

1. Figures represent the average annual impact relative to Plan-1958-DD, in millions of U.S. dollars. **Blue** indicates a positive net benefit relative to 1958-DD and **red** indicates a negative net benefit relative to 1958-DD.
2. S1 through S4 represent four separate 101-year extreme centuries selected from the 50,000-year stochastic series, where S1 is extremely dry, S2 is extremely wet and has a large range, S3 is similar to historical and S4 has the longest drought.
3. Plan E is shown for comparison purposes only to represent the natural flow condition. Plan E is not a candidate plan.

Table C-8: ***Economic results for candidate plans by interest and region based on the extreme stochastic supply sequence S2—the century with the most severe wet Lake Ontario supply period, as well as the largest range from wet to dry supplies***

S2 – Extremely Wet with Largest Range (Economic – Average Annual $M)

Average Annual Net Benefits ($M)	Plan A+	Plan B+	Plan D+	Plan E
Total	**$9.76**	**$3.97**	**$5.42**	**-$33.96**
COASTAL	**$4.31**	**-$1.05**	**$0.06**	**-$43.32**
Lake Ontario	*$4.40*	*-$0.77*	*$0.02*	*-$39.41*
Shore Protection Maintenance	$3.20	$0.84	$0.58	-$11.85
Erosion to Unprotected Developed Parcels	-$0.10	-$0.10	-$0.02	-$0.27
Flooding	$1.30	-$1.52	-$0.53	-$27.29
Upper St. Lawrence River	*$0.17*	*-$0.07*	*-$0.22*	*-$3.56*
Flooding	$0.17	-$0.07	-$0.22	-$3.56
St. Lawrence	*-$0.26*	*-$0.21*	*$0.25*	*-$0.34*
Flooding	-$0.34	-$0.13	$0.09	-$0.40
Shore Protection Maintenance	$0.09	-$0.08	$0.16	$0.06
COMMERCIAL NAVIGATION	**-$0.61**	**$0.73**	**$1.41**	**$5.08**
Lake Ontario	-$0.04	-$0.01	-$0.01	-$0.02
Seaway	-$0.49	$0.80	$1.44	$5.11
Montreal down	-$0.09	-$0.06	-$0.02	$0.00
HYDROPOWER	**$0.40**	**$4.39**	**$0.99**	**$12.22**
NYPA-OPG	$1.01	$2.64	$0.28	$9.24
Hydro Quebec	-$0.61	$1.75	$0.71	$2.99
RECREATIONAL BOATING	**$5.46**	**-$0.10**	**$2.76**	**-$7.95**
Above Dam	*$3.17*	*-$0.88*	*$0.95*	*-$9.64*
Lake Ontario	$2.26	-$0.78	$0.53	-$7.48
Alex Bay	$0.88	-$0.15	$0.36	-$2.06
Ogdensburg	$0.06	$0.01	$0.04	-$0.15
Lake St. Lawrence	-$0.03	$0.05	$0.03	$0.05
Below Dam	*$2.29*	*$0.78*	*$1.81*	*$1.69*
Lac St. Louis	$1.17	$0.50	$0.85	$0.91
Montreal	$0.88	$0.27	$0.73	$0.63
Lac St. Pierre	$0.24	$0.01	$0.22	$0.16
M&I	**$0.20**	**$0.00**	**$0.20**	**$0.00**
SL One-time infrastructure costs	$0.00	$0.00	$0.00	$0.00
LSL Water Quality Investments	$0.20	$0.00	$0.20	$0.00

Notes to Table C-8:
1. Figures represent the average annual impact relative to Plan 1958-DD and are measured in millions of U.S. dollars. **Blue** indicates a positive net benefit relative to 1958-DD and **red** indicates a negative net benefit relative to 1958-DD.
2. S1 through S4 represent four separate 101-year extreme centuries selected from the 50,000-year stochastic series, where S1 is extremely dry, S2 is extremely wet and has a large range, S3 is similar to historical and S4 has the longest drought.
3. Plan E is shown for comparison purposes only to represent the natural flow condition. Plan E is not a candidate plan.

Table C-9: Economic results for candidate plans by interest and region based on the extreme stochastic supply sequence S3—a century with a similar range and average of supplies as the historical

S3 –Similar to Historical (Economic – Average Annual $M)

Average Annual Net Benefits ($M)	Plan A+	Plan B+	Plan D+	Plan E
Total	**$7.28**	**$5.69**	**$5.02**	**-$7.69**
COASTAL	**$0.33**	**-$3.19**	**$0.59**	**-$22.27**
Lake Ontario	*$1.00*	*-$2.87*	*$0.47*	*-$20.49*
Shore Protection Maintenance	$1.09	-$2.66	$0.47	-$10.65
Erosion to Unprotected Developed Parcels	-$0.09	-$0.08	$0.00	-$0.28
Flooding	$0.00	-$0.12	$0.00	-$9.57
Upper St. Lawrence River	*$0.00*	*$0.00*	*$0.00*	*-$1.16*
Flooding	$0.00	$0.00	$0.00	-$1.16
St. Lawrence	*-$0.67*	*-$0.32*	*$0.11*	*-$0.62*
Flooding	-$0.54	-$0.24	$0.08	-$0.48
Shore Protection Maintenance	-$0.13	-$0.08	$0.03	-$0.13
COMMERCIAL NAVIGATION	**$0.40**	**$3.00**	**$1.69**	**$4.22**
Lake Ontario	-$0.03	-$0.01	-$0.01	-$0.01
Seaway	$0.49	$3.01	$1.72	$4.18
Montreal down	-$0.06	$0.00	-$0.02	$0.04
HYDROPOWER	**$3.23**	**$6.32**	**$2.05**	**$14.62**
NYPA-OPG	$2.95	$4.02	$0.91	$10.42
Hydro Quebec	$0.28	$2.29	$1.14	$4.20
RECREATIONAL BOATING	**$3.33**	**-$0.44**	**$0.69**	**-$4.26**
Above Dam	*$1.25*	*-$0.76*	*-$0.81*	*-$5.76*
Lake Ontario	$0.53	-$0.69	-$0.90	-$4.85
Alex Bay	$0.68	-$0.14	$0.04	-$0.89
Ogdensburg	$0.01	$0.00	$0.00	-$0.08
Lake St. Lawrence	$0.03	$0.07	$0.06	$0.07
Below Dam	*$2.08*	*$0.32*	*$1.49*	*$1.50*
Lac St. Louis	$1.13	$0.35	$0.74	$0.88
Montreal	$0.72	$0.01	$0.60	$0.49
Lac St. Pierre	$0.22	-$0.04	$0.15	$0.13
M&I	**$0.00**	**$0.00**	**$0.00**	**$0.00**
SL One-time infrastructure costs	$0.00	$0.00	$0.00	$0.00
LSL Water Quality Investments	$0.00	$0.00	$0.00	$0.00

Notes to Table C-9:
1. Figures represent the average annual impact relative to Plan-1958-DD, in millions of U.S. dollars. **Blue** indicates a positive net benefit relative to 1958-DD and **red** indicates a negative net benefit relative to 1958-DD.
2. S1 through S4 represent four separate 101-year extreme centuries selected from the 50,000-year stochastic series, where S1 is extremely dry, S2 is extremely wet and has a large range, S3 is similar to historical and S4 has the longest drought.
3. Plan E is shown for comparison purposes only to represent the natural flow condition. Plan E is not a candidate plan.

Table C-10: Economic results for candidate plans by interest and region based on the extreme stochastic supply sequence S4—the century with the longest sustained Lake Ontario drought

S4 –Longest Lake Ontario Drought (Economic – Average Annual $M)

Average Annual Net Benefits ($M)	Plan A+	Plan B+	Plan D+	Plan E
Total	**$16.07**	**-$6.81**	**$8.74**	**-$19.42**
COASTAL	**-$1.77**	**-$0.96**	**-$0.45**	**-$3.63**
Lake Ontario	*-$1.29*	*-$0.54*	*-$0.34*	*-$3.19*
Shore Protection Maintenance	-$1.18	-$0.61	-$0.41	-$2.77
Erosion to Unprotected Developed Parcels	-$0.11	$0.07	$0.07	$0.04
Flooding	$0.00	$0.00	$0.00	-$0.47
Upper St. Lawrence River	*$0.00*	*$0.00*	*$0.00*	*$0.00*
Flooding	$0.00	$0.00	$0.00	$0.00
St. Lawrence	*-$0.48*	*-$0.41*	*-$0.11*	*-$0.44*
Flooding	-$0.38	-$0.29	-$0.06	-$0.31
Shore Protection Maintenance	-$0.10	-$0.13	-$0.05	-$0.13
COMMERCIAL NAVIGATION	**-$0.33**	**-$0.17**	**$0.26**	**-$0.39**
Lake Ontario	-$0.02	-$0.06	$0.05	-$0.16
Seaway	-$0.02	$0.21	$0.35	$0.00
Montreal down	-$0.29	-$0.32	-$0.13	-$0.23
HYDROPOWER	**$2.96**	**$1.52**	**$0.84**	**$0.90**
NYPA-OPG	$2.47	$0.17	$0.29	-$1.37
Hydro Quebec	$0.49	$1.35	$0.55	$2.27
RECREATIONAL BOATING	**$15.21**	**-$7.20**	**$8.09**	**-$16.30**
Above Dam	*$11.61*	*-$7.23*	*$6.72*	*-$17.65*
Lake Ontario	$9.67	-$5.66	$5.64	-$14.15
Alex Bay	$1.68	-$1.64	$0.84	-$3.32
Ogdensburg	$0.21	$0.01	$0.18	-$0.24
Lake St. Lawrence	$0.05	$0.05	$0.05	$0.05
Below Dam	*$3.60*	*$0.03*	*$1.37*	*$1.35*
Lac St. Louis	$1.63	-$0.05	$0.45	$0.58
Montreal	$1.64	$0.29	$0.76	$0.76
Lac St. Pierre	$0.33	-$0.21	$0.16	$0.01
M&I	**$0.00**	**$0.00**	**$0.00**	**$0.00**
SL One-time infrastructure costs	$0.00	$0.00	$0.00	$0.00
LSL Water Quality Investments	$0.00	$0.00	$0.00	$0.00

Notes to Table C-10:

1. Figures represent the average annual impact relative to Plan 1958-DD, in millions of U.S. dollars. **Blue** indicates a positive net benefit relative to 1958-DD and **red** indicates a negative net benefit relative to 1958-DD.
2. S1 through S4 represent four separate 101-year extreme centuries selected from the 50,000-year stochastic series, where S1 is extremely dry, S2 is extremely wet and has a large range, S3 is similar to historical and S4 has the longest drought.
3. Plan E is shown for comparison purposes only to represent the natural flow condition. Plan E is not a candidate plan.

Table C-11: Environmental results for candidate plans by interest and region based on the extreme stochastic supply sequence S1—the century with the most severe Lake Ontario supply drought

S1 – Extremely Dry (Environmental – Ratios)

Environmental Performance Indicators	Plan A+	Plan B+	Plan D+	Plan E
Lake Ontario				
Wetland Meadow Marsh Community	0.88	1.22	1.01	1.44
Low Veg 18C - spawning habitat supply	0.95	1.01	0.99	0.98
High Veg 24C - spawning habitat supply	1.15	1.02	1.12	1.01
Low Veg 24C - spawning habitat supply	0.97	1.00	0.98	1.04
Northern Pike - YOY recruitment	1.04	1.02	1.06	1.00
Largemouth Bass - YOY recruitment	1.02	0.99	1.07	0.98
Least Bittern (IXEX) - reproductive index	0.80	1.05	0.84	1.12
Virginia Rail (RALI) - reproductive index	0.77	1.07	0.83	1.11
Black Tern (CHNI) - reproductive index	0.77	1.07	0.84	1.11
Yellow Rail (CONO) - preferred breeding habitat	0.85	0.99	0.87	1.06
King Rail (RAEL) - preferred breeding habitat	0.75	0.96	0.76	1.17
Upper River				
Low Veg 18C - spawning habitat supply	0.97	1.00	0.97	1.04
High Veg 24C - spawning habitat supply	1.01	1.01	1.01	1.01
Low Veg 24C - sspawning habitat supply	0.96	1.00	0.97	1.02
Northern Pike - YOY recruitment	1.00	1.01	1.00	1.04
Largemouth Bass - YOY recruitment	0.98	1.00	1.00	1.01
Northern Pike - YOY net productivity	8.62	2.33	1.49	6.39
Virginia Rail (RALI) - reproductive index	1.19	1.17	1.25	0.99
Muskrat (ONZI) - house density in drowned river mouth wetlands	0.51	4.13	0.43	15.81
Lower River				
Golden Shiner - suitable feeding habitat area	1.03	1.08	0.95	1.09
Wetlands fish - abundance index	1.00	1.10	0.95	1.08
Migratory wildfowl - habitat area	1.13	1.13	0.95	1.13
Least Bittern - reproductive index	1.15	1.10	0.99	1.14
Virginia Rail (RALI) - reproductive index	0.96	0.96	1.16	0.96
Migratory wildfowl - productivity	1.07	1.05	0.97	1.08
Black Tern (CHNI) - reproductive index	1.03	1.04	1.15	1.05
Northern Pike (ESLU) - reproductive area	1.01	1.00	0.92	1.05
Frog sp. - reproductive habitat surface area	0.75	0.79	1.08	0.81
Eastern Sand Darter (AMPE) - reproductive area	1.01	1.01	1.03	1.01
Spiny Softshell Turtle (APSP) - reproductive habitat surface area	1.04	1.03	1.07	1.01
Bridle Shiner (NOBI) - reproductive habitat surface area	1.00	1.00	0.96	0.97
Muskrat (ONZI) - surviving houses	0.96	0.94	1.07	0.97
Percentage "good" scores for each plan	**16%**	**19%**	**22%**	**28%**
Overall Environmental Index	**0.99**	**1.31**	**0.97**	**2.33**

Notes to Table C-11:

1. Figures represent the impact relative to Plan 1958-DD expressed as ratios, where 1 represents no change from 58-DD, > 1.00 an improvement relative to 58-DD, and < 1.00 a deterioration relative to 58-DD.
2. S1 through S4 represent four separate 101-year extreme centuries selected from the 50,000-year stochastic series, where S1 is extremely dry, S2 is extremely wet and has a large range, S3 is similar to historical and S4 has the longest drought.
3. Aqua shading identifies species at risk.
4. Yellow shading indicates essentially no change from 1958-DD (within 10% difference). Anything above 1.10 is marked in **blue** and anything below 0.90 is marked in **red**.

Table C-12: Environmental results for candidate plans by interest and region based on the extreme stochastic supply sequence S2—the century with the most severe wet Lake Ontario supply period, as well as the largest range between wet and dry supplies

S2 – Extremely Wet with Largest Range (Environmental – Ratios)

Environmental Performance Indicators	Plan A+	Plan B+	Plan D+	Plan E
Lake Ontario				
Wetland Meadow Marsh Community	0.93	1.23	1.17	2.21
Low Veg 18C - spawning habitat supply	0.93	0.97	0.96	0.97
High Veg 24C - spawning habitat supply	1.09	1.01	1.08	1.08
Low Veg 24C - spawning habitat supply	0.98	1.02	1.00	1.13
Northern Pike - YOY recruitment	1.02	1.02	1.04	1.09
Largemouth Bass - YOY recruitment	0.97	0.98	0.99	0.97
Least Bittern (IXEX) - reproductive index	1.12	1.11	1.13	1.17
Virginia Rail (RALI) - reproductive index	1.11	1.13	1.08	1.19
Black Tern (CHNI) - reproductive index	1.11	1.12	1.08	1.19
Yellow Rail (CONO) - preferred breeding habitat	0.89	1.00	0.91	1.02
King Rail (RAEL) - preferred breeding habitat	0.83	1.02	0.84	1.20
Upper River				
Low Veg 18C - spawning habitat supply	1.00	1.01	1.01	1.04
High Veg 24C - spawning habitat supply	1.02	1.01	1.02	0.98
Low Veg 24C - sspawning habitat supply	0.98	1.01	0.99	1.01
Northern Pike - YOY recruitment	1.04	1.02	1.01	1.06
Largemouth Bass - YOY recruitment	0.99	1.00	1.01	1.01
Northern Pike - YOY net productivity	5.39	2.44	1.03	4.24
Virginia Rail (RALI) - reproductive index	1.08	1.15	1.25	1.29
Muskrat (ONZI) - house density in drowned river mouth wetlands	0.66	2.01	0.62	8.62
Lower River				
Golden Shiner - suitable feeding habitat area	1.01	1.03	0.97	1.04
Wetlands fish - abundance index	1.01	1.11	0.97	1.08
Migratory wildfowl - habitat area	1.05	1.11	0.93	1.09
Least Bittern - reproductive index	1.07	1.08	1.03	1.12
Virginia Rail (RALI) - reproductive index	0.93	0.95	1.12	0.97
Migratory wildfowl - productivity	1.11	1.08	1.03	1.12
Black Tern (CHNI) - reproductive index	1.03	1.05	1.14	1.04
Northern Pike (ESLU) - reproductive area	1.03	1.03	0.93	1.00
Frog sp. - reproductive habitat surface area	0.96	0.99	1.08	1.00
Eastern Sand Darter (AMPE) - reproductive area	1.08	1.05	1.03	1.07
Spiny Softshell Turtle (APSP) - reproductive habitat surface area	1.01	1.04	1.04	1.04
Bridle Shiner (NOBI) - reproductive habitat surface area	1.09	1.09	1.05	1.08
Muskrat (ONZI) - surviving houses	1.13	1.00	1.15	1.00
Percentage "good" scores for each plan	**22%**	**28%**	**22%**	**44%**
Overall Environmental Index	**1.04**	**1.17**	**1.04**	**1.91**

Notes to Table C-12:
1. Figures represent the impact relative to Plan 1958-DD expressed as ratios, where 1 represents no change from 58-DD, > 1.00 an improvement relative to 58-DD, and < 1.00 a deterioration relative to 58-DD.
2. S1 through S4 represent four separate 101-year extreme centuries selected from the 50,000-year stochastic series, where S1 is extremely dry, S2 is extremely wet and has a large range, S3 is similar to historical and S4 has the longest drought.
3. Aqua shading identifies species at risk.
4. Yellow shading indicates essentially no change from 1958-DD (within 10% difference). Anything above 1.10 is marked in **blue** and anything below 0.90 is marked in **red**.

***Table C-13:** Environmental results for candidate plans by interest and region based on the extreme stochastic supply sequence S3—a century with a similar range and average of supplies as the historical*

S3 –Similar to Historical (Environmental – Ratios)

Environmental Performance Indicators	Plan A+	Plan B+	Plan D+	Plan E
Lake Ontario				
Wetland Meadow Marsh Community	0.93	1.51	0.90	1.57
Low Veg 18C - spawning habitat supply	0.92	0.99	0.96	0.93
High Veg 24C - spawning habitat supply	1.03	1.01	0.99	1.08
Low Veg 24C - spawning habitat supply	1.01	1.02	1.03	1.13
Northern Pike - YOY recruitment	1.04	1.03	1.08	1.12
Largemouth Bass - YOY recruitment	0.96	1.00	0.98	0.97
Least Bittern (IXEX) - reproductive index	1.15	1.13	1.25	1.20
Virginia Rail (RALI) - reproductive index	1.16	1.13	1.25	1.19
Black Tern (CHNI) - reproductive index	1.16	1.15	1.25	1.19
Yellow Rail (CONO) - preferred breeding habitat	0.97	1.01	1.01	0.99
King Rail (RAEL) - preferred breeding habitat	1.05	1.10	1.09	1.22
Upper River				
Low Veg 18C - spawning habitat supply	1.02	1.00	1.03	1.04
High Veg 24C - spawning habitat supply	1.02	1.00	1.02	1.00
Low Veg 24C - sspawning habitat supply	1.01	1.00	1.02	1.02
Northern Pike - YOY recruitment	1.07	1.03	1.03	1.09
Largemouth Bass - YOY recruitment	0.99	1.00	1.00	1.00
Northern Pike - YOY net productivity	4.20	1.74	1.02	3.90
Virginia Rail (RALI) - reproductive index	1.13	1.20	1.31	1.33
Muskrat (ONZI) - house density in drowned river mouth wetlands	0.22	2.74	0.39	45.17
Lower River				
Golden Shiner - suitable feeding habitat area	1.05	1.03	0.96	1.11
Wetlands fish - abundance index	0.99	1.06	0.93	1.08
Migratory wildfowl - habitat area	1.11	1.05	0.86	1.08
Least Bittern - reproductive index	1.18	1.08	1.03	1.15
Virginia Rail (RALI) - reproductive index	0.93	0.96	1.07	0.97
Migratory wildfowl - productivity	1.09	1.07	1.01	1.11
Black Tern (CHNI) - reproductive index	0.96	1.07	1.09	1.08
Northern Pike (ESLU) - reproductive area	1.04	0.96	0.92	0.95
Frog sp. - reproductive habitat surface area	0.92	0.89	1.11	0.95
Eastern Sand Darter (AMPE) - reproductive area	1.07	1.01	1.05	1.04
Spiny Softshell Turtle (APSP) - reproductive habitat surface area	1.00	1.05	1.08	1.03
Bridle Shiner (NOBI) - reproductive habitat surface area	1.08	1.07	1.05	1.07
Muskrat (ONZI) - surviving houses	1.00	0.94	1.03	1.00
Percentage "good" scores for each plan	**25%**	**25%**	**19%**	**47%**
Overall Environmental Index	**0.99**	**1.26**	**0.99**	**4.72**

Notes to Table C-13:

1. Figures represent the impact relative to Plan 1958-DD expressed as ratios, where 1 represents no change from 58-DD, > 1.00 an improvement relative to 58-DD, and < 1.00 a deterioration relative to 58-DD.
2. S1 through S4 represent four separate 101-year extreme centuries selected from the 50,000-year stochastic series, where S1 is extremely dry, S2 is extremely wet and has a large range, S3 is similar to historical and S4 has the longest drought.
3. Aqua shading identifies species at risk.
4. Yellow shading indicates essentially no change from 1958-DD (within 10% difference). Anything above 1.10 is marked in **blue** and anything below 0.90 is marked in **red**.

Table C-14:* *Environmental results for candidate plans by interest and region based on the extreme stochastic supply sequence S4—the century with the longest sustained Lake Ontario drought

S4 –Longest Lake Ontario Drought (Environmental – Ratios)

Environmental Performance Indicators	Plan A+	Plan B+	Plan D+	Plan E
Lake Ontario				
Wetland Meadow Marsh Community	1.16	1.42	1.18	1.76
Low Veg 18C - spawning habitat supply	1.00	1.02	1.03	0.99
High Veg 24C - spawning habitat supply	1.16	1.03	1.13	0.95
Low Veg 24C - spawning habitat supply	0.97	0.99	0.98	0.99
Northern Pike - YOY recruitment	0.97	0.97	1.00	0.93
Largemouth Bass - YOY recruitment	1.03	1.03	1.08	1.01
Least Bittern (IXEX) - reproductive index	0.56	0.99	0.44	1.08
Virginia Rail (RALI) - reproductive index	0.60	0.95	0.44	1.09
Black Tern (CHNI) - reproductive index	0.59	0.95	0.44	1.09
Yellow Rail (CONO) - preferred breeding habitat	0.87	1.00	0.90	1.11
King Rail (RAEL) - preferred breeding habitat	0.73	0.93	0.74	1.16
Upper River				
Low Veg 18C - spawning habitat supply	0.94	1.00	0.95	1.04
High Veg 24C - spawning habitat supply	1.00	1.02	0.99	1.03
Low Veg 24C - sspawning habitat supply	0.95	1.01	0.95	1.05
Northern Pike - YOY recruitment	0.97	1.00	0.99	1.02
Largemouth Bass - YOY recruitment	0.97	1.01	1.00	1.03
Northern Pike - YOY net productivity	6.79	2.24	0.90	2.83
Virginia Rail (RALI) - reproductive index	1.28	0.99	1.23	0.59
Muskrat (ONZI) - house density in drowned river mouth wetlands	0.00	5.39	0.00	23.68
Lower River				
Golden Shiner - suitable feeding habitat area	0.80	1.03	0.87	0.99
Wetlands fish - abundance index	1.04	1.10	0.86	1.08
Migratory wildfowl - habitat area	1.16	1.18	0.97	1.19
Least Bittern - reproductive index	1.16	1.08	0.97	1.11
Virginia Rail (RALI) - reproductive index	0.88	0.91	1.08	0.88
Migratory wildfowl - productivity	1.05	1.01	0.96	1.07
Black Tern (CHNI) - reproductive index	0.84	0.86	0.93	0.89
Northern Pike (ESLU) - reproductive area	1.10	1.01	0.88	1.01
Frog sp. - reproductive habitat surface area	0.65	0.70	0.95	0.76
Eastern Sand Darter (AMPE) - reproductive area	0.67	0.82	0.97	0.75
Spiny Softshell Turtle (APSP) - reproductive habitat surface area	0.87	0.97	1.05	0.92
Bridle Shiner (NOBI) - reproductive habitat surface area	1.00	1.04	0.97	1.03
Muskrat (ONZI) - surviving houses	1.03	1.00	1.11	1.08
Percentage "good" scores for each plan	**19%**	**13%**	**16%**	**25%**
Overall Environmental Index	**0.93**	**1.41**	**0.88**	**2.95**

Notes to Table C-14:
1. Figures represent the impact relative to Plan 1958-DD expressed as ratios, where 1 represents no change from 58-DD, > 1.00 an improvement relative to 58-DD, and < 1.00 a deterioration relative to 58-DD.
2. S1 through S4 represent four separate 101-year extreme centuries selected from the 50,000-year stochastic series, where S1 is extremely dry, S2 is extremely wet and has a large range, S3 is similar to historical and S4 has the longest drought.
3. Aqua shading identifies species at risk.
4. Yellow shading indicates essentially no change from 1958-DD (within 10% difference). Anything above 1.10 is marked in **blue** and anything below 0.90 is marked in **red**.

Four Climate Change Sequences (C1-C4)

Table C-15: Economic results for candidate plans by interest and region based on the climate change sequence C1—warm and dry

C1 – Warm and Dry (Economic – Average Annual $M)

Average Annual Net Benefits ($M)	Plan A+	Plan B+	Plan D+	Plan E
Total	**$34.89**	**-$1.42**	**$20.09**	**-$4.91**
COASTAL	**-$0.20**	**$0.07**	**-$0.06**	**$0.14**
Lake Ontario	*-$0.46*	*$0.00*	*-$0.26*	*$0.06*
Shore Protection Maintenance	-$0.30	-$0.05	-$0.27	$0.01
Erosion to Unprotected Developed Parcels	-$0.15	$0.05	$0.01	$0.05
Flooding	$0.00	$0.00	$0.00	$0.00
Upper St. Lawrence River	*$0.00*	*$0.00*	*$0.00*	*$0.00*
Flooding	$0.00	$0.00	$0.00	$0.00
St. Lawrence	*$0.25*	*$0.07*	*$0.20*	*$0.08*
Flooding	$0.04	$0.00	$0.05	$0.00
Shore Protection Maintenance	$0.21	$0.07	$0.15	$0.08
COMMERCIAL NAVIGATION	**$0.70**	**$0.63**	**$0.68**	**$0.23**
Lake Ontario	$0.25	$0.18	$0.22	$0.07
Seaway	$0.69	$0.63	$0.71	$0.30
Montreal down	-$0.24	-$0.18	-$0.25	-$0.15
HYDROPOWER	**$6.57**	**$3.01**	**$1.98**	**$2.57**
NYPA-OPG	$5.00	-$0.06	$2.21	-$0.78
Hydro Quebec	$1.57	$3.07	-$0.23	$3.35
RECREATIONAL BOATING	**$27.86**	**-$5.09**	**$17.49**	**-$7.79**
Above Dam	*$25.55*	*-$7.71*	*$16.94*	*-$10.99*
Lake Ontario	$20.81	-$6.33	$13.36	-$9.03
Alex Bay	$3.77	-$1.79	$2.72	-$2.17
Ogdensburg	$0.72	$0.15	$0.60	$0.00
Lake St. Lawrence	$0.26	$0.26	$0.26	$0.21
Below Dam	*$2.31*	*$2.62*	*$0.55*	*$3.19*
Lac St. Louis	$1.34	$1.49	$0.30	$1.79
Montreal	$0.95	$1.01	$0.29	$1.20
Lac St. Pierre	$0.02	$0.12	-$0.05	$0.21
M&I	**-$0.03**	**-$0.05**	**$0.00**	**-$0.05**
SL One-time infrastructure costs	-$0.03	-$0.05	$0.00	-$0.05
LSL Water Quality Investments	$0.00	$0.00	$0.00	$0.00

Notes to Table C-15:

1. Figures represent the average annual impact relative to Plan 1958-DD, in millions of U.S. dollars. No discounting applied. **Blue** indicates a positive net benefit relative to 1958-DD and **red** indicates a negative net benefit relative to 1958-DD.
2. C1 through C4 represent four separate 101-year climate-change time series based on different supply series, where C1 is warm/dry, C2 is not so warm/dry, C3 is warm/wet and C4 is not so warm/wet.
3. Plan E is shown for comparison purposes only to represent the natural flow condition. Plan E is not a candidate plan.

Table C-16: Economic results for candidate plans by interest and region based on the climate change sequence C2—not as warm but dry

C2 – Not as Warm but Dry (Economic – Average Annual $M)

Average Annual Net Benefits ($M)	Plan A+	Plan B+	Plan D+	Plan E
Total	**$22.33**	**$11.17**	**$14.14**	**$8.04**
COASTAL	**-$0.02**	**$0.11**	**$0.07**	**$0.14**
Lake Ontario	*-$0.28*	*-$0.03*	*-$0.16*	*$0.12*
Shore Protection Maintenance	-$0.19	$0.10	-$0.16	$0.25
Erosion to Unprotected Developed Parcels	-$0.09	-$0.13	$0.01	-$0.13
Flooding	$0.00	$0.00	$0.00	$0.00
Upper St. Lawrence River	*$0.00*	*$0.00*	*$0.00*	*$0.00*
Flooding	$0.00	$0.00	$0.00	$0.00
St. Lawrence	*$0.26*	*$0.14*	*$0.22*	*$0.02*
Flooding	$0.05	$0.06	$0.19	-$0.01
Shore Protection Maintenance	$0.21	$0.08	$0.04	$0.03
COMMERCIAL NAVIGATION	**$0.21**	**$0.38**	**$0.27**	**$0.26**
Lake Ontario	$0.03	$0.03	$0.03	-$0.02
Seaway	$0.27	$0.41	$0.33	$0.30
Montreal down	-$0.09	-$0.06	-$0.09	-$0.02
HYDROPOWER	**$6.46**	**$8.12**	**$2.31**	**$8.12**
NYPA-OPG	$3.20	$3.43	$0.98	$3.00
Hydro Quebec	$3.26	$4.69	$1.33	$5.12
RECREATIONAL BOATING	**$15.48**	**$2.56**	**$11.30**	**-$0.48**
Above Dam	*$11.49*	*-$1.26*	*$8.22*	*-$4.81*
Lake Ontario	$9.44	-$1.06	$6.48	-$3.81
Alex Bay	$1.80	-$0.27	$1.52	-$0.96
Ogdensburg	$0.21	$0.03	$0.18	-$0.08
Lake St. Lawrence	$0.04	$0.04	$0.04	$0.04
Below Dam	*$3.99*	*$3.82*	*$3.08*	*$4.33*
Lac St. Louis	$2.02	$2.00	$1.49	$2.28
Montreal	$1.52	$1.34	$1.17	$1.52
Lac St. Pierre	$0.44	$0.48	$0.42	$0.53
M&I	**$0.20**	**$0.00**	**$0.20**	**$0.00**
SL One-time infrastructure costs	$0.00	$0.00	$0.00	$0.00
LSL Water Quality Investments	$0.20	$0.00	$0.20	$0.00

Notes to Table C-16:

1. Figures represent the average annual impact relative to Plan 1958-DD, in millions of U.S. dollars. No discounting is applied. **Blue** indicates a positive net benefit relative to 1958-DD and **red** indicates a negative net benefit relative to 1958-DD.
2. C1 through C4 represent four separate 101-year climate-change time series based on different supply series, where C1 is warm/dry, C2 is not so warm/dry, C3 is warm/wet and C4 is not so warm/wet.
3. Plan E is shown for comparison purposes only to represent the natural flow condition. Plan E is not a candidate plan.

Table C-17: Economic results for candidate plans by interest and region based on the climate change sequence C3—warm and wet

C3 – Warm and Wet (Economic – Average Annual $M)

Average Annual Net Benefits ($M)	Plan A+	Plan B+	Plan D+	Plan E
Total	**$21.61**	**$2.61**	**$17.77**	**-$2.46**
COASTAL	**-$1.36**	**$0.10**	**-$0.26**	**-$0.96**
Lake Ontario	*-$0.39*	*$0.13*	*-$0.31*	*$0.23*
Shore Protection Maintenance	-$0.32	$0.13	-$0.35	$0.23
Erosion to Unprotected Developed Parcels	-$0.08	$0.00	$0.04	$0.00
Flooding	$0.00	$0.00	$0.00	$0.00
Upper St. Lawrence River	*$0.00*	*$0.00*	*$0.00*	*$0.00*
Flooding	$0.00	$0.00	$0.00	$0.00
St. Lawrence	*-$0.97*	*-$0.02*	*$0.06*	*-$1.18*
Flooding	-$0.77	$0.04	$0.23	-$0.86
Shore Protection Maintenance	-$0.20	-$0.06	-$0.17	-$0.32
COMMERCIAL NAVIGATION	**-$0.06**	**-$0.01**	**$0.33**	**-$0.24**
Lake Ontario	$0.08	$0.05	$0.12	-$0.03
Seaway	$0.13	$0.14	$0.38	-$0.06
Montreal down	-$0.26	-$0.20	-$0.17	-$0.14
HYDROPOWER	**$4.95**	**$4.17**	**$4.11**	**$3.67**
NYPA-OPG	$3.93	$1.49	$1.94	$0.71
Hydro Quebec	$1.02	$2.67	$2.17	$2.95
RECREATIONAL BOATING	**$18.11**	**-$1.62**	**$13.58**	**-$4.88**
Above Dam	*$14.90*	*-$4.07*	*$11.61*	*-$8.16*
Lake Ontario	$12.13	-$3.22	$9.17	-$6.43
Alex Bay	$2.26	-$1.03	$1.96	-$1.75
Ogdensburg	$0.38	$0.04	$0.35	-$0.10
Lake St. Lawrence	$0.13	$0.13	$0.13	$0.12
Below Dam	*$3.21*	*$2.46*	*$1.97*	*$3.28*
Lac St. Louis	$1.55	$1.20	$0.84	$1.65
Montreal	$1.34	$1.02	$0.89	$1.28
Lac St. Pierre	$0.31	$0.23	$0.24	$0.35
M&I	**-$0.03**	**-$0.05**	**$0.00**	**-$0.05**
SL One-time infrastructure costs	-$0.03	-$0.05	$0.00	-$0.05
LSL Water Quality Investments	$0.00	$0.00	$0.00	$0.00

Notes to Table C-17:

1. Figures represent the average annual impact relative to Plan 1958-DD, in millions of U.S. dollars. No discounting is applied. **Blue** indicates a positive net benefit relative to 1958-DD and **red** indicates a negative net benefit relative to 1958-DD.
2. C1 through C4 represent four separate 101-year climate-change time series based on different supply series, where C1 is warm/dry, C2 is not so warm/dry, C3 is warm/wet and C4 is not so warm/wet.

Table C-18: Economic results for candidate plans by interest and region based on the climate change sequence C4—not as warm but wet

C4 – Not as Warm but Wet (Economic – Average Annual $M)

Average Annual Net Benefits ($M)	Plan A+	Plan B+	Plan D+	Plan E
Total	**$8.33**	**$11.78**	**$9.65**	**-$21.38**
COASTAL	**-$3.42**	**-$2.67**	**-$0.90**	**-$38.13**
Lake Ontario	*-$1.63*	*-$2.26*	*-$0.68*	*-$34.10*
Shore Protection Maintenance	-$1.46	-$2.04	-$0.60	-$12.26
Erosion to Unprotected Developed Parcels	-$0.16	-$0.20	-$0.08	-$0.40
Flooding	-$0.01	-$0.03	$0.00	-$21.45
Upper St. Lawrence River	*$0.00*	*$0.00*	*$0.00*	*-$1.84*
Flooding	$0.00	$0.00	$0.00	-$1.84
St. Lawrence	*-$1.80*	*-$0.41*	*-$0.22*	*-$2.19*
Flooding	-$1.62	-$0.43	-$0.10	-$1.95
Shore Protection Maintenance	-$0.18	$0.02	-$0.12	-$0.24
COMMERCIAL NAVIGATION	**-$0.61**	**$2.74**	**$3.06**	**$5.21**
Lake Ontario	-$0.04	-$0.01	-$0.01	-$0.01
Seaway	-$0.56	$2.73	$3.00	$5.17
Montreal down	-$0.01	$0.02	$0.07	$0.06
HYDROPOWER	**$7.29**	**$8.89**	**$4.01**	**$17.95**
NYPA-OPG	$5.73	$7.50	$3.62	$15.26
Hydro Quebec	$1.56	$1.39	$0.39	$2.69
RECREATIONAL BOATING	**$5.07**	**$2.83**	**$3.48**	**-$6.40**
Above Dam	*$3.28*	*$1.73*	*$2.62*	*-$8.06*
Lake Ontario	$1.93	$0.68	$1.36	-$7.06
Alex Bay	$1.33	$0.94	$1.14	-$0.96
Ogdensburg	$0.01	$0.01	$0.01	-$0.15
Lake St. Lawrence	$0.00	$0.10	$0.11	$0.11
Below Dam	*$1.79*	*$1.10*	*$0.86*	*$1.66*
Lac St. Louis	$1.03	$0.68	$0.50	$0.95
Montreal	$0.64	$0.40	$0.32	$0.60
Lac St. Pierre	$0.12	$0.02	$0.04	$0.11
M&I	**$0.00**	**$0.00**	**$0.00**	**$0.00**
SL One-time infrastructure costs	$0.00	$0.00	$0.00	$0.00
LSL Water Quality Investments	$0.00	$0.00	$0.00	$0.00

Notes to Table C-18:

1. Figures represent the average annual impact relative to Plan 1958-DD, in millions of U.S. dollars. No discounting is applied. **Blue** indicates a positive net benefit relative to 1958-DD and **red** indicates a negative net benefit relative to 1958-DD.
2. C1 through C4 represent four separate 101-year climate-change time series based on different supply series, where C1 is warm/dry, C2 is not so warm/dry, C3 is warm/wet and C4 is not so warm/wet.
3. Plan E is shown for comparison purposes only to represent the natural flow condition. Plan E is not a candidate plan.

Participants

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Annex 4
Mitigation and Adaptive Management Action Plans

Introduction

This annex includes prototypes of mitigation and adaptive management plans. The International Joint Commission (IJC) would rely on agencies from both Canada and the United States if it were to pursue mitigation or adaptive management, and practical plans could be developed only as the result of those negotiations; they cannot be rigorously defined in the abstract by the Study Board.

The Study Board articulated its philosophy on mitigation in its fourth guiding principle, including the idea that mitigation would be required for those who suffered disproportionate losses from the change in regulation plans. The great majority of Study Board members felt that none of the candidate plans creates disproportionate loss or requires mitigation, but those who felt mitigation was necessary identified coastal stakeholders. The mitigation plan outlined in this annex calls for regulatory process relief (not a reduction in environmental protection) from state, provincial and federal authorities for the people who live along the shoreline, and an extension of the Corps of Engineers "Advance Measures" flood protection program, which are initiatives that the Board feels could be pursued without a finding of disproportionate loss.

The prototype action plan for adaptive management presented in this annex is a template developed by the Plan Formulation and Evaluation Group (PFEG). It was not reviewed and discussed by the full Study Board and therefore should not be construed as having full Board endorsement.

Mitigation Action Plan

Summary

- Since the IJC has no authority to implement mitigation, it can only suggest certain adjustments in existing management and mitigation measures related to flood risk reduction, for implementation by other federal, provincial, state and local authorities, where appropriate.

- The Commission's principal role in promoting mitigation will be its authority to *convene and convince the respective responsible entities* to undertake the suggested mitigation actions as a desirable complement to the selected Plan.

- Most of the potential mitigation requirements address slightly increased flooding and shoreline erosion, primarily on the U.S. side. Shoreline erosion, however, is inexorable, and long-term maintenance of existing shoreline protection structures is unsustainable under any of the Plans.

- The potential mitigation measures must be compatible with and build on prevailing coastal zone management practices.

- The following two principal mitigation measures are proposed for further consideration as part of the IJC Mitigation Action Plan:

  1. Consolidation and revision of the current shoreline protection permit procedures of New York State (Department of Environmental Conservation and Coastal Management Dept) and the Corps of Engineers as part of a new General Permit for existing shore protection structures. This will accommodate new design criteria necessitated by changes in Lake Ontario's average and 100-year range levels, inherent in the selected Plan.
  2. Extension of the Corps' Advance Measures flood protection program, to be specifically adapted to the unique conditions of the Great Lakes, for extreme flood conditions greater than the 100-year range.

Background

Mitigation actions are rarely taken as single measures—most are packages of complementary measures, relying on an extensive web of supporting regulations and mechanisms that already exist to address such problems. Rarely is a mitigation action implemented that is new or unique to the issue at hand. Hence, most mitigation actions are extensions, improvements or refinements of existing practices—that are not quite well coordinated or well adapted to the existing situations. The rationale and the logic behind mitigation are based on three generally accepted conditions:

- There must be significant loss or disproportionate harm, when evaluated against a baseline or existing condition.
- Damage (or losses) must be caused by an action by an identifiable entity.
- Mitigation action must be commensurate with loss, and compatible with and complementary to prevailing practices.

The great majority of potential actions and measures aimed at flood damage reduction and erosion protection are available, accessible, and part of the existing suite of conventional regulatory and coastal and land use management practices in most jurisdictions, applicable to both new development and existing private infrastructure. These measures are designed to provide homeowners with a range of remedies for flood damage and erosion reduction and protection, in acknowledgment that these risk reduction measures are components of an overall strategy, none of which individually, or collectively, can entirely prevent flooding or erosion under all circumstances.

The following is a summary of the losses for each of the candidate Plans, compared with the existing baseline condition, Plan 1958-DD:

- **Plan A^+** has small flooding damages in the upper and lower St. Lawrence River and a reduction in the numbers of the Least Bittern, a threatened species.

- **Plan B^+** has small erosion and shore protection maintenance losses on Lake Ontario, and flooding and maintenance losses on the upper St. Lawrence River as well as the lower St. Lawrence River. There is also a small loss in recreational boating on Lake Ontario and the upper St. Lawrence River. Plan B^+ has some reduction in the numbers of a few species, none of which are threatened or endangered.

- **Plan D^+** has minor shore protection and erosion damages on Lake Ontario, and recreational boating damages above the dam. The only environmental loss is a reduction in the wetlands fish abundance index on the lower river, rather than in a particular species, and the reduction is unidirectional for all plans, including the Natural Flow plan.

Fundamentally, plans A^+ and B^+ raise average water levels on Lake Ontario somewhat, while Plan D^+ decreases them slightly (+8 cm, Plan A^+; +5 cm, Plan B^+; -1 cm, Plan D^+), with some seasonal differences among the plans (see Final Report – Figure 29). The candidate plans also change the frequency of occurrence of extreme high and low lake levels, but by relatively small amounts. Plan A^+ reduces the frequency of the most extreme high and low levels on Lake Ontario somewhat, but with some increase in range in the levels on the lower St. Lawrence. Plan B^+ increases the frequency of the most extreme high levels slightly but reduces the frequency of very low levels on Lake Ontario somewhat, again with some increase in range in the levels on the lower St. Lawrence. Plan D^+ changes the frequency of the extremes by the least amount. Although the absolute peak levels are increased somewhat with Plan B^+, the frequency of those peaks is beyond the 100-year return period. The statistically determined 100-year peak of lake levels, does not change significantly, however, for any of the plans (-6 cm, Plan A^+; +11 cm, Plan B^+; +1 cm, Plan D^+). Changes in the 100-year peak levels of the St. Lawrence River in the Montreal area are somewhat larger for Plan A^+, but still relatively small for the other plans (+33 cm, Plan A^+; +10 cm, Plan B^+; -6 cm, Plan D^+). The physical flooding and erosion effects of such minor alterations of hydrologic variability can be significant at the extremes, and there are specific existing programs that deal with these unique conditions, such as the Corps of Engineers Advance Measures program. This program subsidizes the rapid upgrading of flood protection infrastructure *in advance of* predicted extreme flood conditions. The situation in the Great Lakes, and especially in the Lake Ontario-St. Lawrence River system, is one that lends itself to long-term (3-6 months) predictions of inflows, and provides adequate time for responses and adjustments.

Action Plan

Canada, as a rule, is better adapted to the hydrologic conditions on the Lake and River in terms of its regulatory criteria and land use management practices. As a consequence, the erosion damages associated with each Plan are significantly smaller on the Canadian side of the border. Flooding does not tend to be a major problem under any of the candidate plans, although there is a small increase in flooding on the lower St. Lawrence River under plans A^+ and B^+. Although the suggested mitigation pertains mostly to the U.S. side, where the anticipated damages are the most pervasive, the general principles can be applied in Canada. The mitigation plan has two components: adapting to the modified 'normal' 100-year range, and dealing with extreme events beyond the 100-year range. It should be understood, however, that shoreline and bluff erosion is inexorable, under any plan, ranging from 10 to 15 m (30-50 ft) over the next 30 years, for sandy shorelines. Ultimately, maintenance of the existing shore protection structures will not be sustainable, under any circumstance, because of erosion and undercutting of those structures. Private property owners will have to gradually set back their protection structures.

100-Year Range

The most significant and practical mitigation measure that directly addresses the flooding, erosion damage and shore protection maintenance issues is *amendment of the permitting procedures* for individual homeowners with *existing shore protection structures*. This is needed to allow homeowners to adjust, in a timely manner, to the new hydrologic regime imposed by whatever plan is selected. The current rules, regulations and procedures have adapted to the historical conditions and ranges of flows and lake levels, and there has been an accumulation of various local land use, coastal zone management and environmental regulations both for new construction and maintenance of existing structures. These types of rules and procedures have proliferated to such an extent that a comprehensive review and streamlining of them would be worthwhile under any circumstance. It is recommended that this review, consolidation and streamlining of the permitting procedures be undertaken jointly by New York State and the Corps of Engineers, under the rubric of a *General Permit* that specifically addresses those existing structures which would be affected by the new Lake Ontario regulation plan.

Extreme Flood Conditions

Public Law 84-99 (*Flood and Coastal Storm Emergencies Act*) (PL 84-99) provides the legal authority for the involvement of the Corps of Engineers in civil disaster response. Advance Measures constitute one of six response activities under PL 84-99 and cover preventive temporary works executed, prior to predicted unusual flooding, in order to protect against loss of life and damage to property. The Advance Measures program is used frequently in those regions where flood forecasts can be made sufficiently in advance to undertake preventive measures before flooding begins. This is especially true for the Great Lakes, where fairly reliable forecasts of lake levels can be made up to six months in advance of the inflows.

Given the new regulations and criteria established for the Plans, and the requirements for a probabilistic forecast for inflows into Lake Ontario, the situation lends itself to the Corps' Advance Measures program as it meets all the prerequisites established for the Program. Hence, it has been recommended by the Corps that a separate Advance Measures program be legislatively authorized to focus exclusively on the unique conditions and problems within the Great Lakes. A rough draft of such legislation is attached below. The role of the IJC would be to assist the Corps in advocating such legislation as part of the mitigation requirements for the adoption of any of the candidate Plans.

Great Lakes Advance Emergency Management Program

Draft Legislative Proposal

1. PURPOSE OF LEGISLATION: Advance Planning and Preparation for Emergency Protection and Hazard Mitigation for At-risk Communities and Homeowners Along the Great Lakes.

2. CITATION OF LAW (LAWS) BEING AMENDED: P.L. 84-99.

3. LEGISLATIVE OBJECTIVE: The objective of this proposal is to overcome substantial and repeated deficiencies and challenges in providing timely, economic and fully effective emergency protection and hazard mitigation for at-risk communities along the Great Lakes when severe storms occur during periods of record or near record high lake levels. Providing for programmatic development of contingency plans and preparations for mitigation projects during non-emergency periods would facilitate this objective. Actual construction of protection measures and employment of other mitigation measures would be deferred until such time as the next episode of high lake levels occurs.

4. EXISTING AUTHORITIES CONSIDERED AND REJECTED: Neither P.L. 84-99, as amended, nor other authorities such as for Planning Assistance to States or Flood Plain Management Services, provides the authority to develop emergency plans prior to the existence of imminent emergency conditions, especially in consideration of the expansive scope of at-risk development around the Great Lakes.

5. OTHER FACTS AND DISCUSSION: During 1997 - 1998, the Great Lakes experienced near record lake levels. High lake levels also were present in 1973-1974 and 1985-1986, with record lake levels in 1986. During each episode, property damages were severe, even though many communities had been provided limited emergency protection as part of the Corps' Advance Measures program under authority of PL 84-99. Advance Measures are being used repeatedly in the same locations in the Great Lakes when lake levels become high. Often, the sites considered for Advance Measures projects in 1997-1998 had "semi-permanent" protection measures built during the earlier periods. All previous protective work required rebuilding, strengthening, expanding and/or raising. Some projects met insurmountable delays such that they could not be completed prior to lake levels receding late in 1998. Delays were caused by inclement weather, acquisition problems, court actions, contractor problems, and difficulties with Project Cooperation Agreements. These delays could have been avoided by pre-disaster development of contingency plans and preparations in coordination with non-Federal sponsors, contractors and resource agencies.

Adequate protection and hazard mitigation has not been developed for the Great Lakes over the past 30 years through repeated application of emergency authority. Neither could it have been through non-emergency, traditional procedures. A principal reason is that although truly permanent projects are evaluated over their lifetimes for high water levels that will occur in some unknown future year, in most years, they will not be needed. Because the chance that high levels will happen in any given year is low, the probable or expected damages that the project is intended to avoid are often lower than the project costs. But when the time comes that high waters threaten those homes that could not be protected in advance, emergency measures are often taken to protect against the most immediate dangers. As emergency measures, they may not be well planned or their impacts carefully reviewed, the scale may be shortsighted, and competitive bidding from contractors may be harder to secure. Moreover, high lake levels, unlike river floods, tend to persist for a few years and may even be worse in the second or third year, requiring still more incremental emergency work. In the end, more money will have been spent than would have been required for a well-planned project that offered better protection and fewer negative impacts. The consternation induced by this dilemma revolves around predictive analysis and the "hard" nature of constructed works necessary to withstand the forces of storm induced wave action.

To resolve the dilemma, a comprehensive program is needed that would be tailored to the Lakes' unique and complex circumstances. Pre-planned, phased development is key to adapting to the multiple levels of probabilities, and their economic ramifications. Such an approach would provide for non-emergency site preparation and contingency planning, coupled with delayed, or phased construction of protective works only when and if threatening conditions eventuate.

The non-emergency phase would include acquisition of lands, easements and rights-of-way for an ultimately completed project, limited site preparation (e.g., relocation of utilities and other obstructions) and, where feasible, relocation of existing development, such that the later construction phase could proceed uninhibited under emergency conditions. Contingency planning would provide for the plans and specifications for the emergency phase, including options to construct protection only to the forecast levels.

This phased approach would greatly reduce the dependency of economic analysis on the uncertainty of base lake level probabilities, and would defer major expenditures until immediately before benefits would begin to accrue, thereby greatly enhancing economic propriety. The economic analysis could be accomplished in advance, while largely ignoring long-term lake level probabilities. Further, the first phase work and the contingency planning would greatly ease the demands on Corps capabilities and resources during emergencies of disaster proportions.

To accommodate such an approach, a general plan for all Great Lakes communities at risk would be developed, considering priorities based on degree of risk and non-Federal desire to participate. The general plan would include baseline environmental and economic assessments, such that planning for individual projects might be expedited. Upon adoption of a general plan, individual feasibility studies would be conducted for specific areas of potential flood threat, including the contingency plans for ultimate project completion during emergency periods. Both the general plan and the specific plans would be reviewed periodically to keep the plans and funding requirements current. At that point, the first phase of projects could be implemented. The contingency plans would then be implemented if certain threshold emergency conditions were met, such as a given lake level.

6. BUDGETARY IMPACT (cost, revenue, or savings): The cost of the program is estimated to be $750,000 for development of the general plan and $50,000 for each specific project plan. It is the objective to develop specific project plans for the 50 most at-risk communities, resulting in total program costs, funded through the Flood Control and Coastal Emergencies (FCCE) account over the next five years, of $3,250,000. Savings which would accrue in future years as a result of eliminating the periodically repeated rebuilding of less permanent measures could be expected to be in the order of $500,000 to $1,500,000 per project. Substantial benefits would accrue as the result of providing adequate, timely protection and other mitigation measures.

7. DRAFT LEGISLATIVE LANGUAGE: "SECTION XXX. Great Lakes Advance Emergency Management Program.

"(a) Program. The Secretary of the Army is authorized to undertake an advance emergency management program to reduce the risk of storm and flood damages at communities along the Great Lakes, and to otherwise provide hazard mitigation in accordance with a general plan to be developed by the Secretary.

"(b) General Plan. (1) The Secretary shall complete a general plan for the program authorized in subsection (a), setting forth an economically justifiable and environmentally sound program to mitigate risks and provide protection to at-risk communities along the Great Lakes. (2) The general plan shall identify those communities having high risk of extraordinary damage as a result of storms and lake levels of a magnitude equivalent to the maximum of record, and establish guidelines and criteria for subsequent development of specific project plans in accordance with subsection (c) of this Section. (3) The general plan shall include the Secretary's schedule for initiating and completing specific project plans and for implementing advance project preparations in accordance with subsection (d) of this Section. (4) No later than 18 months from the date of enactment of this section, the Secretary shall submit the general plan to Congress.

"(c) Specific Project Plans. (1) The Secretary is authorized to prepare specific project plans, provided that work on such plans shall not commence prior to submission of the General Plan to Congress. (2) Such plans shall: (i) provide for advance project preparation in accordance with subsection (d) of this Section; and (ii) include contingency plans for implementing the emergency phase completion of projects at such time as threshold risk levels occur.

"(d) Advance Project Preparations. The Secretary is authorized to undertake, during non-emergency periods, advance project preparations of project sites including, but not limited to, stockpiling of construction materials, advance arrangements with contractors, and implementation of agreements with non-Federal sponsors for acquisition of lands, easements and rights-of-way, limited site preparation including relocation of utilities and other obstructions, and relocation of existing developments, and other advance preparations as the Chief of Engineers may deem advisable.

"(e) Threshold Risk Levels. The Secretary shall establish threshold risk levels for commencing emergency phase completion of specific projects. Such threshold levels shall be no less than the still water level at the point in time when a still water level within 0.3 m (1.0 ft) of the maximum still water level of record, or higher, can be reliably forecast.

"(f) Emergency Phase Project Completion. The Secretary is authorized to undertake completion of projects for which advance preparations have been made, at such time as threshold levels established in accordance with subsection (e) of this Section have been reached.

"(g) Annual Report to Congress. The Secretary shall provide, at least annually, a report on the status, progress, and effects of work accomplished pursuant to this Section.

"(h) Appropriations. There is hereby authorized to be appropriated, to carry out the requirements of this Section, not in excess of $1,000,000 annually for the first four years subsequent to enactment of this Section.

8. DRAFT REPORT LANGUAGE.

"Section XXX establishes a mechanism for the Corps of Engineers to provide adequate storm protection and hazard mitigation for communities along the Great Lakes where repeated emergency measures have failed to provide timely and reliable protection, and where excessive costs have been incurred for rehabilitation and expansion during periods of historically high lake levels.

"The Section authorizes an advance emergency management program, based on a general plan for the Great Lakes to be developed by the Secretary. The general plan will consider priorities based on degree of risk and non-Federal desire to participate, and will include baseline environmental and economic assessments, such that planning for individual projects are expedited. Upon adoption of the general plan, specific project studies will develop advance preparation plans and contingency plans for later project completion during emergency periods. The advance preparation phase of projects will be implemented during non-emergency periods. Contingency plans will be implemented when certain threshold emergency conditions pose a risk of imminent and substantial losses.

"The phased approach will reduce the dependency of economic analysis on the uncertainty of lake level probabilities, and will defer major expenditures until immediately before benefits would begin to accrue, thereby greatly enhancing economic propriety. The advance preparation phase work and the contingency planning will ease the demands on Corps capabilities and resources during emergencies of disaster proportions. Savings will accrue in future years as a result of eliminating the periodically repeated rebuilding of less permanent measures under emergency conditions without advance preparation."

Adaptive Management Action Plan (AMAP)

This is the Plan Formulation and Evaluation Group's outline of a formal adaptive management action plan (AMAP) for the regulation of Lake Ontario. One of the Board's guiding principles was to propose solutions that could be adapted to changing conditions and knowledge. This AMAP is meant to address uncertainty in the information and models that were used to forecast benefits and costs, serving as a check to verify that the actual system outcomes are consistent with projections. The AMAP can provide the basis for revising the regulation rules as improved information becomes available, rather than waiting for a new comprehensive study. The AMAP addresses four issues the Study Board feels need to be verified and updated in the foreseeable future: Lake Ontario wetlands, damages to Lake Ontario riparians, recreational boating above the dam and forecasting water flow into Lake Ontario. The purpose of the outline is to create a tangible proposal that can be debated and improved by the Study Board and the international Joint Commission (IJC). Once they agree on a revised outline, work can proceed on a practical work plan with budgets, schedules and personnel assignments.

Management is adaptive if it changes as the managed system, or knowledge of it, changes. The adaptation can be formal or *ad hoc*. The deviations from Plan 1958-D constitute a form of adaptive management; had the IJC not deviated from 1958-D, many of the homes along the Lake Ontario shore would have been destroyed.

An adaptive management strategy is not necessary for every aspect of the regulation plan because the regulation strategy for Lake Ontario has been tested for decades and it is capable of effectively addressing multiple purposes (with clear exceptions described below). In general, the strategy for regulation of Lake Ontario is to keep sufficient water in Lake Ontario for use in long droughts, but not so much that it would cause flooding along the Lake Ontario shore. Releases are limited by conditions in Lake St. Lawrence and the St. Lawrence River. Stakeholders in the lower river, who need enough depth for boating or navigation or drinking water, benefit from this general strategy, as do multiple interests on Lake Ontario. This means that the future could bring major changes in the system demands without diminishing the wisdom of this basic regulation strategy. For example, if the Seaway closed, water would still have to be released through the Seaway channel for boating, municipal supply and shipping in Montreal Harbor.

Areas for Adaptive Management

The study team identified the following four circumstances in which changes in the system or changes in what we know about the system could provide reason to change any of the candidate plans:

- If the effect of water levels on erosion and flooding along the Lake Ontario shore is different from what the models predicted;
- If the response of Lake Ontario wetlands is different from what the models predicted;
- If recreational boaters and related groups change their vulnerability to low water or if our modeling of impacts is wrong;
- If we were able to make better forecasts of the net total water supply to Lake Ontario each fall through to the end of the next spring.

The Board of Control would be responsible for the adaptive management program. A technical advisor from the Corps of Engineers and an advisor from Environment Canada could manage the program jointly, arranging funding, scheduling work, interpreting new information, drafting reports, reformulating and re-evaluating plans and advising the Board of Control. All funding for adaptive management would be provided through existing agency programs in both countries. The agencies are unlikely to reshape their budgets and programs to provide the monitoring services needed unless the IJC actively lobbies for a better-integrated, results-oriented investment and management strategy for government and non-government Great Lakes programs.

The AMAP has three principal components:
1. Mathematical models of how water levels drive the impact;
2. A monitoring program;
3. A protocol for determining whether and how the discovery of new information would lead to changes to the model or the regulation plan.

1. Mathematical models

Tradeoffs among erosion, wetlands and recreational boating above the dam dominated the final year of the Board's deliberation. Under that scrutiny, the Board identified specific uncertainties about the erosion, wetlands and recreational boating models. Adaptive management can help resolve the remaining doubts and may lead to regulation plan revisions that reduce damages and increase overall benefits.

The following concepts shape the models:

- High Lake Ontario levels, especially in spring, fall and winter, increase the risk of flooding, hasten the loss of shore property and increase annual maintenance and replacement costs for shore protection structures. Low levels can also increase erosion and shore protection costs because wave action erodes the toe of the bank, undermining the shoreline and requiring new shore protection structures that are more expensive because they have to be extended more deeply.

- More natural variability in Lake Ontario levels, especially more natural extended low lake levels, will provide more diverse wetland plant communities which will favor different animals at different times. This increases the chances of having sustainable populations of many different animals, including birds that are now at risk. Greater species diversity should make the Lake Ontario ecosystem more robust and therefore better able to withstand the threats of invasive species and pollution.

- Low water problems for recreational boaters begin at water levels that are quite common. This is in part because the popularity of boating has caused people to put docks, boat ramps and marinas in marginal locations that often do not have enough water to support the boats that moor there.

There is some conflict among these three: keep levels near average to avoid erosion; keep levels lower during long droughts to help the environment, and keep levels higher to avoid boating problems. These conflicts were balanced in slightly different proportions in the three candidate plan options, which explains why Plan 1958-DD is so good for shore property but not as good for the environment as Plan B, and why Plan B is so good for the environment, but not as good as Plan 1958-DD for shore properties or boaters on Lake Ontario down to Alexandria Bay.

The Board's evaluations have highlighted some specific issues in mathematical models that are both uncertain and influential in shaping the regulation plan. The key variables most likely to change the regulation plan, if future monitoring shows model algorithms were misleading, are:

- **Erosion rates and shore protection replacements.** The three candidate plans all take slightly different approaches to minimizing coastal damages, and each causes negative impacts in some other sector. Estimates of coastal damage may not be accurate enough to guide these tradeoffs. For example, the so-called design water level used in the Flooding and Erosion Prediction System (FEPS) model is a single number for each county around Lake Ontario that represents the additional design height of shore protection structures to account for waves and surges. The number used reflects accepted engineering standards based on historical wave and surge patterns. Homeowners should have followed these specifications when building their shore protection structures, but field studies were not conducted to confirm this. Experience with the Lake Ontario shore indicates that few homeowners "overbuild" their structures, and relatively small changes in this one parameter can make a big difference in evaluations. If, for example, the as-built shore protection structures were about 25 cm (9 in) higher than design standards on the U.S. shore, Plan B^+ shore protection maintenance costs would be about the same as other plans.

- **Populations of wetland birds considered at risk.** Data collected for this study demonstrate the strong correlation between flooding history and plant mixes in coastal wetlands. Data also demonstrate correlations among bird occurrence, specific vegetation communities, and habitat flooding. There is less certainty about the degree of wetland bird response to future changes in habitat availability, especially in the case of those species considered at risk. This is because our bird models assume that habitat availability, as influenced by water level regulation, is the primary limitation to wetland bird population distribution and abundance in Lake Ontario. The models did not capture all of the factors that can affect population, e.g., the effects of pollution, predation and competition for habitat.

- **Muskrat population in the upper river.** The muskrat is important because it helps control cattails, because it is an indicator species, and because the trapping of muskrats is a traditional Akwesasne activity. Models predict that different plans will have dramatically different effects, but the models are based on limited data.

- **Fall boating activity.** Models estimate recreational benefits based on days boated in 2002 plus boaters' estimates of the number of days they would have boated if water levels were sufficient. The International Water Levels Coalition argues that boating activity declines in the fall partially because boaters fear they will not have enough water to use their boats or to get them out of the water for winter storage. This hypothesis was not tested and there is no "feedback loop" in the model to adjust boating benefits accordingly. If this does happen, the negative impacts of Plan B^+ would be reduced.

- **Boating impacts in marginal areas.** Boating impacts related to insufficient depth occur when Lake Ontario is at its long-term average levels. Cornell University researchers obtained a bottom elevation measurement for every slip in every U.S. marina, and the results of that survey show that 1 to 3% of all Lake Ontario marina slips will have depth problems at average levels between May 1st and September 30th. Further problems may be experienced in entrance channels, at boat ramps and on private docks. This represents a population of over two hundred boaters who will have problems in most seasons. There were discussions during the Study about how boaters and marinas in this group could address shallow-water issues individually, but no further steps to assist them were taken.

2. Monitoring program

The key variables described above would be monitored after a new plan is put into effect. If the monitoring suggests that the system has changed or the algorithms were wrong, the protocol in the section that follows this would be used to determine what model and plan changes the IJC should consider.

The monitoring plan would consist of field studies of wetlands, at-risk wetland bird populations, Northern Pike, and muskrats, aerial and satellite photographic studies of shorelines, data collection from permit applications for new shore protection, and information collected voluntarily by boating and marina organizations.

Environmental monitoring

Purpose: Monitoring for the environment would help determine whether the impact of regulation on wetlands, birds at risk, and muskrats is consistent with the predictions of the models.

Outcome: Continuous monitoring of animal populations along with wetland conditions could provide a rationale for adjusting the regulation plan according to whether it is clearly effective or clearly not effective.

Assessment of existing programs shows that the environmental monitoring would have to be based mostly on new efforts carried out specifically for the IJC, with existing monitoring programs used solely for comparison and validation. A selected subset of the Study's 32 wetland sites would be monitored, using similar methods, to inventory plant species. Population studies of birds at risk on Lake Ontario and muskrat on the upper river would also be commissioned. Monitoring would begin as soon as possible for birds and muskrat, but could wait until after unusual water level conditions for wetlands. Monitoring could be coordinated at the IJC, with field work carried out by contractors, probably working for the New York State Department of Environmental Conservation (NYSDEC) and Environment Canada.

Funding: No sure source of funding for this work has been identified. Funding could come from a U.S. Fish and Wildlife Service grant to NYSDEC to carry out the state wildlife management plan. This plan—the Comprehensive Wildlife Conservation Strategy (CWCS)—has recently been submitted, and the portions that address the Lake Ontario shoreline highlight the need for monitoring of Least Bittern and Black Tern populations in coastal marshes.

No funds options: Failing new funding, some ongoing programs can be identified that would offer small pieces of what is needed. We know of no efforts to sample the coverage of different wetland plant types on a routine basis (the center of study modeling) and none for muskrat. The Environment Canada Durham Region monitoring program and Bird Study Canada's Marsh Monitoring Program would offer valuable information about wetland birds, but those efforts are not designed to separate the effects of water levels from other factors that have an impact on population.

On the U.S. side, New York State's Comprehensive Wildlife Conservation Strategy calls for coastal wetland monitoring, particularly for "species of greatest conservation need" like the Black Tern and Least Bittern. The Nature Conservancy is prepared to work with partners as a catalyst for coastal wetland monitoring, seeking support to carry out recommendations of the CWCS. In order to receive federal funds through the CWCS, "planning" projects (like monitoring) require a non-federal match of 25%.

Other funding issues: An endowment could generate interest income that could pay for monitoring. If a way could be found to raise $1 million, New York State already has a mechanism, through the Great Lakes Protection Fund, to invest and manage an endowment and distribute the income for specified purposes. The NYSDEC makes recommendations to the citizen representatives on the Great Lakes Basin Advisory Council concerning the awarding of grants from its existing Protection Fund endowment. A monitoring program supported by this sort of dedicated funding would be less prone to interruption by future difficulties in the politics of state and provincial budgets.

Coastal Monitoring

Purpose: Monitoring for erosion and shore protection would be used to verify the modeled damages so that regulation could be modified if the actual damages are significantly different from the damages used to support plan selection.

Outcome: If damages are clearly less significant than modeled, the IJC could consider changes to the regulation plan that would allow for lake levels that produce greater benefits to other users. If the actual damages are more significant, the IJC would consider plan changes that would lower lake levels.

There are about 5,500 homes along the coast of Lake Ontario that already have shore protection structures, and only about 1,000 more shore protection structures will be built over the next hundred years, so the greatest cost (estimated at about $15 million per year) to riparians is the maintenance and replacement of existing shore protection. The next greatest cost (estimated at about $2.5 million per year) is the construction of new shore protection to prevent damage to buildings threatened by erosion. Flooding is an order-of-magnitude less costly, about $170,000 per year on average. The FEPS evaluations show real differences in shore protection costs among the plans, amounting to millions of dollars per year. The strategy for coastal monitoring would be to gather data on recession and new and replacement shore protection structure events to determine whether the model predicts these damages well and whether the response to low, average and high water events is as expected.

The FEPS model calculates the recession in the top of bank over time and specifies the time and type of failure of each shore protection structure. The FEPS model could be run each year with real water and wave data, and the predicted recession and shore protection events could be compared with what really happened. The cheapest and most effective way to monitor the position of the top of bank is through the use of satellite imagery. Construction or replacement of shore protection requires a permit in both countries, and permit data could be used, with owner permission, to monitor shore protection failures. A review of permits for new shore protection would also provide data on the position of top of bank.

Funding: There is no known source of funding specifically for this monitoring, nor have costs been estimated. Satellite monitoring would certainly require new authorization of funding.

Recreational Boating

Purpose: Monitoring for recreational boating would be used primarily to monitor and actively support user community efforts to reduce vulnerability to low water levels. User activity could also be monitored to determine if higher fall levels increase boating activity after Labour Day.

Outcome: Better communication among boating groups and marinas will help verify, fill in and update the data that drove plan formulation. IJC active outreach through the New York State, Ontario and Quebec governments and boating groups could discourage further placement of boating facilities in marginal areas and will at least give the most vulnerable boaters and businesses more information so they can adapt individually. If fall boating activity increases because of higher fall levels, the IJC would have more reason to persist in that strategy.

Recreational boating impacts typically involve lower water levels. Research on the U.S. shore was more successful because of the availability of boat information in that country, and it provided information on the bottom elevation of every marina slip. Many slips have marginal locations and will not be serviceable unless Lake Ontario levels are fairly high. The negative impact on boating is the main reason to oppose naturally low Lake Ontario levels during long droughts, even though such lows provide significant environmental benefits in evaluations.

Monitoring would be a volunteer effort organized through a semi-formal boating advisory committee representing existing boating organizations, such as the Ontario Marine Operators Association and the Canadian Power and Sail Squadrons. The Board of Control could revise its communication strategy to formalize two-way communications with an advisory committee. The Board could provide information regarding forecasted extreme levels to the boating community via an "early-alert system." An Advisory Committee would help spread those alerts to boaters. The Board could develop a practical guidebook for marina owners that would allow marinas to factor water levels into their business planning.

An Advisory Committee could report problems with water levels to the Board. The reports could focus on the most sensitive areas (e.g., the Gananoque area, Lac St. Louis, Alexandria Bay, North Sandy Pond), answering a short list of standard questions.

Adapting the plan as better forecasts are developed

Lake Ontario tends to reach its highest levels late in the spring, after spring runoff finally makes it way down from the upper Great Lakes. Plan 1958-DD generally causes the Lake to drain from its peak faster than it would naturally, and by fall this creates storage volume on the Lake to hold water in case the winter and spring ahead are wet. Plan B brings the Lake down at a more natural rate, usually leaving Lake Ontario at a higher level in the fall, with a higher risk of flooding the following year.

Studies showed that real-time forecasts of the net total supply of water over the next year are no better than statistically based forecasts. If accurate forecasts of even the next six to eight months' net total supplies to Lake Ontario were available, any of the candidate plans could be more precisely adjusted to lower the fall elevations only if the following year was going to be unusually wet. This would preserve (for example) the environmental benefits of Plan B^+, but would reduce coastal damages while not affecting or even improving recreational boating benefits.

The issue of better forecasting ties the three conflicting outcomes together and should also be a part of the adaptive management program. It might be possible to slightly improve forecasts through more clever statistical analysis, but a breakthrough in forecasting will probably be required in order to make a significant difference in benefits. Such breakthroughs may come from the research involved in long-term ocean temperature studies. In an April 2004 issue of Science magazine, Siegfried Schubert of NASA's Goddard Space Flight Center, found that it was possible to "forecast" the thirties' Dust Bowl drought by looking at tropical Pacific Ocean surface temperatures and tropical Atlantic Ocean temperatures together. The IJC should at least publicize the need for such research and encourage its supporting agencies to fund or conduct it.

Adaptive Management Program Summary Table

Study PI/Algorithm	Monitoring Area	Data collected	Possible links to existing programs*
Meadow marsh community surface area	Some of 32 study wetlands	Plant densities by type and elevation	1. New York State's Comprehensive Wildlife Conservation Strategy – CWCS. Requires 25% non-Federal cost sharing. 2. U.S. Fish and Wildlife Service grant to NYSDEC to implement the state wildlife management plan. 3. Environment Canada Durham Region monitoring program. 4. Bird Study Canada's Marsh Monitoring Program.
Least Bittern, Black Tern reproductive index Yellow Rail, King Rail preferred breeding habitat coverage	Lake Ontario	Marsh-nesting obligate bird populations, focus on species at risk	
Muskrat house density in drowned river mouths, Thousand Islands area.	Upper River	Populations	New program required.
Erosion	Lake Ontario	Bank recession	1. New satellite imagery capture and analysis program. 2. State and provincial permitting programs.
Shore protection	Lake Ontario	New and replacement structures	State and provincial permitting programs.
Boating benefits	Gananoque area, Lac St. Louis, Alexandria Bay, North Sandy Pond	Shallow water incidents	Would use a new network of existing boating groups.

* No existing programs will provide the monitoring needed, but they provide an authority and cost efficiencies that should be explored.

In addition, the IJC would encourage or fund research into improved six to twelve-month forecasts of net total supply to Lake Ontario.

3. The protocol for changing the regulation plan

The Board of Control would have overall management responsibility for adaptive management. The Board would issue a report every five years on the performance of the new plan. The report would include a comparison of modeled and measured impacts, the Board's conclusions on whether the plan was achieving the expected results, and recommendations for any model and plan changes. The Board would formulate and evaluate plan modifications and would present its report to the public as part of its public information program. The IJC would be free to accept, modify or reject the proposals. The Board would direct hydrologic forecasting research.

The Challenge of Funding Adaptive Management

Monitoring the effects of government regulations on public resources is inherently a government obligation, but there is no readily available source of government funding for this work, and it would be an extraordinary achievement if the IJC were able to secure the funding, as modest as it is. The preliminary estimate of cost for this adaptive management plan for all three purposes and the hydrologic forecasting research is $500,000 per year.

There are several initiatives that are intended to draw U.S. and Canadian agencies together to manage the Great Lakes in a more integrated way. Nonetheless, no unified set of quantifiable, prioritized management objectives for the Lakes exists, nor is there a formal or informal attempt to measure progress towards meeting management objectives or to tie progress to overall or specific investments. This means that the agencies invest the funds they receive in accordance with their own goals.

Real integration would require a sea change in agency cultures, but all agencies support the concept in principle. The best hope for securing funding for the monitoring portion of adaptive management of Lake Ontario regulation is to work with agencies from both countries as well as the Province of Ontario and New York State to integrate existing programs in such a way that the specific needs of IJC Boundary Water responsibilities could be met. This integration would be a two-way street. For example, Study Board work has focused on the effect of water levels on wetlands, whereas most ongoing work has targeted the impacts of pollution and development. An integrated program would look at all wetland functions on the Lake and all stressors and try to focus attention where the greatest increase in wetland services could result.

Only the IJC Commissioners themselves have the stature to approach the agencies on this subject with any hope of success. Until the end of the year, the Study Board, followed by the permanent agency staffs assigned to support both the Study and the operation of the regulation plan, can draft the arguments and do some of the legwork required to support the Commissioners.

The AMAP would help the Control Board address dissatisfaction with whatever regulation plan is used by bringing hard data to bear on what has been determined as the three principle areas of conflict. Although PFEG is suggesting that the Board of Control run the program, the current Board structure would have to change to accommodate that responsibility. Such change could include the use of Ottawa and Washington-based IJC staff members to manage this work as Board liaisons.

Glossary of Terms

ABIOTIC – Non-living factors in the environment (air, water, sunlight, minerals, etc.).

ACCRETION – An increase by natural growth or addition, used in the Study in terms of increased beach area or wetland.

ACOUSTIC SOUNDINGS – Technique of determining bottom depth in a body of water by transmitting sound waves through the water and measuring the reflected signals.

ADVERSE CONSEQUENCES – Negative implication of fluctuating water levels for social, economic, environmental or political investments.

AGREEMENTS – Joint statements among two or more governmental units on (i) goals and purposes which should guide basin decision-making, (ii) processes of decision-making and (iii) authorities of governments to act. Agreements are an attempt to remedy a shared problem, and they serve to define the boundaries and constraints on choice of measures.

ALGAE – Microscopic organisms found in or near water, classified as plants and capable of photosynthesis but having no roots, flowers or seeds. These constitute the primary producers in lakes. Freshwater and marine algae are found in many forms and are therefore a diverse group of photosynthetic plant organisms that vary widely in size, shape and color. Algae form ranges from the substance on rocks that it attaches to, to the froth on the water surface, to the seaweed on the shore.

ALTERNATIVE DISPUTE RESOLUTION (ADR) – A process aimed at reaching a consensus agreement in order to end a dispute or reduce conflict among interest groups that have some stake in and can influence the outcome of decisions or actions related to the water level issue. The distinguishing characteristics of alternative dispute resolution are that: (1) interest groups are actively included in developing and assessing alternatives and making tradeoffs between alternatives, and (2) issues are decided on their merits rather than on the interest's access to the decision-making process. Policy dialogues and negotiation are types of alternative dispute resolution processes.

ANTHROPOGENIC HABITAT LOSS – The loss of habitat due to human activities.

AQUIFER – Any subsurface material that holds a relatively large quantity of groundwater and is able to transmit that water readily.

AREA OF NATURAL AND SCIENTIFIC INTEREST (ANSI) – An area of land and water which, due to its natural landscapes or features, has been classified as having life science or earth science values related to protection, scientific study or education.

ARCHIPELAGOS – Expansive water with many scattered islands or a group of islands.

AUTHORITY – The right to enforce laws and regulations or to create policy.

AVERAGE WATER LEVEL – The arithmetic average of all past observations (of water levels or flows) for that month. The period of record used in this Study commences January 1900. This term is used interchangeable with monthly-mean water level.

AWNED SEDGE – An endangered species in New York State that is known as Carex atherodes or sedge.

BARRIER BEACH – An offshore ridge of unconsolidated material (sand, pebbles, etc.) that runs parallel to a coastline, is formed in part by high tides and acts as a natural barrier.

BASIN – The rounded depression of a lake bed.

BASIN (LAKE ONTARIO – ST. LAWRENCE RIVER) – The surface area contributing runoff to Lake Ontario and the St. Lawrence River downstream to Trois Rivières, Quebec.

BASIN; WATERSHED – The region or area of which the surface waters and groundwater ultimately drain into a particular course or body of water.

BATHYMETRY – The measurement and charting of water depths in large bodies of water; also information derived from such measurements.

BEACH – The zone of unconsolidated material that extends landward from the average annual low water level to either the place where there is marked change in material or physiographic form, the line of permanent vegetation, or the high water mark.

BENEFICIAL CONSEQUENCE – Positive implication of fluctuating water levels for social, economic, environmental or political investments.

BENTHOS - The plants and animals that live at the bottom of a body of water (ocean, river, lake, pond, etc.) either attached or unattached to substrate (sediment, rock, plant, etc.).

BIOTA – All plants and animals living in a given area.

BIRD GUILD – 1. A group of birds that have similar breeding habits. 2. A group of birds, not necessarily of the same species, that depend on the same environmental resources.

BLUFF – A steep bank or cliff or variable heights, composed of glacial tills and lacustrine deposits consisting of clay, silt, gravel and boulders.

BOAT LAUNCHING RAMP – A sloping structure allowing small recreational water craft and trailers access to water.

BOUNDARY WATERS TREATY OF 1909 – The agreement between the United States and Canada that established principles and mechanisms for the resolution of disputes between the two countries related to water. The International Joint Commission was created as a result of this treaty.

BREAKWATER – A barrier built offshore to protect a harbor or a beach from the force of waves.

BUFFER ZONE – The minimum amount of land needed between a structure and an eroding shoreline before shoreline protection is needed.

CHART DATUM – The water level used to calculate the water depths that are shown on “navigation charts” and are a reference point for harbour and channel dredging.

CLIMATE – The prevalent weather conditions of a given region (temperature, precipitation, windspeed, atmospheric pressure, etc.) observed throughout the year and averaged over a number of years.

COAST – The land or zone adjoining a large body of water.

COASTAL EROSION – The wearing away of a shoreline as a result of the action of water current, wind and waves.

COASTAL PROCESSES TECHNICAL WORK GROUP – A scientific and technical work group for the International Lake Ontario-St. Lawrence River Study that is investigating the impacts of water level fluctuations on shore property, with particular attention to erosion and flood processes.

COLONIAL BIRDS – Birds that nest in groups.

COMMERCIAL NAVIGATION TECHNICAL WORK GROUP – A scientific and technical work group for the Study that is investigating the impacts of water levels on cargo shipping, including tug and barge operations.

COMPUTER MODELLING – The use of computers to develop mathematical models of complex systems or processes.

CONNECTING CHANNELS – A natural or artificial waterway of perceptible extent, which either periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. The Detroit River, Lake St. Clair and the St. Clair River comprise the connecting channel between Lake Huron and Lake Erie. Between Lake Superior and Lake Huron, the connecting channel is the St. Marys River.

CONSERVATION – The planned management of a natural resource, with the goal of protecting and carefully preserving it from exploitation, destruction or neglect.

CONSUMPTIVE USE – The quantity of water withdrawn or withheld from the Great Lakes and assumed to be lost or otherwise not returned to them, due to evaporation during use, leakage, incorporation into manufactured products or otherwise consumed in various processes.

CONTROL WORKS – Hydraulic structures (channel improvements, locks powerhouses, or dams) built to control outflows and levels of a lake or lake system.

COSMOS MODEL – Name of the erosion prediction numerical model used in this Study for the Lake and upper river.

CRITERIA – A principle or standard by which a judgement or decision is made. Criteria are conceptual but must have operational (measurable in principle) components. Any single criterion can be used to compare the merit of measures or policies along the dimensions encompassed by the criterion. Criteria are used to assess measures and criteria are used to assess the decision-making process (for example, group access to the decision-making bodies).

CRITERIA, CORE – The broad principles upon which the overall value of any measure can be assessed relative to other measures. They include economic sustainability, environmental integrity, social desirability, uncertainty and risk, political acceptability and implementability, and equitability.

CRITERIA, OPERATIONAL – These criteria are subsets of the core criteria. These sub-criteria are quantified on the basis of the application of specific group rules to data or estimates of impacts of the measure. Impact assessments used to score sub-criteria are ultimately used to compare the profiles of measures.

CURRENT – The flowing of water in the lakes caused by the earth's rotation, inflows and outflows, and wind.

DESIGN RANGE – The range of factors (including expected water levels) taken into consideration when making an investment decision.

DIGITAL ELEVATION MODEL (DEM) – A digital image of geographical features consisting of a grid, in which the colour of each cell reflects an average elevation above or below sea level.

DIGITAL ORTHOIMAGERY – Computer-assisted cartography technique allowing representation of surface features with the positional accuracy of a map, through elimination of errors due to camera or sensor orientation and terrain relief.

DIGITAL ORTHOPHOTO – A computer-rendered image representing surface features, in which inaccuracies due to camera or sensor orientation and terrain relief have been removed. Such an image combines the positional accuracy of a map with the image quality of a photograph.

DIKE – A wall or earth mound built around a low lying area to prevent flooding.

DIVERSIONS – A transfer of water either into the Great Lakes watershed from an adjacent watershed, or vice versa, or from the watershed of one of the Great Lakes into that of another.

DRAINAGE BASIN – The area that contributes runoff to a stream, river, or lake.

DROWNED RIVER MOUTHS (also known as estuaries) – The place where lake and river waters mix. They provide valuable habitat for spawning fish, nesting and migrating birds, and many rare or specialized plants. These wetlands typically have deep organic soils that have accumulated due to deposition of watershed-based silt loads and protection from coastal processes (waves, currents, seiche, etc.).

DUNE – a mound or ridge of sand formed by the action of wind or waves.

ECOLOGY – The science which relates living forms to their environment.

ECOSYSTEM – A biological community in interaction with its physical environment, and including the transfer and circulation of matter and energy.

ECOSYSTEM INTEGRITY – A state of health, or wholesomeness of an ecosystem. It encompasses integrated, balanced and self-organizing interactions among its components, with no single component or group of components breaking the bounds of interdependency to singularly dominate the whole.

EMERGENTS – Plants rooted in soil under water but which emerge partially above the surface.

ENDANGERED SPECIES – A species threatened with extinction.

ENVIRONMENT – Air, land or water; plant and animal life including humans; and the social, economic, cultural, physical, biological and other conditions that may act on an organism or community to influence its development or existence.

ENVIRONMENTAL INTEGRITY – The sustenance of important biophysical processes which support plant and animal life and which must be allowed to continue without significant change. The objective is to assure the continued health of essential life support systems of nature, including air, water, and soil, by protecting the resilience, diversity, and purity of natural communities (ecosystems) within the environment.

ENVIRONMENTAL TECHNICAL WORK GROUP – A group of scientific and technical experts that is investigating impacts of water level variations on fish, birds, plants and other wildlife in the Lake Ontario-St. Lawrence River system, with particular attention to ecological effects on wetlands.

EQUITABILITY – The assessment of the fairness of a measure in its distribution of favorable or unfavorable impacts across the economic, environmental, social, and political interests that are affected.

EROSION – The wearing away of land surfaces through the action of rainfall, running water, wind, waves and water current. Erosion results naturally from weather or runoff, but human activity such as the clearing of land for farming, logging, construction or road building can intensify the process.

ESTUARIES – The place where lake and river waters mix. They provide valuable habitat for spawning fish, nesting and migrating birds, and many rare or specialized plants. These wetlands typically have deep organic soils that have accumulated due to deposition of watershed-based silt loads and protection from coastal processes (waves, currents, seiche, etc.).

EUTROPHIC – Waters high in nutrient content and productivity arising either naturally or from agricultural, municipal, or industrial sources; often accompanied by undesirable changes in aquatic species composition.

EVALUATION – The application of data, analytical procedures and assessment related to criteria to establish a judgment on the relative merit of a measure, policy or institution. Evaluation is a process which can be conducted both within formal studies and by separate interests, although different data, procedures and criteria may be employed in the evaluation by different interests.

EVALUATION FRAMEWORK – A systematic accounting of the criteria considered and methodologies applied in determining the impact of measures on lake levels, stakeholders, and stakeholder interests.

EVAPOTRANSPIRATION – Evaporation from water bodies and soil and transpiration from plant surface.

EXOTIC SPECIES – Non-native species found in a given area as a direct or indirect result of human activity.

FEEDBACK LOOP – Feedback loops are circular cause and effect relationships dominating some interaction of particular sets of system's key variables. Feedback loops belong generally to one of two types. "negative feedback loops" which act to maintain the value of a particular variable around a given level, and "positive feedback loops" which act to cause the value of a particular variable to increase or decrease in a self-amplifying manner; and, usually at a geometric rate.

FISH GUILD – 1. A group of fish that have share similar breeding habits. 2. A group of fish, not necessarily of the same species, that depend on the same environmental resources.

FLOOD AND EROSION PROTECTION SYSTEM (FEPS) – A series of numerical models including COSMOS that compile and evaluate shoreline data to compute flood and erosion damages.

FLOODING – The inundation of low-lying areas by water.

FLOODPLAIN – The lowlands surrounding a watercourse (river or stream) or a standing body of water (lake), which are subject to flooding.

FLOW – The rate of movement of a volume of water over time.

FLUCTUATION – A period of rise and succeeding period of decline of water level. Fluctuations occur seasonally with higher levels in late spring to mid-summer and lower levels in winter. Fluctuations occur over the years due to precipitation and climatic variability. As well, fluctuations can occur on a short-term basis due to the effects of periodic events such as storms, surges, ice jams, etc.

FLUVIAL – Related to or living in a stream produced by a river.

FRAZIL ICE – Stream ice with the consistency of slush, formed when small ice crystals develop in super-cooled stream water as air temperatures drop below freezing. These ice crystals join and are pressed together by newer crystals as they form.

FRESHET – The sudden overflow or rise in level of a stream as a result of heavy rains or snowmelt.

FUNGIBILITY – Something that is exchangeable or substitutable. In this Study, fungibility refers to the degree to which performance indicators are measured in the same units and are comparable.

GABION – An open-ended, cylinder-shaped wire mesh container which is sunk into a bottom and filled with rocks to form a structure such as a dike used to prevent erosion.

GENERAL CIRCULATION MODEL (GCM) – A three-dimensional computer representation of climate and its various components, used to predict climat scenarios.

GEOGRAPHICAL INFORMATION SYSTEM (GIS) – An information system used to store and manipulate (sort, select, retrieve, calculate, analyze, model, etc.) geographical data.

GEOMORPHOLOGY – The field of earth science that studies the origin and distribution of landforms, with special emphasis on the nature of erosional processes.

GLOBAL POSITIONING SYSTEM (GPS) – A navigation system based on the transmission of signals from a network of satellites, which allows users anywhere on the planet to determine their exact location at all times.

GOVERNANCE SYSTEM – The complex, dynamic mosaic of governmental and non-governmental entities having some authority to manage, or the ability to influence the management of Basin resources.

GREENHOUSE EFFECT – The warming of the earth's atmosphere associated meteorological effects due to increased carbon dioxide and other trace gases in the atmosphere. This is expected to have implications for long-term climate change.

GROUNDWATER – Underground water occurring in soils and in pervious rocks.

GULLIES – Deep, V-shaped trenches carved by newly formed streams, or groundwater action, in rapid headward/forward growth during advanced stages of accelerated soil erosion.

HABITAT – The particular environment or place where a plant or an animal naturally lives and grows.

HABITAT HETEROGENEITY – Habitat encompasses the diverse characteristics of the environment that define an area where specific biota live and is necessary for life functions.

HABITAT SUITABILITY INDEX (HSI) – A relative weighting (usually between 0 and 1) of the suitability of a particular environmental characteristic or combination of characteristics based on a particular biota's requirements.

HAZARD LAND – An area of land that is susceptible to flooding, erosion, or wave impact.

HYDRAULICS – The study of the mechanical properties of liquids, including energy transmission and effects of the flow of water.

HYDRAULIC MODELING – The use of mathematical or physical techniques to simulate water systems and make projections relating to water levels, flows and velocities.

HYDROELECTRIC POWER – Electrical energy produced by the action of moving water.

HYDROELECTRIC POWER GENERATION TECHNICAL WORK GROUP – A group of technical experts for the Study that are evaluating how different regulation plans affect power generation.

HYDROLOGIC ATTRIBUTES – Statistics on water levels and stream flows.

HYDROLOGIC CYCLE – The natural circulation of water, from the evaporation of seawater into the atmosphere, the transfer of water to the air from plants (transpiration), precipitation in the form of rain or snow, and runoff and storage in rivers, lakes and oceans.

HYDROLOGIC MODELING – The use of physical or mathematical techniques to simulate the hydrologic cycle and its effects on a watershed.

HYDROLOGY – The study of the properties of water, its distribution and circulation on and below the earth's surface and in the atmosphere.

HYDROLOGY AND HYDRAULICS MODELING TECHNICAL WORK GROUP – A scientific and technical work group for the Study that is developing models to predict water levels and flows in the Lake Ontario-St. Lawrence River system, based on various regulation plans and climate scenarios.

HYDROPERIOD – The length of time (and seasonality) that water is present over the surface of the wetland.

ICE JAM – An accumulation of river ice, in any form which obstructs the normal river flow.

IMAGERY – Representation of objects as images through electronic and optical techniques.

IMPERIAL CONVERSION FOR FEET TO METERS – 1 foot = .305 meters.

IMPERIAL CONVERSION FOR INCHES TO CENTIMETERS – 1 inch - 2.54 centimeters.

IMPLEMENTABILITY – The ability to put into effect a measure considering factors of engineering, economic, environmental, social, political and institutional feasibility.

IMPLEMENTING AUTHORITY – Any governmental agency at any level having appropriate authority to authorize and execute the implementation of any particular action and the jurisdiction to enforce an action.

INFILTRATION – Movement of water through the soil surface and into the soil.

INFORMATION MANAGEMENT TECHNICAL WORK GROUP – A scientific and technical work group for the Study that is collecting and updating information on depths and elevations (bathymetric and topographic data) in critical areas of the Lake Ontario-St. Lawrence system and sharing findings with other work groups.

INSTITUTION – An organization of governmental units which have the authority and ability to facilitate and/or make decisions affecting the water levels issue.

INTEGRATED ECOLOGICAL RESPONSE MODEL (IERM) – Establishes the framework for evaluating, comparing, and integrating the responses for the environmental performance indicators.

INTERESTS – Any identifiable group, including specialized mission agencies of governments which (1) perceive that their constituents'/members' welfare is influenced by lake level fluctuation or policies and measures to address lake level fluctuation, and which (2) are willing and able to enter the decision-making process to protect the welfare of their constituents/members.

INTERNATIONAL JOINT COMMISSION (IJC) – An international federal government agency formed in 1909 by the United States and Canada as an application of the Boundary Waters Treaty to oversee the resolution and prevention of disputes with regard to all bodies of water shared by the two countries, and to provide recommendations on such water management issues as water quality and water levels.

INTERNATIONAL LAKE ONTARIO - ST. LAWRENCE RIVER STUDY – A study sponsored by the IJC to examine the effects of water level and flow variations on all users and interest groups and to determine if better regulation is possible at the existing installations controlling Lake Ontario outflows.

INTERNATIONAL REACH – The portion of the St. Lawrence River that is between Lake Ontario and the Moses-Saunders Dam.

INTERNATIONAL ST. LAWRENCE RIVER BOARD OF CONTROL – Board established by the International Joint Commission in its 1952 Order of Approval. Its main duty is to ensure that outflows from Lake Ontario meet the requirements of the Commission's Order. The Board also develops regulation plans and conducts special studies as requested by the Commission.

INVESTMENT – Expenditure made by an interest to capture benefits. The investment decision reflects available information and understanding about the system, government responsibilities and risks.

JURISDICTION – The extent or territory over which authority may be legally exercised.

LAKEBED DOWNCUTTING – Progressive erosion or deepening of the water depths in front of riparian property.

LAKE OUTFLOW – The amount of water flowing out of a lake.

LEACHATE – Contaminated liquid resulting from the percolation of water through pervious rocks and soils at a waste site or landfill.

LIDAR – A remote-sensing system similar to radar, in which laser light pulses take the place of microwaves.

LITTORAL – Pertaining to or along the shore, particularly to describe currents, deposits and drift.

LITTORAL CELL – An area under the continuous influence of specific longshore currents.

LITTORAL CELLS – Closed sediment compartments that define the limits of all sand movements, both along the shore and onshore/offshore.

LITTORAL DRIFT – The movement of gravel, sand and other beach material along the coast, which is caused by waves and currents.

LITTORAL ZONE – The area extending from the outermost breaker or where wave characteristics significantly alter due to decreased depth of water to: either the place where there is marked change in material or physiographic form; the line of permanent vegetation (usually the effective limit of storm waves); or the limit of wave uprush at average annual high water level.

LOCATION BENEFIT – Positive effect on the welfare of an interest derived from shore location and water level situation.

LOCATION COST – Negative effect on the welfare of an interest derived from shore location and water level situation.

LOW WATER DATUM – An approximation of mean low water, used for harbour-dredging purposes.

LOWER ST. LAWRENCE RIVER – The portion of the St. Lawrence River downstream of the Moses-Saunders Dam is called the lower St. Lawrence in this Study. It includes Lac St. Francis, Lac St. Louis, Montreal Harbour, Lac St. Pierre and the portions of the River connecting these lakes as far downstream as Trois Rivieres.

MARINA – A private or publicly-owned facility allowing recreational watercraft access to water, and offering mooring and other related services.

MARSH – An area of low, wet land, characterized by shallow, stagnant water and plant life dominated by grasses and cattails.

MEASURE – Any action, initiated by a level(s) of government to address the issue of lake level fluctuations, including the decision to do nothing.

MEASURE, NON-STRUCTURAL – Any measure that does not require physical construction.

MEASURE, STRUCTURAL – Any measure that requires some form of construction. Commonly includes control works and shore protection devices.

METADATA – Data (information) about the characteristics of data such as content, quality (condition, accuracy, etc.), date of capture, user access restrictions and ownership.

META-DATABASE – A database used to store information about data (metadata).

METEROLOGICAL – Pertaining to the atmosphere or atmospheric phenomena; of weather or climate.

METRIC CONVERSION FOR CENTIMETERS TO INCHES – 1 centimeter = 0.4 inch.

METRIC CONVERSION FOR METERS TO FEET – 1 meter = 3.28 feet.

MICRO-ORGANISM – An organism that is too small to be visible without the aid of a microscope.

MODEL – A model may be a mental conceptualization; a physical device; or a structured collection of mathematical, statistical, and/or empirical statements.

MODEL, COMPUTER – A series of equations and mathematical terms based on physical laws and statistical theories that simulate natural processes.

MODEL, HYDRAULIC – A small-scale reproduction of the prototype used in studies of spillways, stilling basins, control structures, riverbeds, etc.

MODEL, VISUAL SITUATION – A pictorial display linked to an automated information/geographic information system(s) which connects the problems associated with fluctuating water levels whith the stakeholders and their interests that are impacted by the problems, with an emphasis on overlapping or interacting relationships.

MONTHLY MEAN WATER LEVEL – The arithmetic average of all past observations (of water levels or flows) for that month. The period of record used in this Study commences January 1900. This term is used interchangeably with average water level.

NEGOTIATION – The process of seeking accommodation and agreement on measures and policies among two or more interests or agencies having initially conflicting positions by a “voluntary” or “non-legal” approach. This is often considered a part of an alternative dispute resolution process.

NET BASIN SUPPLY (NBS) – The net amount of water entering one of the Great Lakes, comprised as the precipitation onto the lake minus evaporation from the lake, plus groundwater and runoff from its local basin. The net basin supply does not include inflow from another Great Lake.

NO NET LOSS – A working principle by which a department or agency strives to balance unavoidable habitat losses with habitat replacement on a project-by-project basis so that further reductions to Canada’s fisheries or U.S. wetland resources due to habitat loss or damage may be prevented.

OPERATING PLAN – A list of procedures to be followed in making changes to the lake levels or their outflows for the specific purpose or to achieve certain objectives. Operation of regulatory facilities on the Great Lakes are carried out by their owners and operators under the supervision of the IJC and in accordance with Plan 1977 (Lake Superior) and Plan 1958-D (Lake Ontario).

OUTFALL – The place or structure where a sewer, drain, conduit or stream discharges into the surface water.

OUTFLOW – The quantity of water flowing out of a lake through surface rivers or streams, measured in time units at a given point.

OXIC – To expose to oxygen.

OZONATION – The application of a substance or compound with ozone as a possible remedy for the occasional taste and odor problems experienced in some municipal water supplies that withdraw water from the lower river.

PEAKING – The variation of hourly water flows above and below the daily average flow (for instance, midday flow higher than evening and night flows), primarily due to hydroelectric generating operations during which water is stocked during periods of off-peak demand in order to increase hydroelectric power generation at peak periods.

PERFORMANCE INDICATOR – A measure of economic, social or environmental health. In the context of the Study, performance indicators relate to impacts of different water levels in Lake Ontario and the St. Lawrence River.

PHOTOSYNTHESIS – The process through which the cells of green plants and certain micro-organisms convert energy from sunlight into stored, usable chemical energy.

PHYSICAL IMPACT SURVEY – A characterization study of the impact of water level fluctuation on infrastructure use or constraints.

PHYSIOGRAPHY – A descriptive study of the earth and its natural phenomena, such as climate, surface etc.

PLAN 1958-D – A plan used by the International St. Lawrence River Board of Control since April 1963 that specifies outflows from Lake Ontario in order to satisfy the existing set of criteria established by the IJC and related to interests on Lake Ontario and the St. Lawrence River.

PLAN FORMULATION AND EVALUATION GROUP – A group established as part of the Study to develop alternative water level regulation plans, establish performance indicators for such plans, and to measure the effectiveness of such alternate criteria and operating plans.

PLAN FORMULATION METHOD – A method involving a multi-objective, multi-stakeholder evaluation procedure used to evaluate factors not previously considered in determining whether a revised operating plan performs better than an existing plan.

PLANIMETRIC CAPABILITIES – The capability of a system to measure areas.

POLICY – The position adopted by a government on an issue which is expected to structure and guide the decision-making process.

PONDING – The variation of daily water flows above and below the weekly average flow (for instance, average weekday flow higher than average weekend flow), primarily due to hydroelectric generating operations.

POSITION OF INTERESTS – The perceptions, beliefs and preferences of interests regarding fluctuating water levels, implications of those levels, and acceptability of a measure or policy to an interest. Positions may be directly stated or may be inferred from supporting or opposing activities taken by the interest in the decision-making process.

PRIORITY CONSERVATION SPECIES – A species protected by federal, state, or provincial laws.

PUBLIC COMMUNICATIONS – Activities where the purpose, design, and plan intends for two-way communication for a defined period of time between Study personnel and the public or various publics.

PUBLIC INFORMATION – Activities where the purpose, design, and plan intends to deliver information to the public or various publics. Examples: press releases and articles in the Study Newsletter, Ripple Effects.

PUBLIC INTEREST ADVISORY GROUP (PIAG) – The group of volunteers from the United States and Canada working to ensure effective communication between the public and the International Lake Ontario-St. Lawrence River Study Team.

PUBLIC INVOLVEMENT – Activities where the purpose, design, and plan is such that members of the public or various publics are engaged in the Study on a continuing basis with other "expert" resources.

PUBLIC PARTICIPATION – Activities where purpose, design, and plan intends that members of the public have an opportunity to participate for a defined period of time in a Study activity.

QUARTER-MONTHLY MEAN WATER LEVEL – This is the average water level that would occur during a quarter-month period. A quarter-month is seven or eight days depending on the number of days in the month.

RAPIDS – A turbulent and swift-flowing section of a river.

REACH – A length of shore with fairly uniform onshore and offshore physiographic features and subject to the same wave dynamics.

REBOUND (CRUSTAL MOVEMENT) – The uplift or recovery of the earth's crust in areas where a past continental glaciation had depressed the earth's crust by the weight of the ice.

RECESSION – A landward retreat of the shoreline by removal of shore materials in a direction perpendicular or parallel to the shore.

RECREATIONAL BOATING AND TOURISM TECHNICAL WORK GROUP – A group of technical experts that will investigate the impacts of water levels on individual boaters, marinas, and boating-related tourism for the Study.

REGULATION – Artificial changes to the lake levels or their outflows for specific purpose or to achieve certain objectives.

REGULATIONS – Control of land and water use in accordance with rules designed to accomplish certain goals.

RELIABILITY – While ranking plans, it is the percentage of time that a criterion is met (i.e., 4,848 out of 4,848 quarter-months = 100%).

RESILIENCE – During plan ranking, it is the average amount of time it takes to get back in compliance (how long). It is calculated as the total number of quarter-months of failure divided by the number of failures.

RESILIENCY – The ability to readily recover from an unexpected event, either because costs were not significantly affected by changing levels, another source of income provided a cushion to levels induced costs, and/or a conscious effort was made on the part of the interest.

RESERVOIR – A place where water is collected and kept for use when wanted, as to supply a fountain, a canal, or a city by means of aqueducts, or to drive a mill wheel, or the like.

REVETMENT – A natural (grass, aquatic plants, etc.) or artificial (concrete, stone, asphalt, earth, sand bag, etc.) covering (facing) to protect an embankment (raised structure made of soil, rock or other material) or other structure (such as a cliff) from erosion.

RIPARIAN – Of, relating to or found along a shoreline.

RIPARIANS – Persons residing on the banks of a body of water.

RIVERINE – Of or relating to a river or a riverbank.

RUNOFF – The portion of precipitation on the land that ultimately reaches streams and lakes.

SCOURING – Erosion, generally in the form of downcutting in front of shore protection or other coastal structures that may be temporary or permanent.

SEDIMENT BUDGET – An accounting system for all of the sand and gravel within a defined study boundary (spatial extents).

SHARED VISION MODEL – A decision-making tool used to develop a collective representation (image or view) of the future a group aspires to create.

SHOALS (SCANNING HYDROGRAPHIC OPERATIONAL AIRBORNE LIDAR SYSTEM) – A LIDAR system that uses a green laser to profile underwater terrain and an infrared laser to detect water surfaces. The system is used to obtain bathymetric and topographic data.

SHORELINE – Intersection of a specified plane of water with the shore.

SILLS – Underwater obstructions placed to reduce a channel's flow capacity.

SOCIAL DESIRABILITY – The continued health and well-being of individuals and their organizations, businesses, and communities to be able to provide for the material, recreational, aesthetic, cultural, and other individual and collective needs that comprise a valued quality of life. The satisfaction of this objective includes a consideration of individual rights, community responsibilities and requirements, the distributional impacts of meeting these needs, and the determination of how these needs should be achieved (paid for) along with other competing requirements of society.

SOCIO-ECONOMIC SURVEY – A survey measuring the basic characteristics of a community, from which statistics can be compiled.

SPATIAL EVALUATION FRAMEWORK – The classification and delineation of terrestrial, wetland and aquatic environments in spatial units meaningful to an assessment of fluctuating levels and measures.

STAKEHOLDER – An individual, group, or institution with an interest or concern, either economic, societal or environmental, that is affected by fluctuating water levels or by measures proposed to respond to fluctuating water levels within the Lake Ontario – St. Lawrence River Basin.

STANDARDIZED HYDROLOGIC STATIONS (SHS) – Water level measurement stations operated by a governmental agency where water depth that was measured at specific geographical locations is translated into International Great Lakes Datum as updated in 1985 equivalent data.

STEADY STATE – No change over time.

STOCHASTIC SUPPLIES – Simulated sequences of water supply conditions that reflect climate variability.

STRATEGY – A general conceptual framework for guiding action based upon a particular purpose and selected means for achieving agreed upon ends.

SUBMERGED MACROPHYTES – Plant species that grow under water during their entire life cycle (not including algae).

SUBSTRATE COMPOSITION – Categorical assignments of the lake/river bottom from silt to bedrock size classes.

SURFACE WATER – Water open to the atmosphere including lakes, ponds, rivers, springs, wetlands, artificial channels and other collectors directly influenced by surface water.

SYSTEM DYNAMICS – A simulation modeling methodology developed at Massachusetts Institute of Technology for the study of the behavior of complex systems. System dynamics is based upon the identification of key system variables, the interactions between them and the study of the effects of these interactions over time.

SYSTEMS APPROACH – A method of inquiry which complements the classical analytical method of science by emphasizing the concept of "whole systems" and the irreducible properties of whole systems that result from the interactions among individual components.

TECHNICAL WORK GROUP (TWG) – A team of scientific and technical experts formed to study each of the following areas: the coastal processes, commercial navigation, common data needs, the environment, hydrology and hydraulics modeling, water uses, hydroelectric power generation, and recreational boating and tourism for the International Lake Ontario-St. Lawrence River Study.

TOPOGRAPHY – The representation on maps or charts of the surface features of a region in such a manner as to illustrate their relative positions and elevations.

TROPHIC – Of, or related to, nutrition.

UNCERTAINTY AND RISK – The evaluation of a proposed measure in terms of the unpredictability and magnitude of the consequence which may follow, the detectability of anticipated or unanticipated consequences, and the ability to reverse, adapt, or redirect the measure, depending on the effects.

UPPER ST. LAWRENCE RIVER – The portion of the St. Lawrence River upstream of the Moses-Saunders Dam is called the upper St. Lawrence in this Study. It includes the entire River from Kingston/Cape Vincent to the power dam and locks at Cornwall-Massena, including Lake St. Lawrence.

URBANIZATION – The change of character of land, due to development, from rural or agricultural to urban.

VULNERABILITY – The average amount of failure when a plan does not meet criterion during ranking (how bad it performs). So if it goes over a criterion in two quarter-months, once by 10 cm (3.9 inches), the other by 20 cm (7.89 inches), the vulnerability is 15 cm (5.9 inches).

VUSILIENCE – How poorly a plan performs multiplied by how long it performs poorly (the product of vulnerability times resilience).

WATER LEVEL – The elevation of the surface of the water of a lake or at a particular site on the river. The elevation is measured with respect to average sea level. Several different types of water levels are used in the Study. In the case of Lake Ontario, the water level is assumed to be the calm water level without wind effects or waves included. In the erosion and flood analysis, these wind effects are added to the calm water level. Many of the analyses done in the Study use the quarter-monthly mean water level. This is the average water level that would occur during a quarter-month period (approximately a week).

WATER SUPPLY – Water reaching the Great Lakes as a direct result of precipitation, less evaporation from land and lake surfaces.

WATER USES TECHNICAL WORK GROUP – A technical and scientific team of the Study that is investigating impacts of water level variations on industrial, municipal, and domestic water intakes and treatment facilities.

WATERFOWL – Birds that are ecologically dependant on wetlands for their food, shelter and reproduction.

WATERSHED; BASIN – The region or area of which the surface waters and groundwater ultimately drain into a particular course or body of water.

WAVE – An oscillatory movement in a body of water which results in an alternate rise and fall of the surfaces.

WAVE CREST – The highest part of a wave.

WAVE DIRECTION – The direction from which a wave approaches.

WAVE PERIOD – The time for two successive wave crests to pass a fixed point.

WEATHER – The meteorological condition of the atmosphere defined by the measurement of the six main meteorological elements: air temperature, barometric pressure, wind velocity, humidity, clouds, and precipitation.

WEIGHTED SUITABLE AREA (WSA) – The aggregate sum of the areas within a region, or larger area, that have been weighted by habitat suitabilities (see Habitat Suitability Index).

WETLAND – An area characterized by wet soil and high biologically productivity, providing an important habitat for waterfowl, amphibians, reptiles and mammals.

WETLAND OBLIGATE BIRD SPECIES – Birds that require wetland habitats for breeding purposes (such as nesting and/or food sources).

WETLANDS – (marshes, swamps, bogs, and fens) – lands where the water table is at, near or above the land surface long enough each year to support the formation of hydric soils and to support the growth of hydrophytes, as long as other environmental variables are favorable.

WILLINGNESS TO PAY (WTP) – The maximum amount that a consumer will pay for a given item or service.

YACHT CLUB – A member-owned facility allowing access to docks or mooring to recreational boaters, and often offering complementary services.