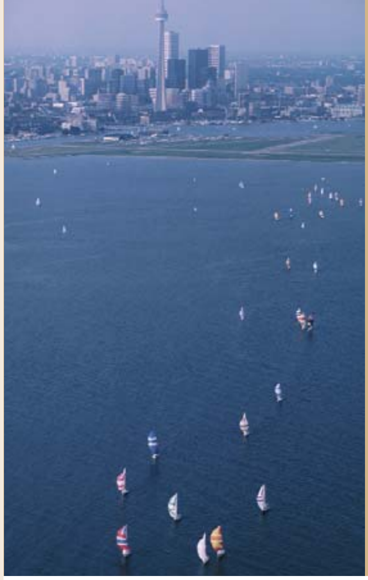


Annex 3
Plan Descriptions and Summary Results

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:

$$Q = 747.2 \text{ (Lake Ontario level} - 69.10)\hat{}1.47,$$

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).

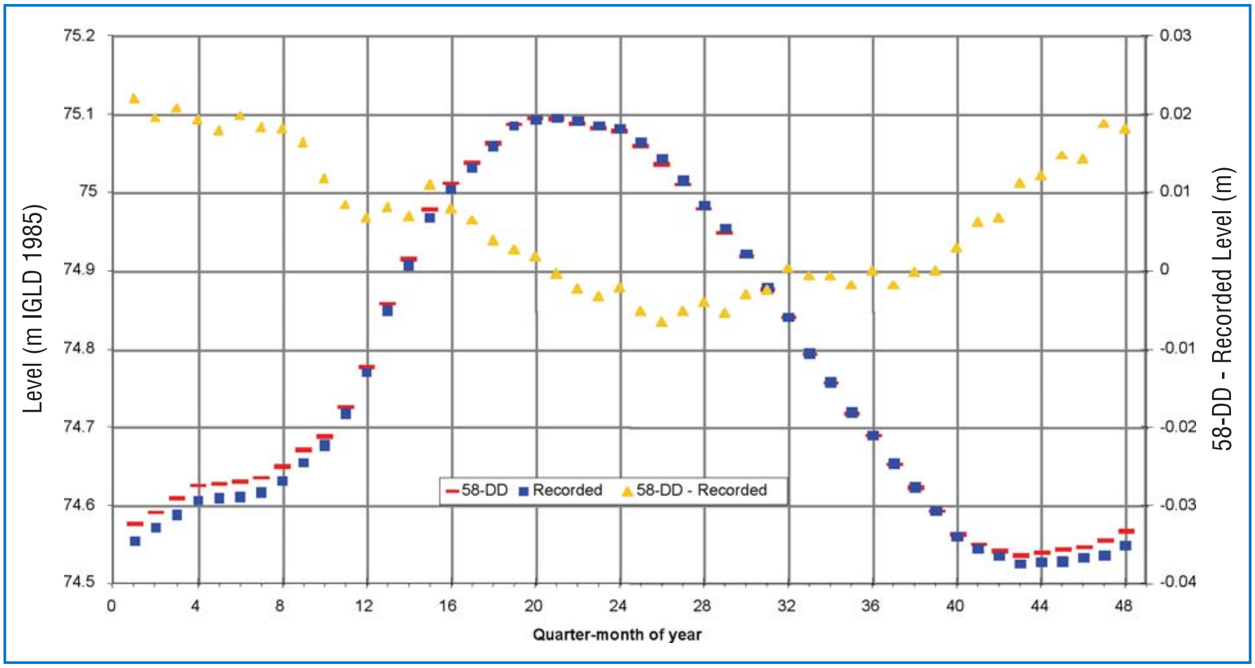


Figure B-1:* *Lake Ontario Average Quarter-Monthly Level 1960-2001 58-DD vs. Recorded

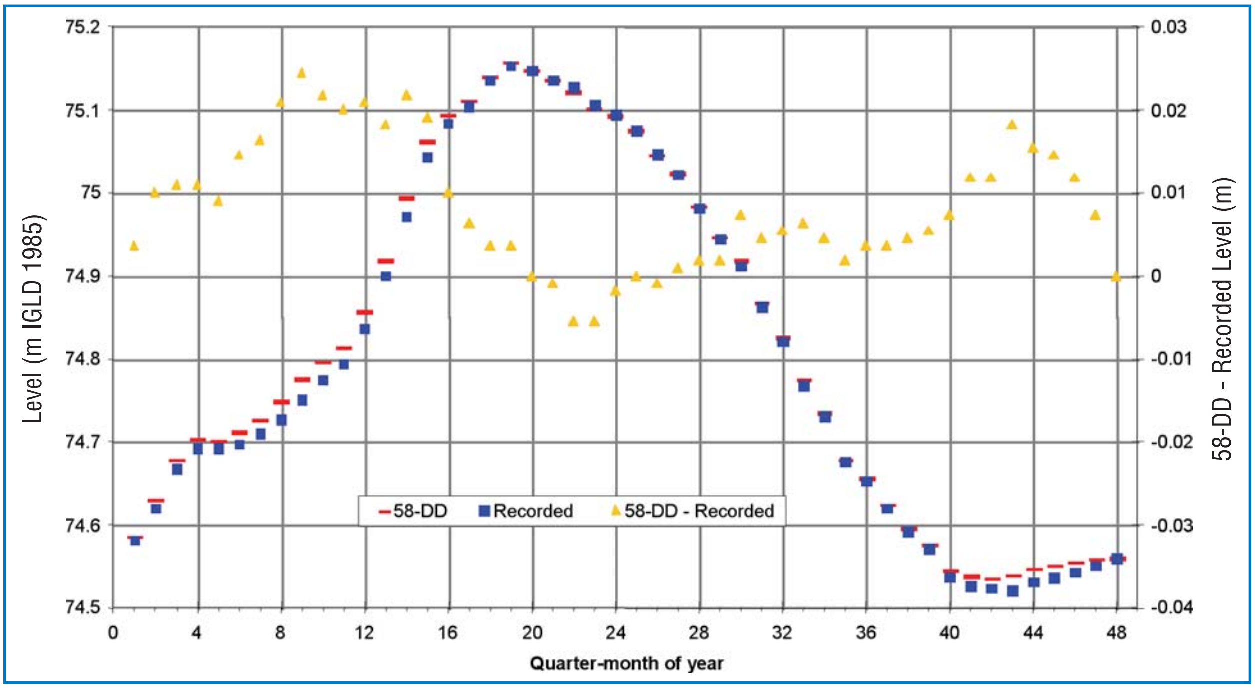


Figure B-2:* *Lake Ontario Average Quarter-Monthly Level 1990-2001 58-DD vs. Recorded

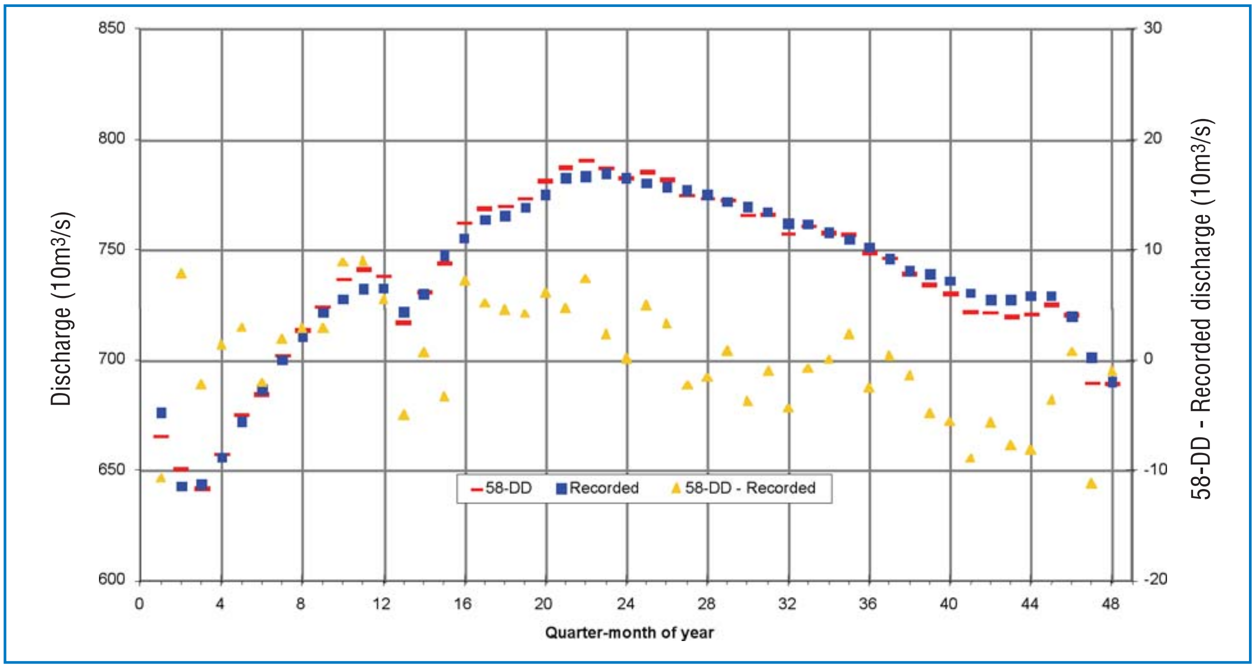


Figure B-3: ***Lake Ontario Average Quarter-Monthly Outflow 1960-2001 58-DD vs. Recorded***

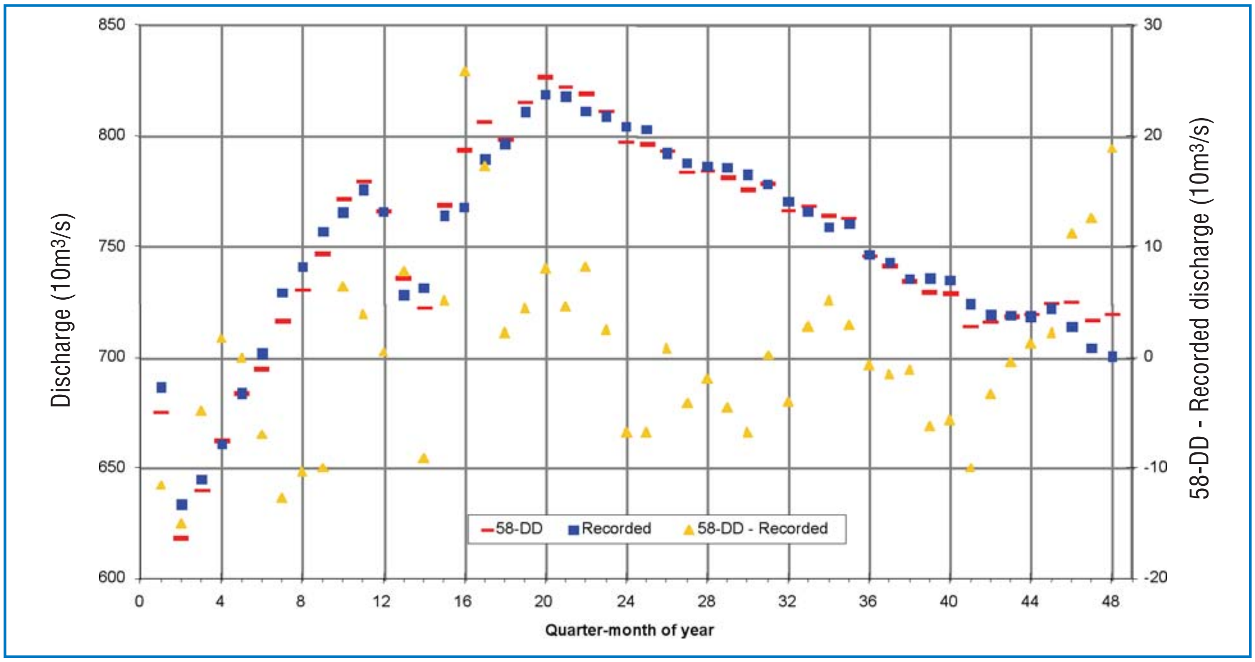


Figure B-4: ***Lake Ontario Average Quarter-Monthly Outflow 1990-2001 58-DD vs. Recorded***

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.

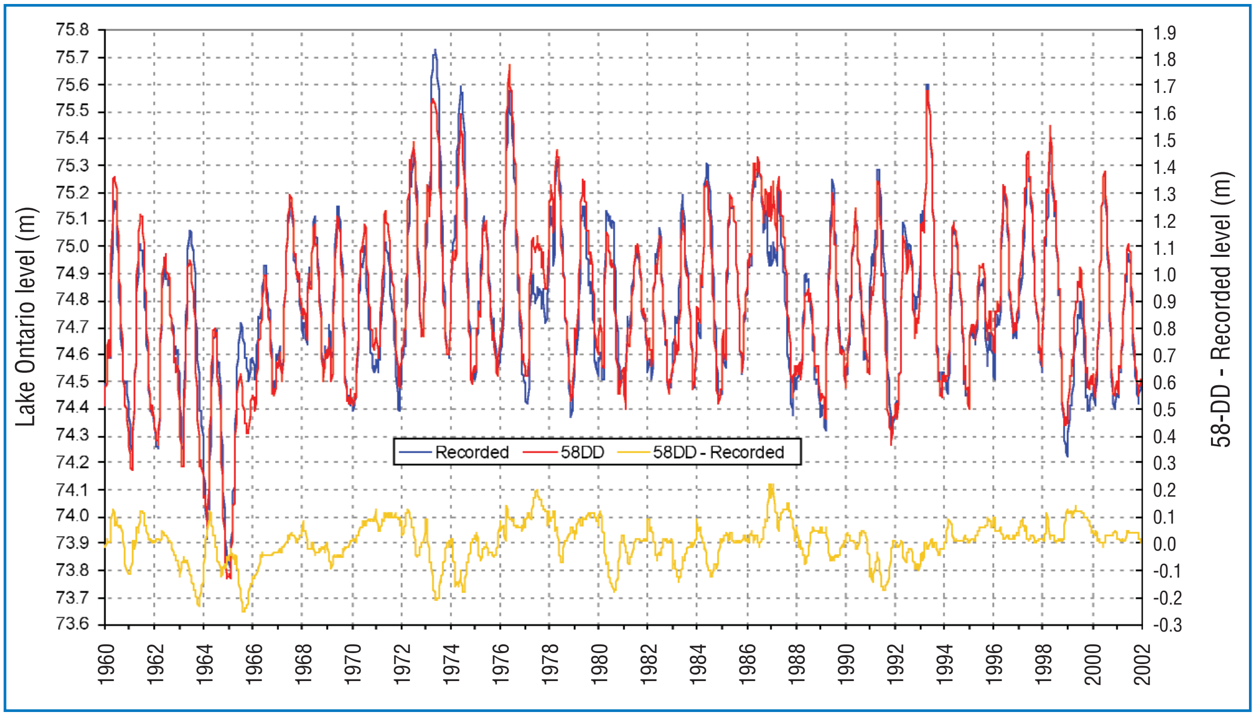


Figure B-5: ***Lake Ontario level 58-DD Simulated vs. Recorded 1960-2001***

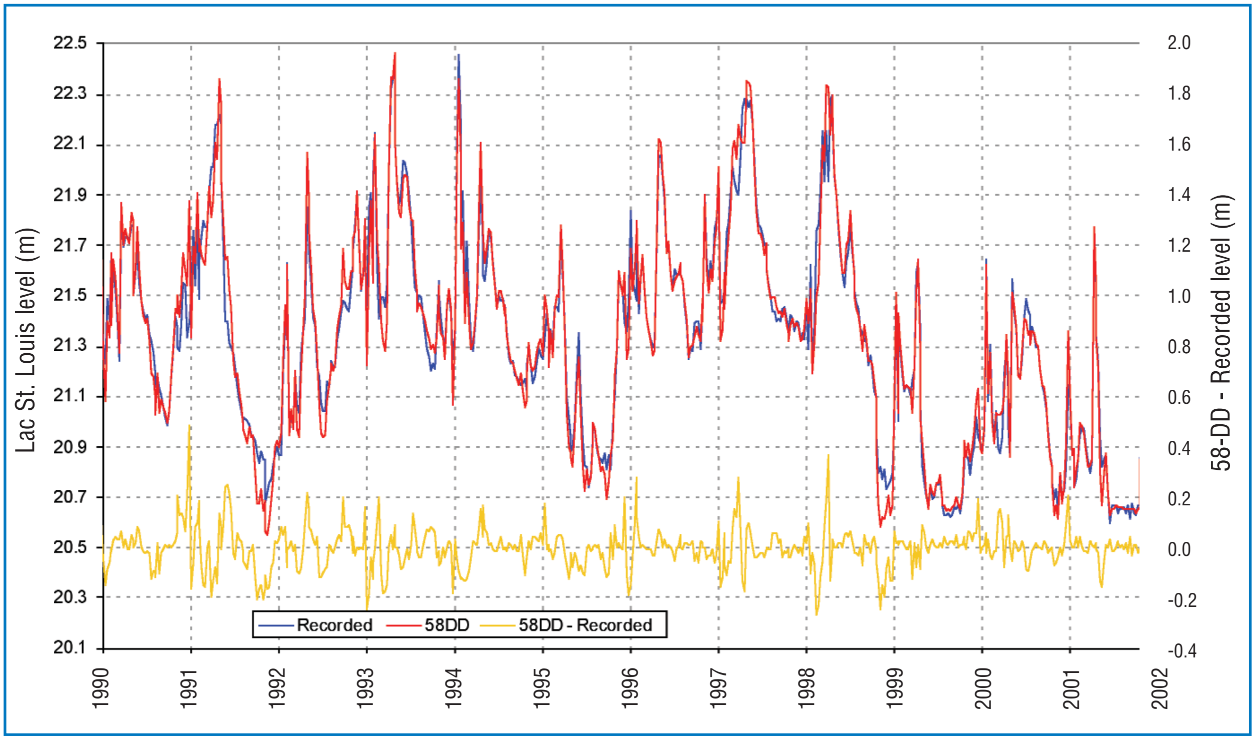


Figure B-5A: ***Lac St. Louis at Pointe Claire level 58-DD Simulated vs. Recorded 1990-2001***

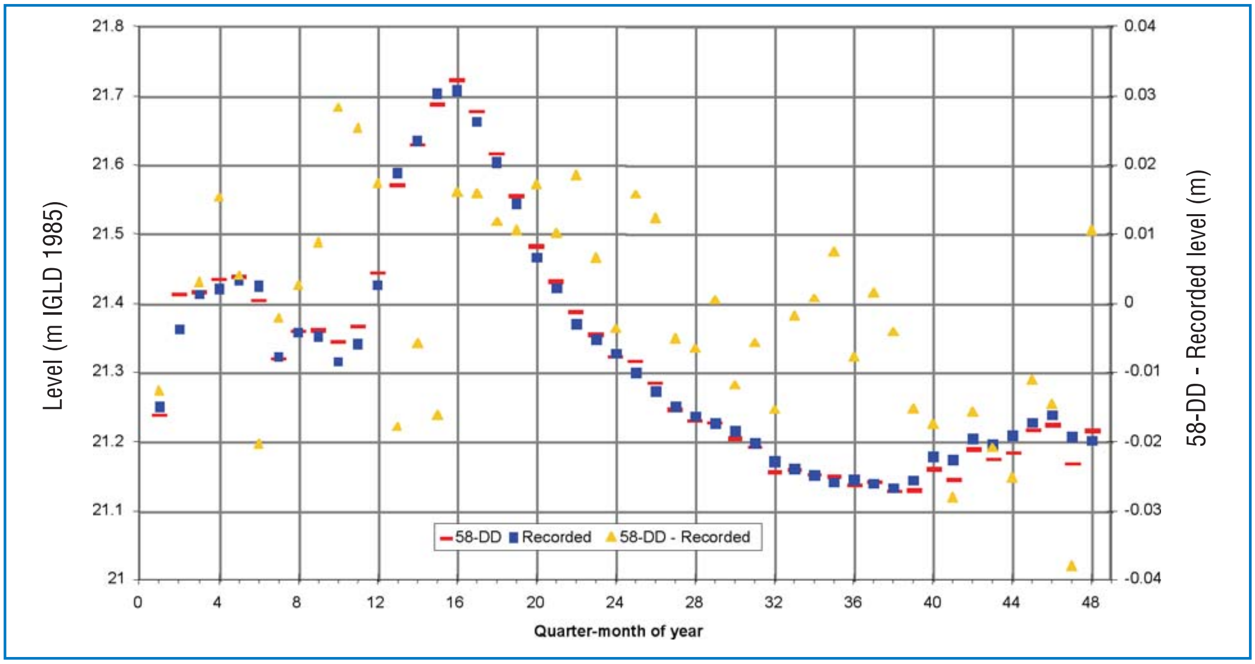


Figure B-6: Lac Saint Louis at Pointe Claire Average Quarterly-Monthly Level 58-DD vs. Recorded

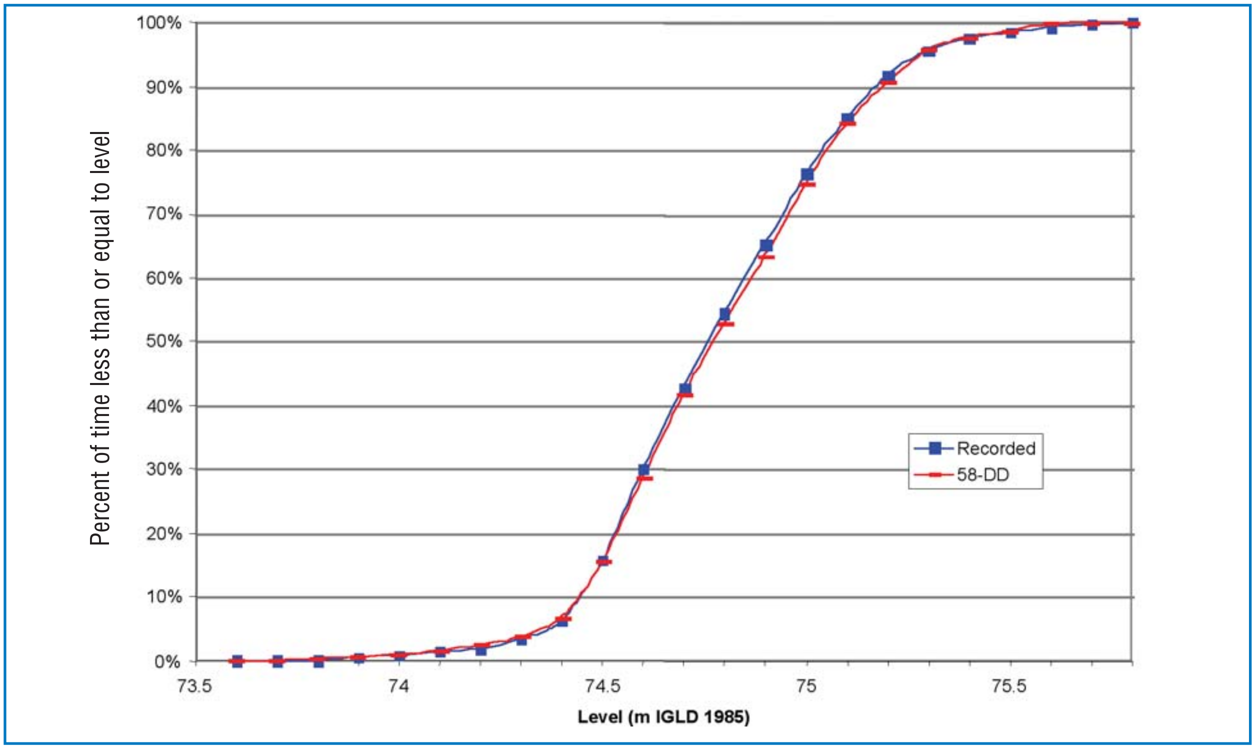


Figure B-7: Cumulative Frequency of Lake Ontario Levels 58-DD vs. Recorded All Year 1960-2001

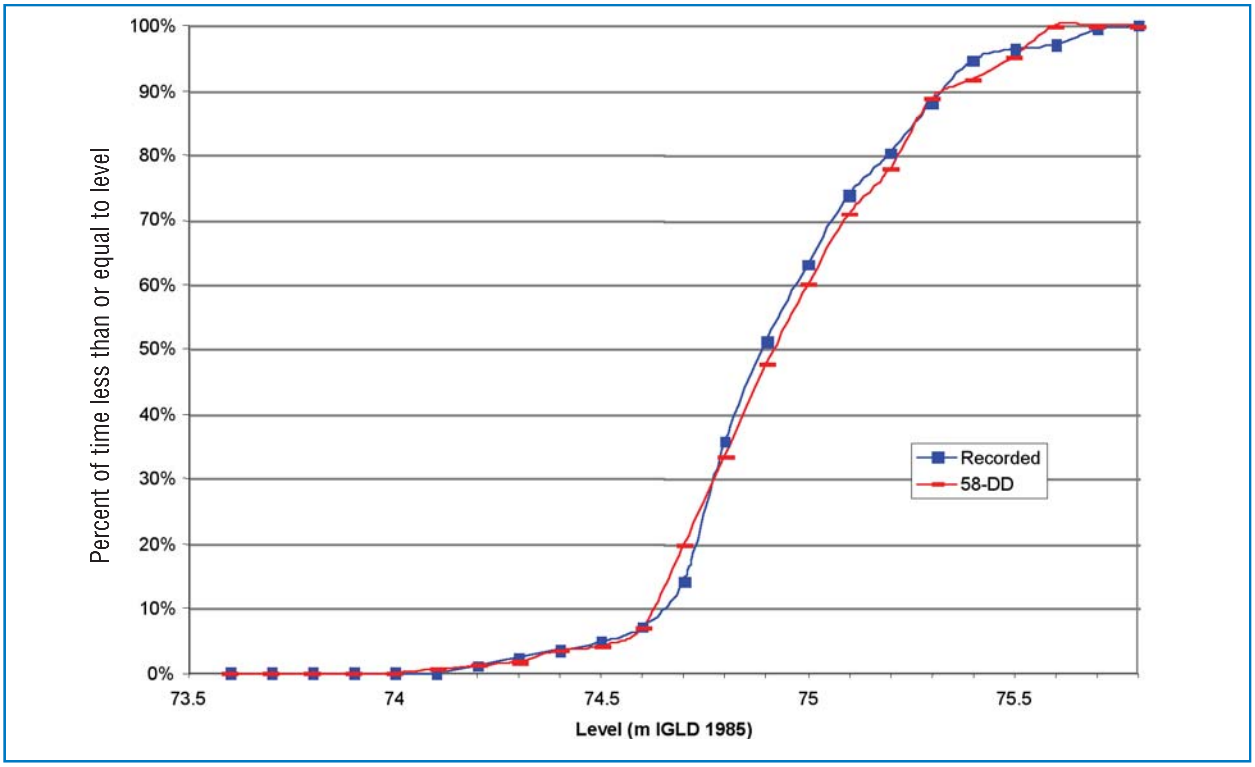


Figure B-8:* *Cumulative Frequency of Lake Ontario Levels 58-DD vs. Recorded April 1960-2001

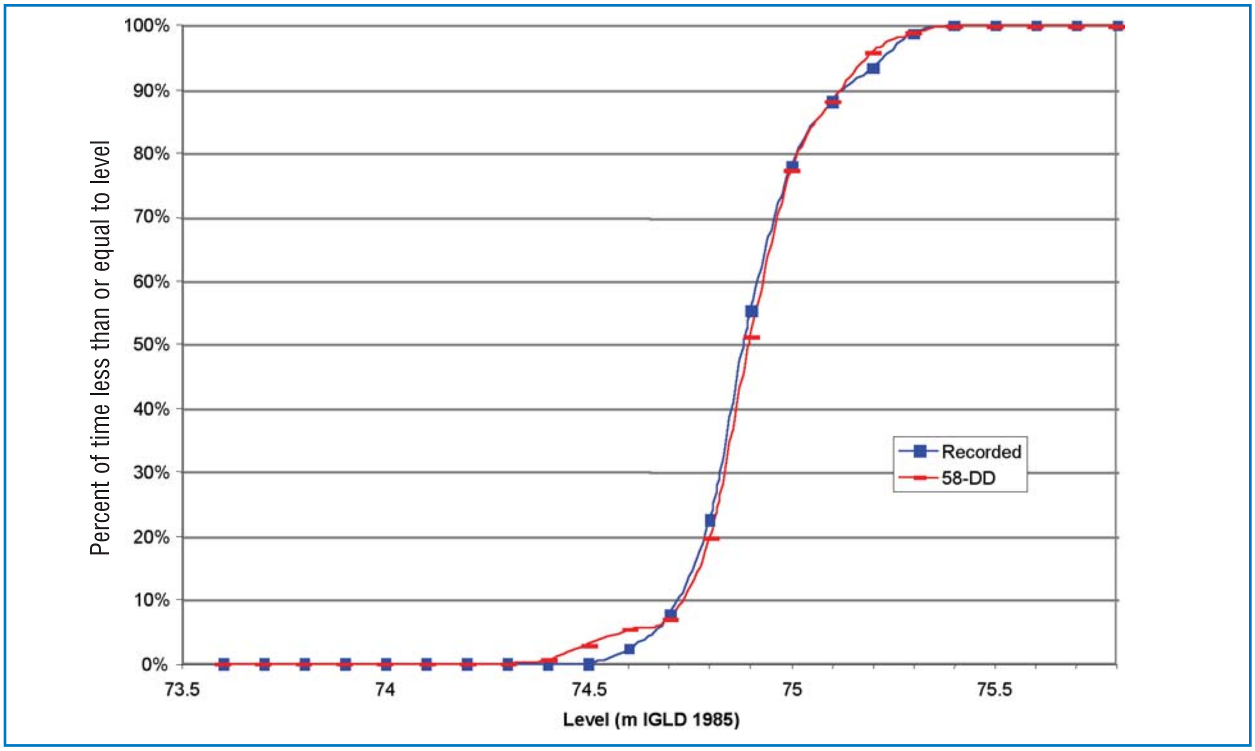


Figure B-9:* *Cumulative Frequency of Lake Ontario Levels 58-DD vs. Recorded August 1960-2001

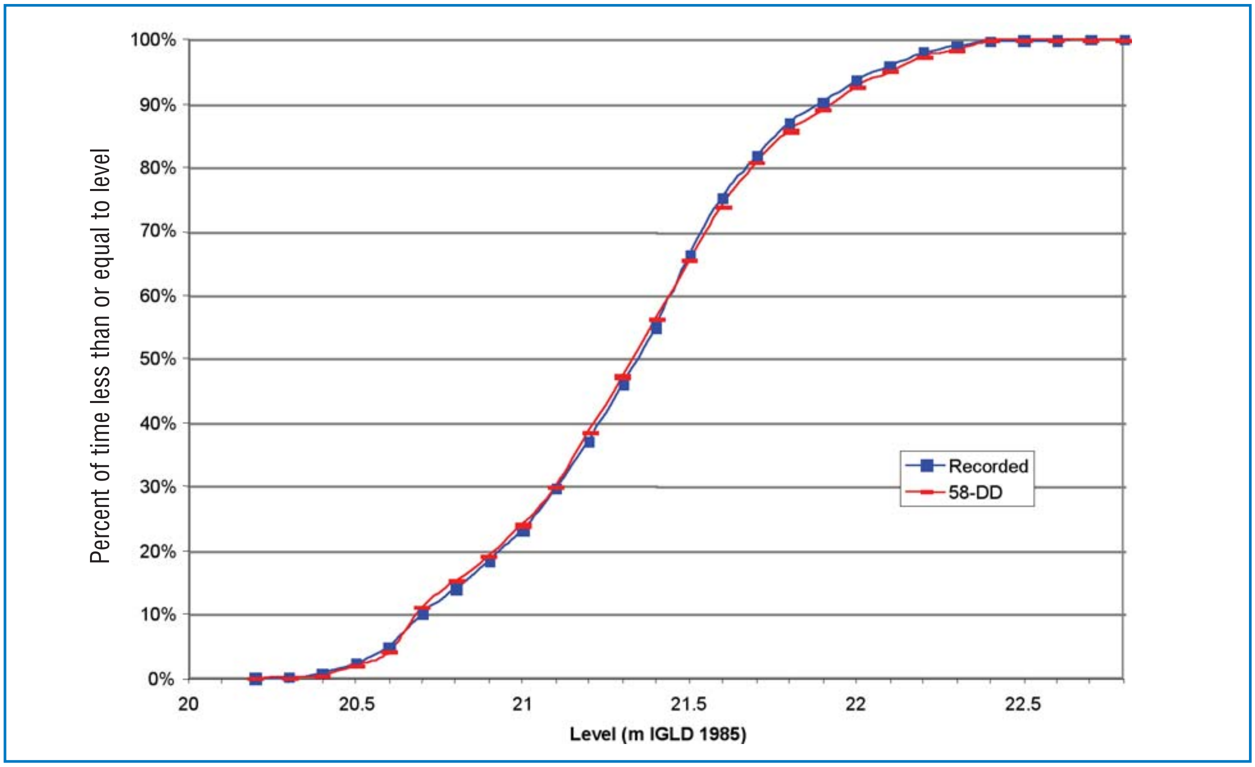


Figure B-10: ***Cumulative Frequency of Lac St. Louis Levels 58-DD vs. Recorded All Year 1960-2001***

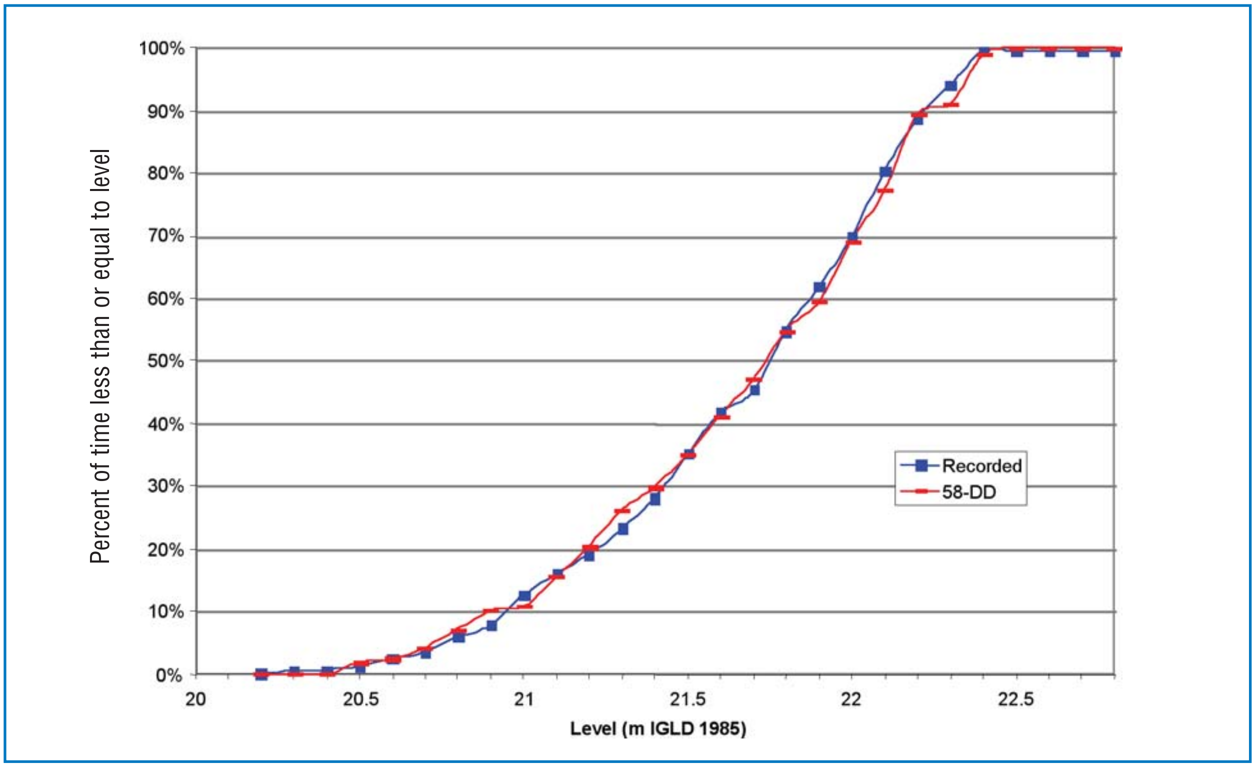


Figure B-11: ***Cumulative Frequency of Lac St. Louis Levels 58-DD vs. Recorded April 1960-2001***

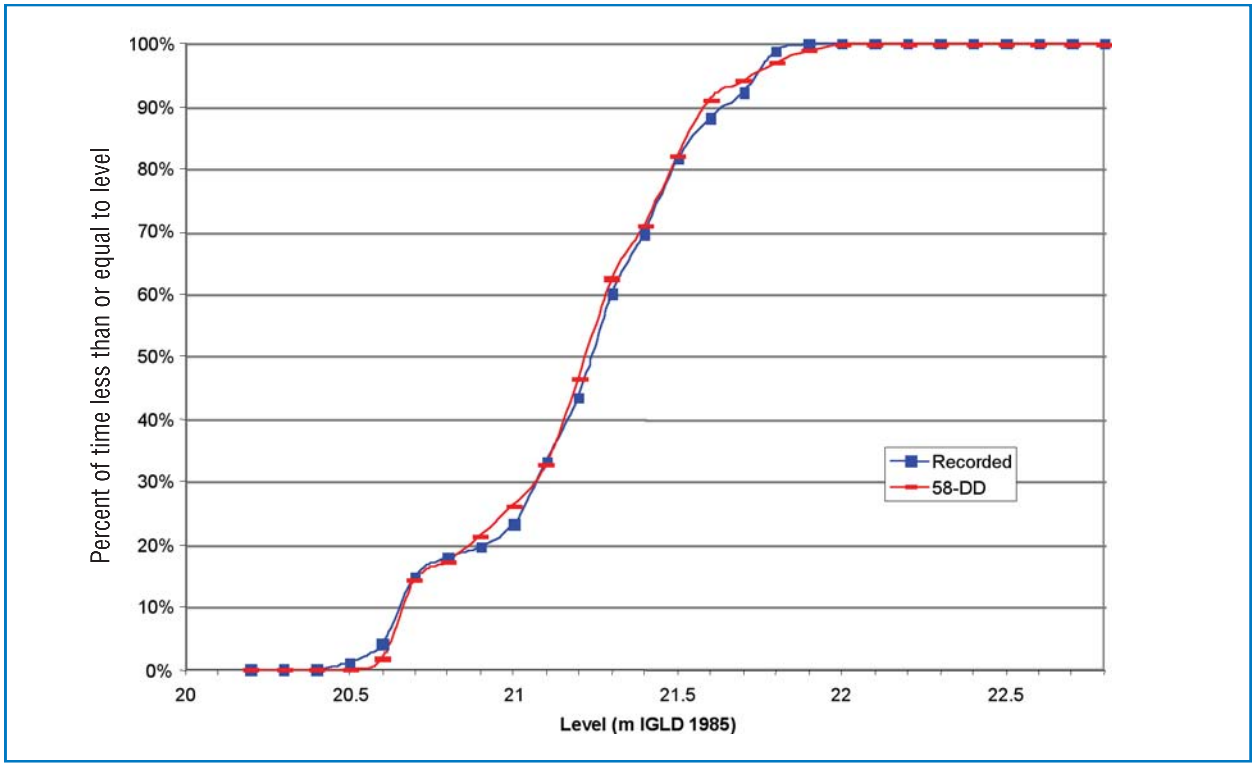


Figure B-12: ***Cumulative Frequency of Lac St. Souis Levels 58-DD vs. Recorded August 1960-2001***

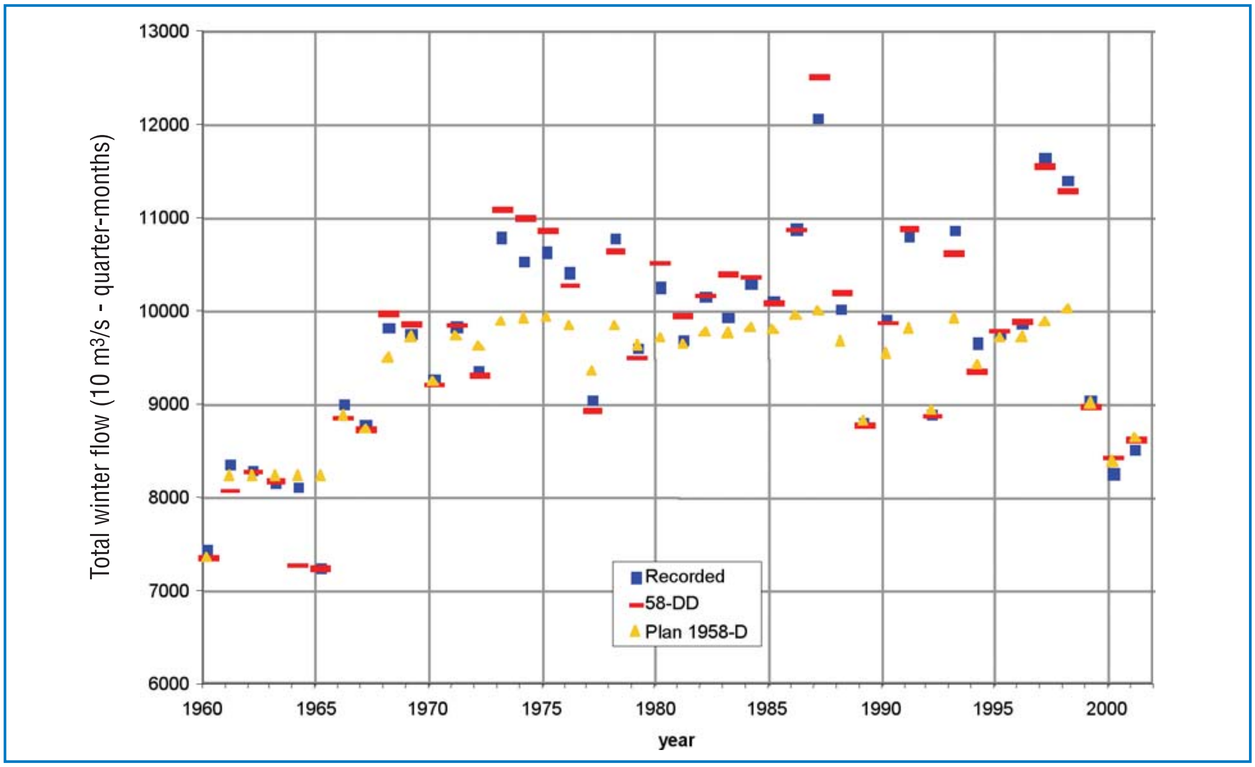


Figure B-13: ***Total Winter Flows 58-DD vs. Recorded and Plan 1958-D 1960-2001***

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."

$$LSq = 22.9896(\text{Kingston level} - 62.4)^{2.2381}((\text{Kingston level} - LSlev)/n)^{0.387}$$

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).

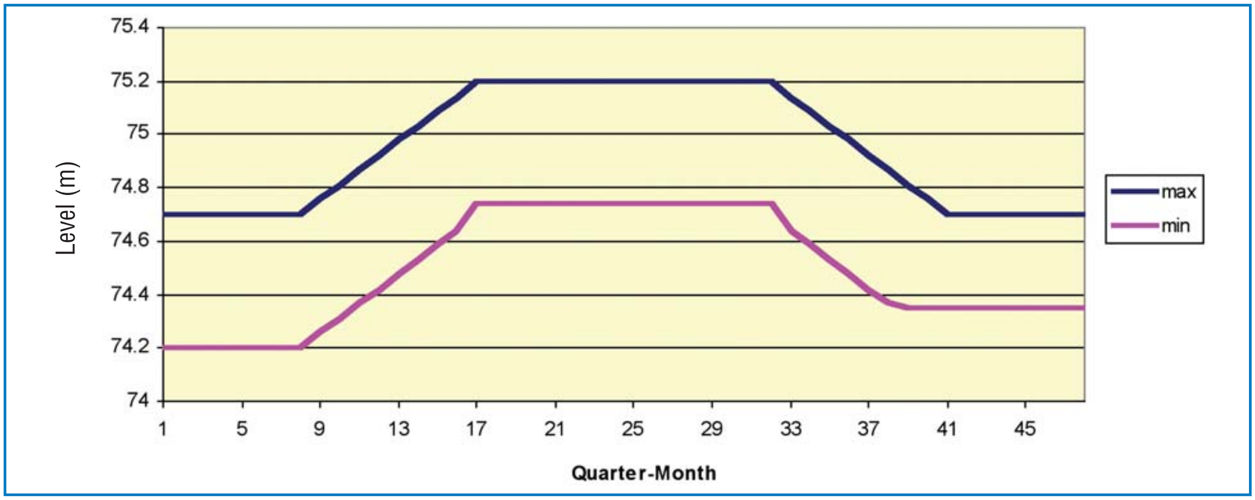


Figure B-14: ***Lake Ontario target levels***

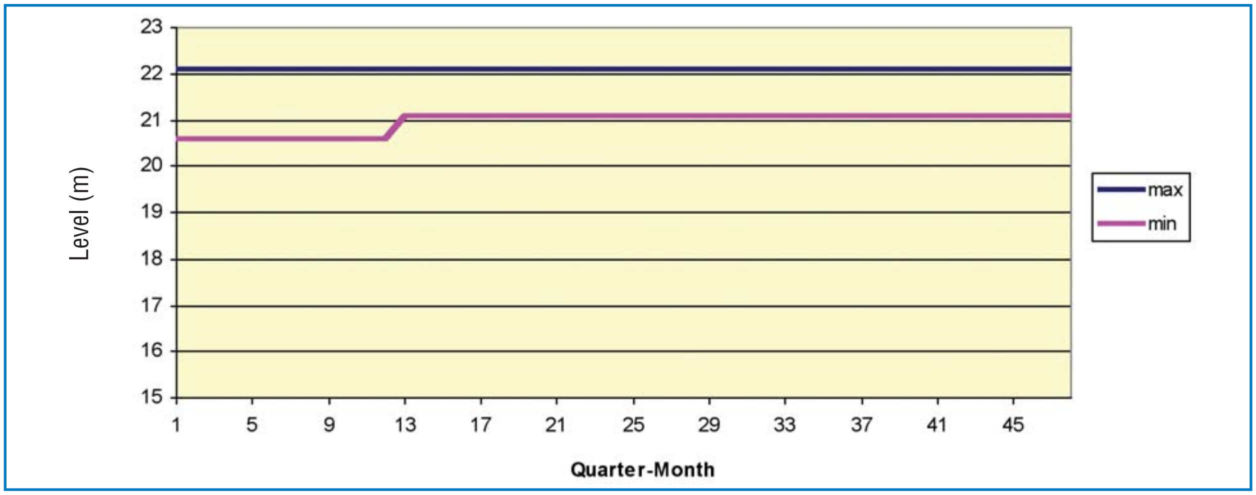


Figure B-15: ***Lac St. Louis at Pointe Claire target levels***

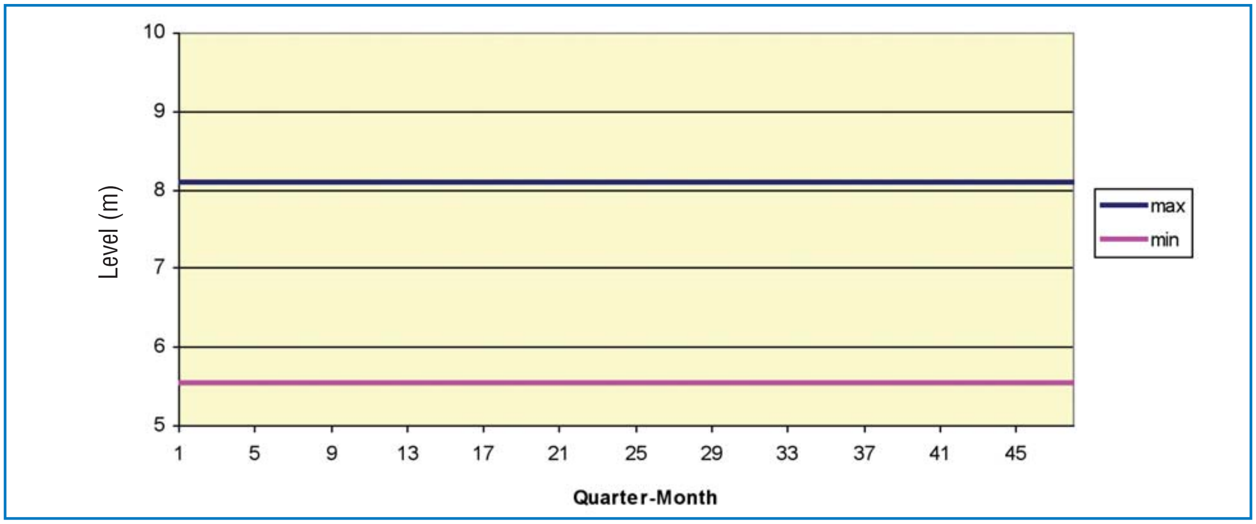


Figure B-16: ***Montreal Harbour target levels***

The target maximum release and target minimum release have been adjusted such that hydropower is produced most efficiently during the summer (high electricity price):

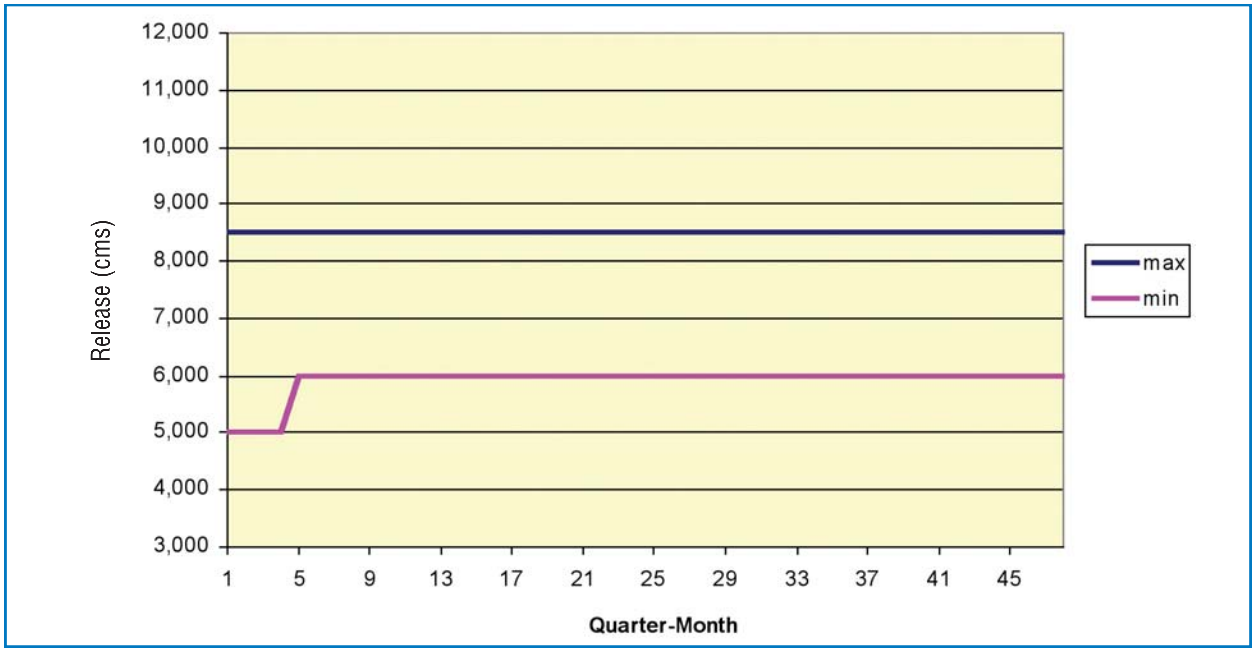


Figure B-17: ***Hydropower target releases***

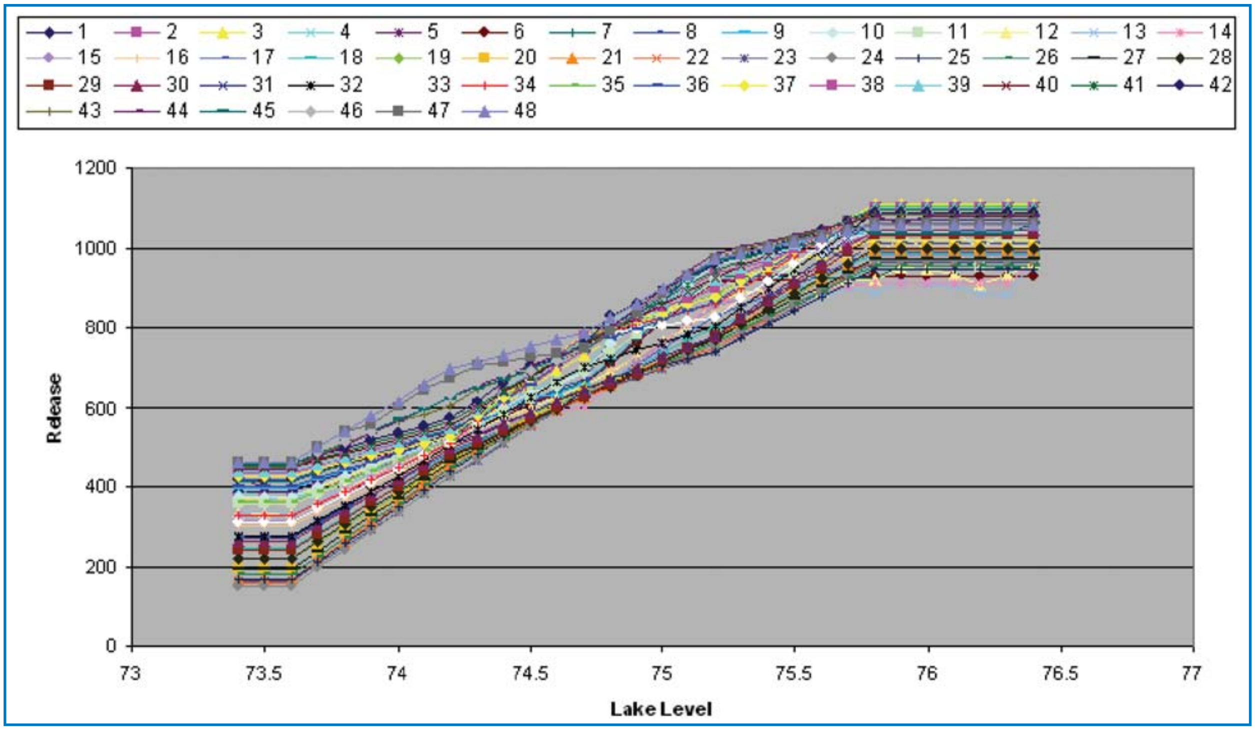


Figure B-18: ***Plan A+ rule curves by quarter-month***

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.

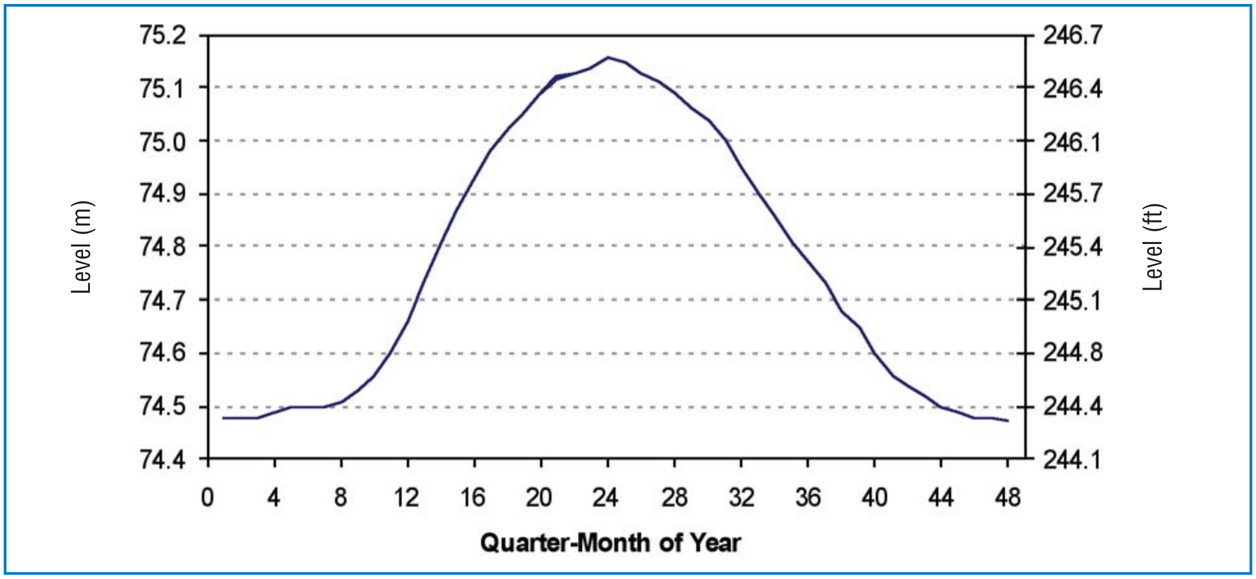


Figure B-19A: ***Lake Ontario normal target level***

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.

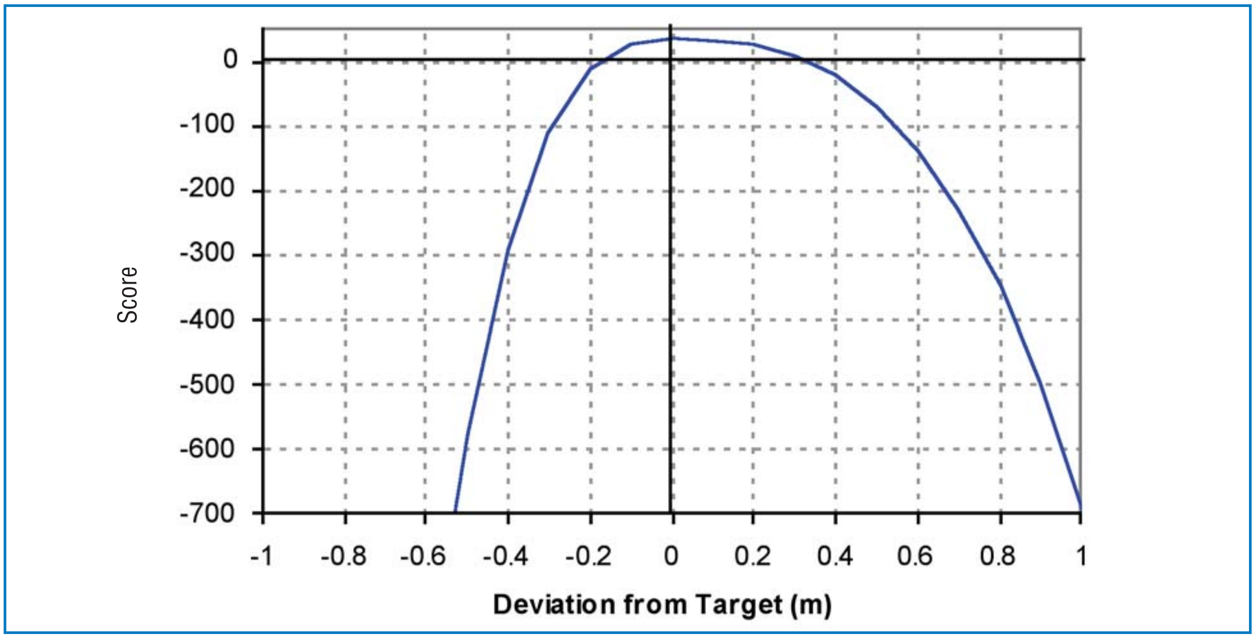


Figure B-19B: ***Lake Ontario score for deviation from target level***

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.

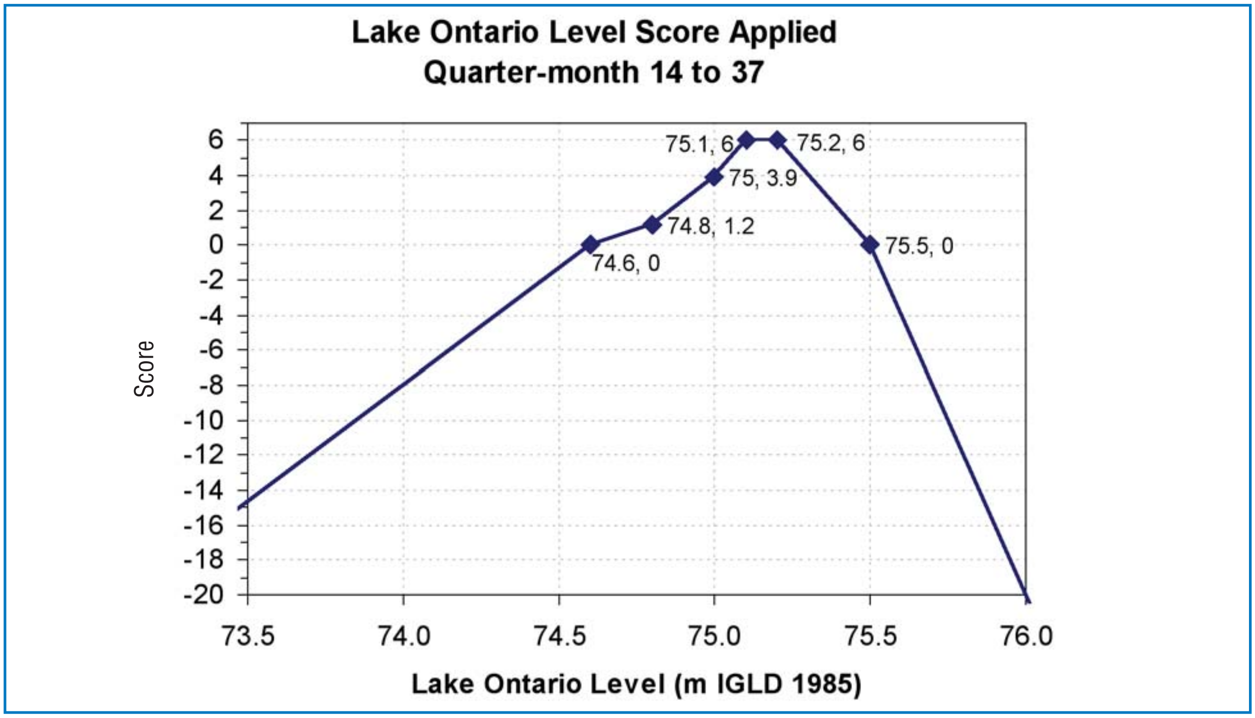


***Figure B-20:* Lake Ontario score added in recreational boating season (2nd quarter-month of April to mid October) (1 metre = 3.28084 ft)**

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).

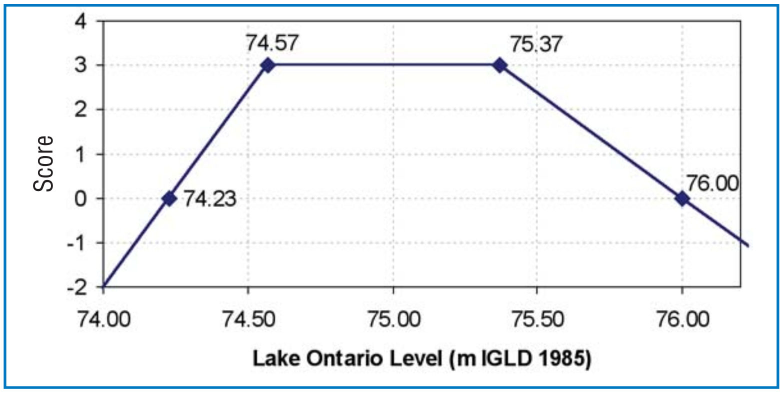


***Figure B-21A:* Lake Ontario level Seaway navigation score**

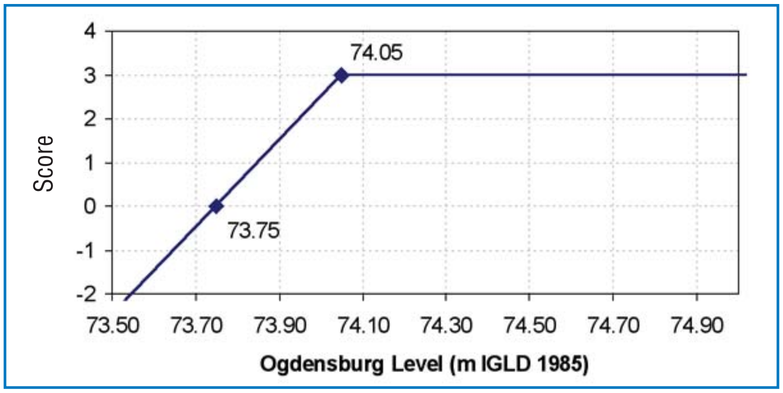


Figure B-21B: ***Ogdensburg level Seaway navigation score***

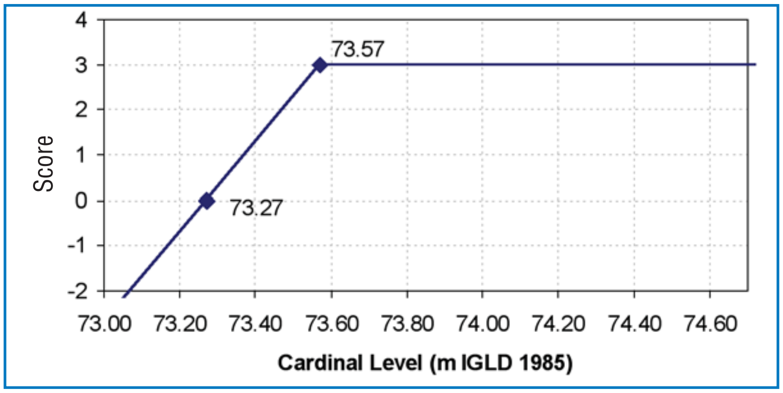


Figure B-21C: ***Cardinal headwater level Seaway navigation score***

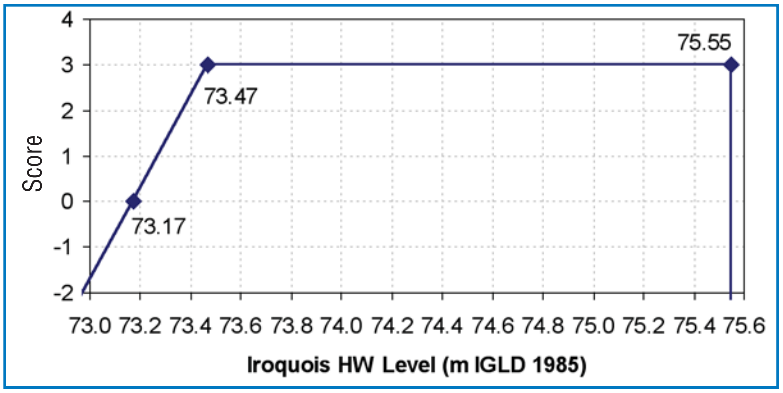


Figure B-21D: ***Iroquois headwater level Seaway navigation score***

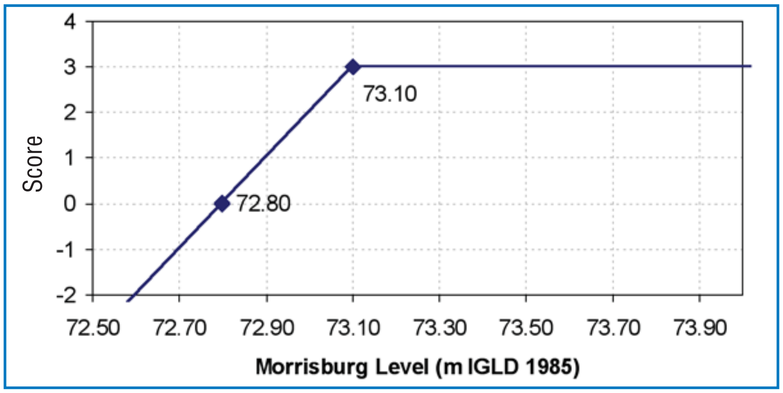


Figure B-21E: ***Morrisburg level Seaway navigation score***

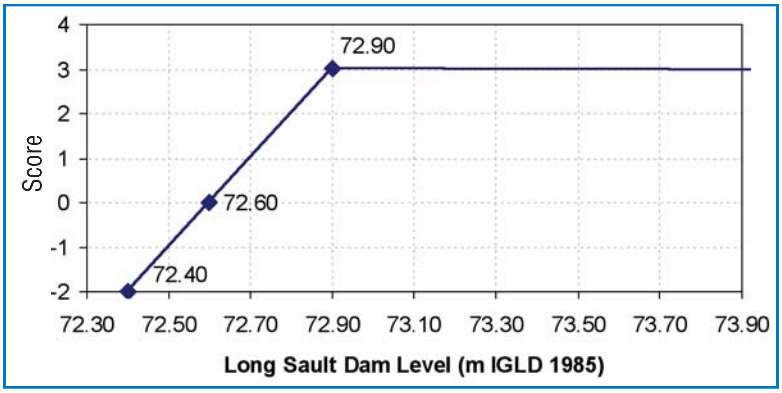


Figure B-21F: ***Long Sault Dam level Seaway navigation score***

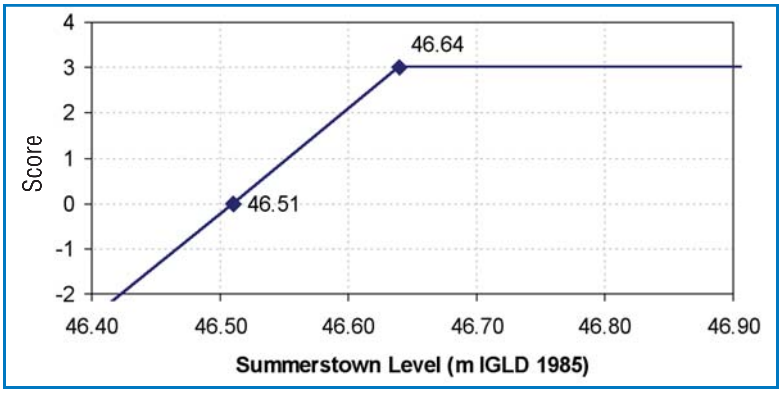


Figure B-21G: ***Summerstown level Seaway navigation score***

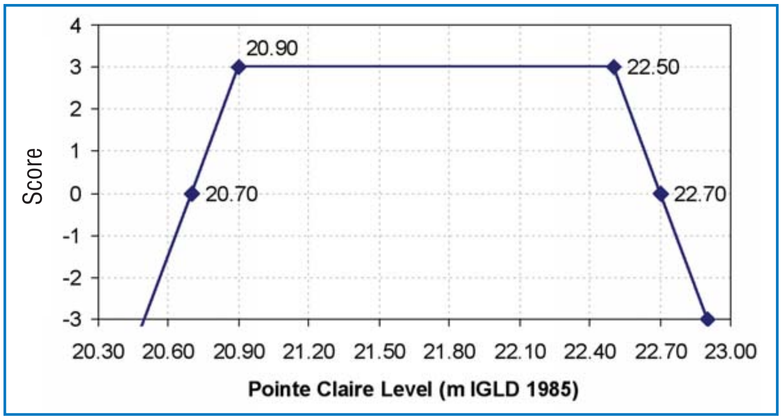


Figure B-21H: ***Pointe Claire level Seaway navigation score***

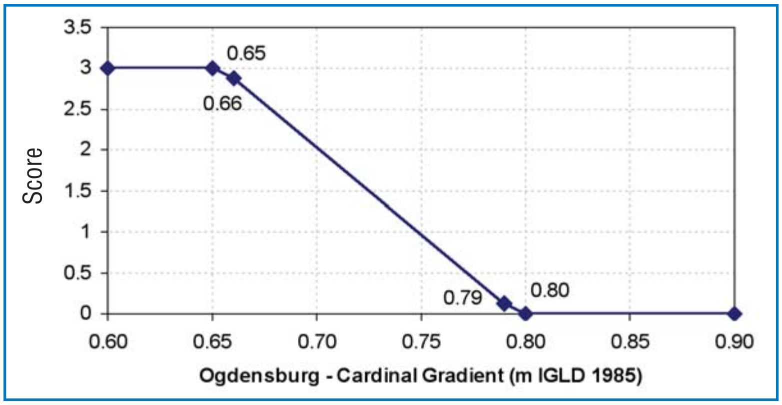


Figure B-21I: ***Ogdensburg–Cardinal gradient Seaway navigation score***

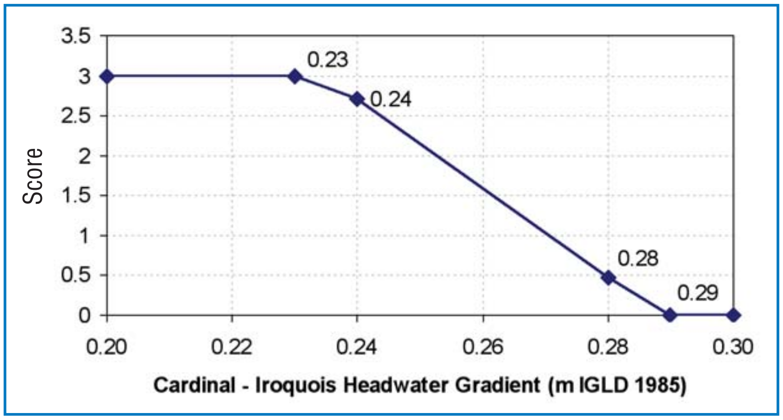


Figure B-21J: Cardinal–Iroquois headwater gradient Seaway navigation score

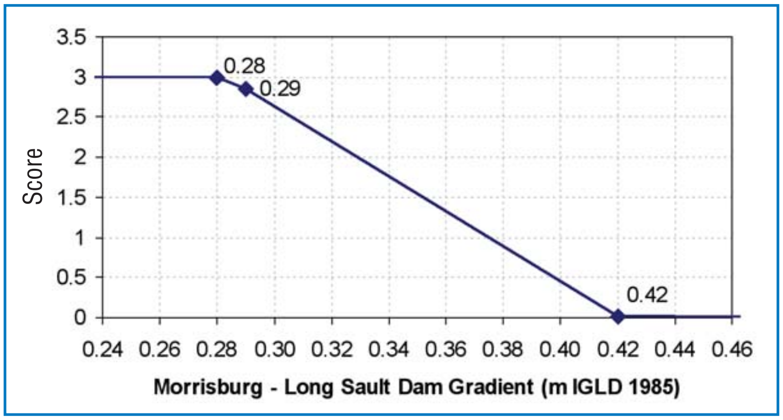


Figure B-21K: Morrisburg–Long Sault Dam gradient Seaway navigation score

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.

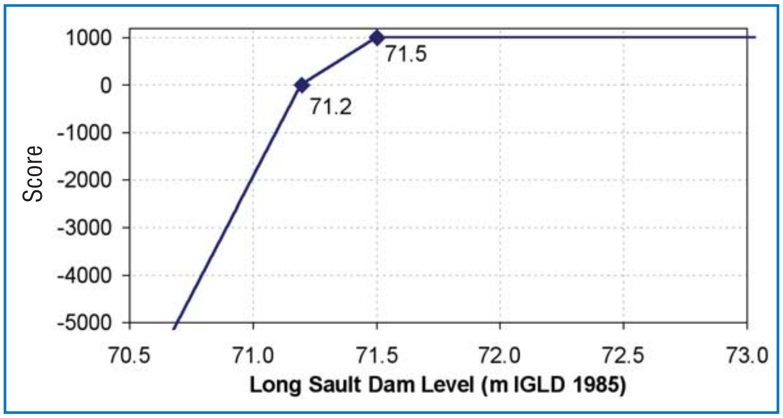


Figure B-22: Score for level at Long Sault Dam

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 m³/s (220,000 ft³/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.

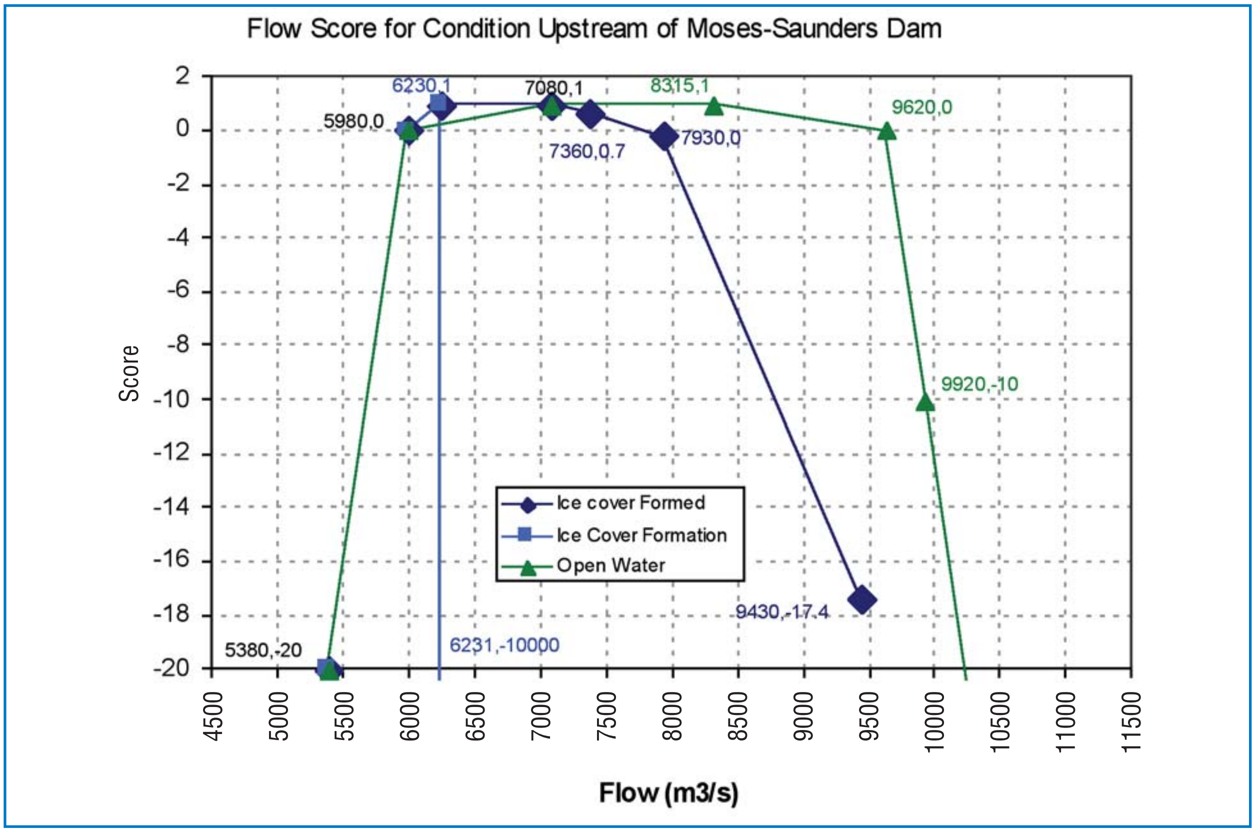


Figure B-23:* *Lake Ontario flow score for different conditions on the St. Lawrence River upstream of Moses-Saunders Dam

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 m³/s (215,400 ft³/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 m³/s (335,500 ft³/s) and 10,000 m³/s (353,100 ft³/s) in the first and second quarter-month after upper river ice disappears, respectively.

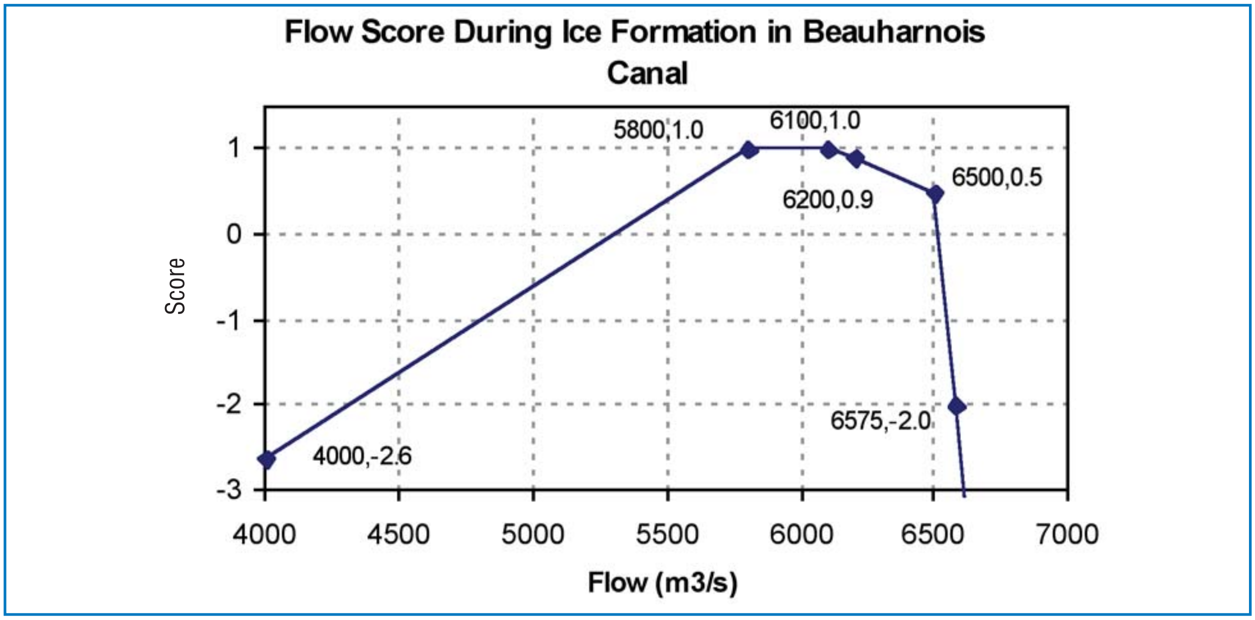


Figure B-24A: ***Lake Ontario flow score during ice formation on the Beauharnois Canal***

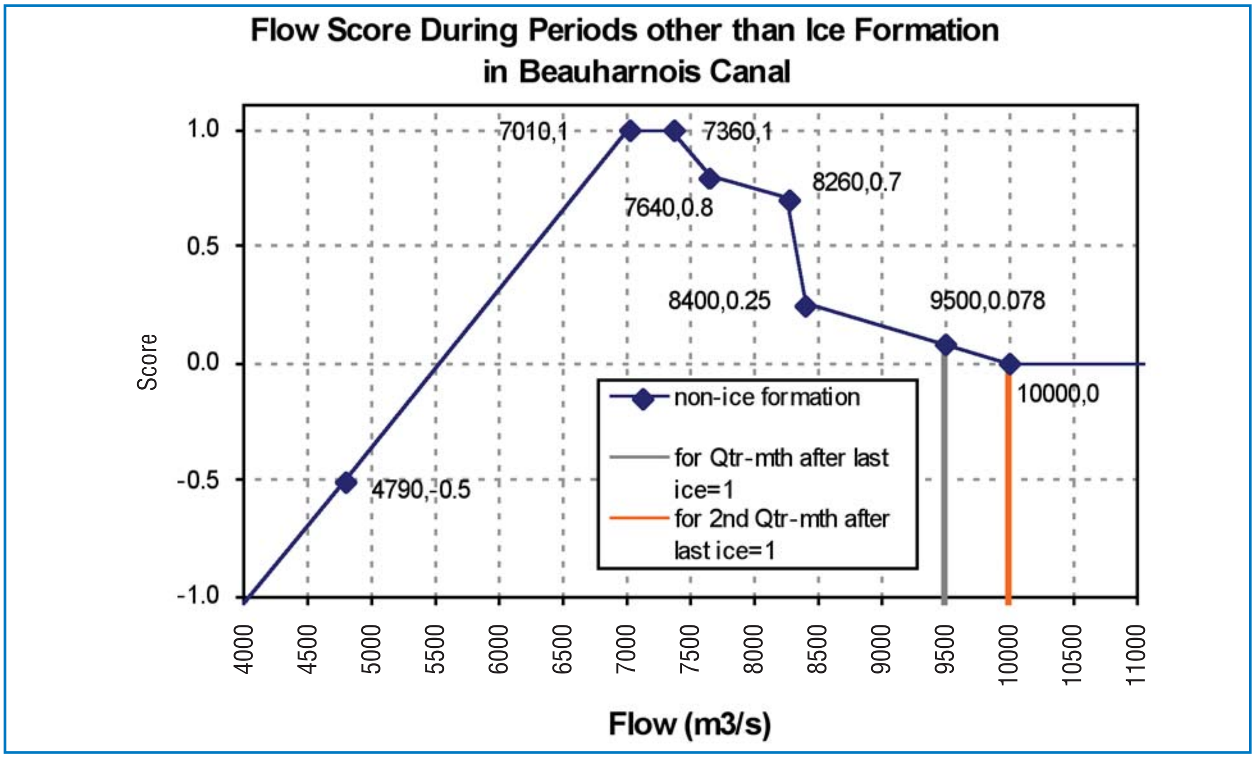


Figure B-24B: ***Lake Ontario flow score for conditions other than ice formation on the Beauharnois Canal***

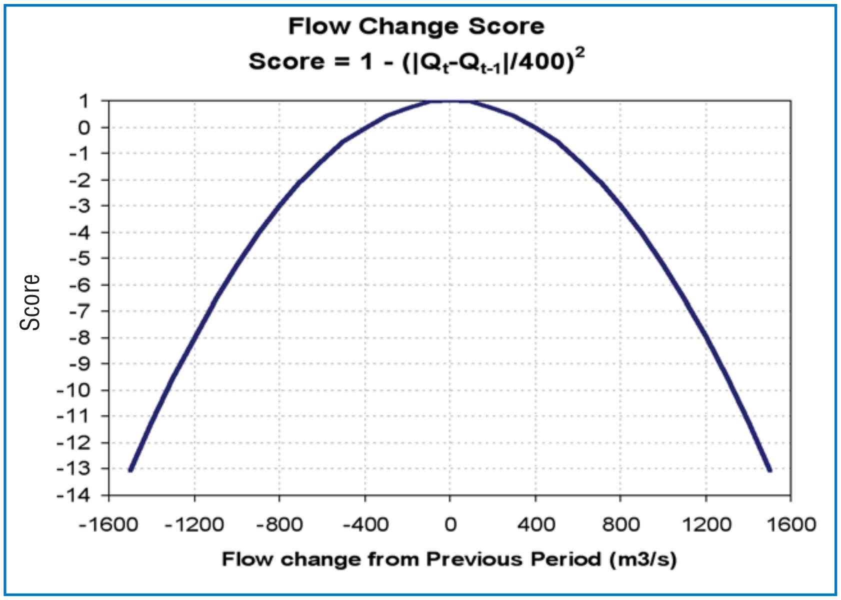


Figure B-25: ***Score based on the change in flow from one period to the next***

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.

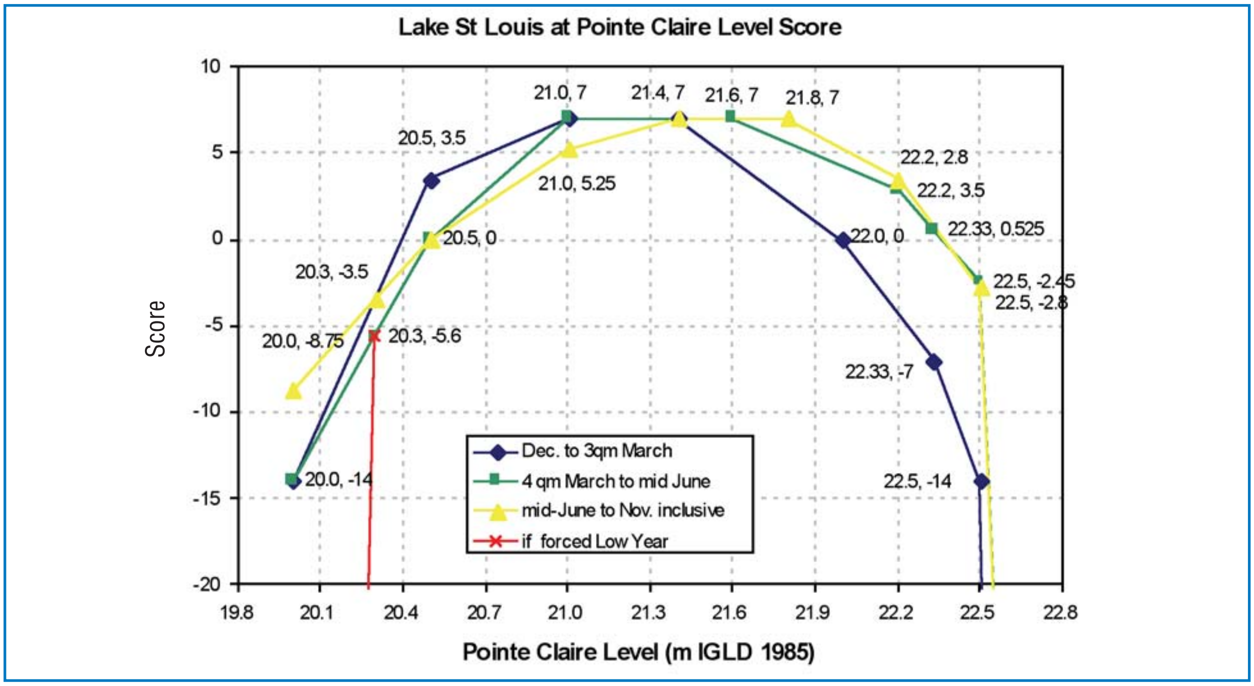


Figure B-26: ***Lac St. Louis at Pointe Claire level score***

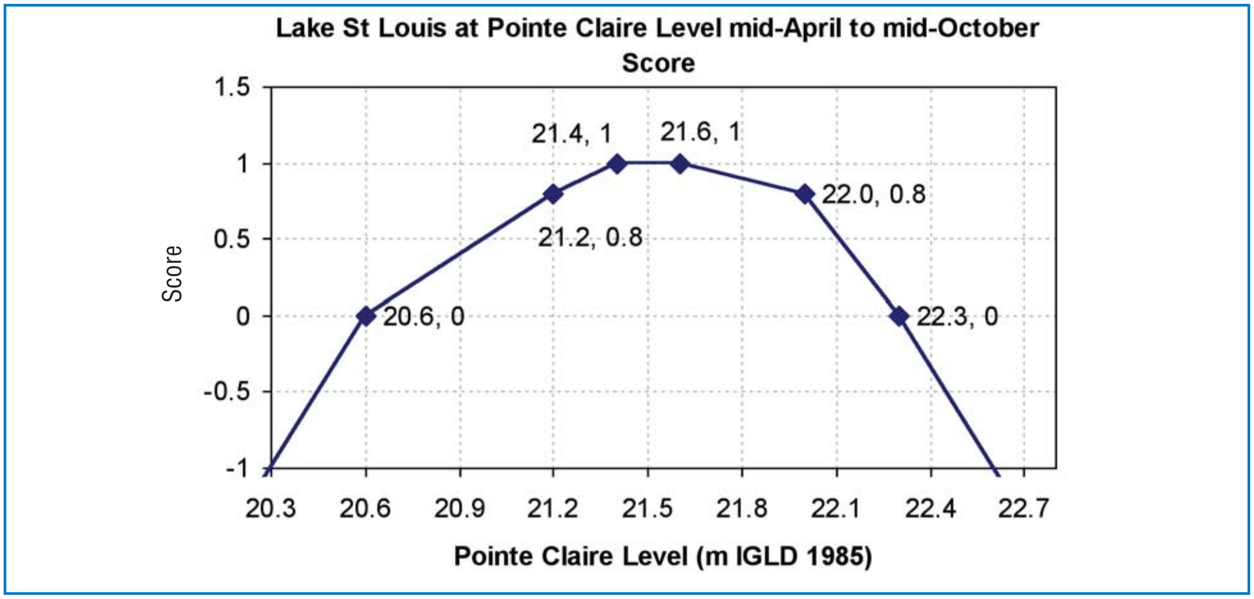


Figure B-27: ***Lac St. Louis at Pointe Claire level score***

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).

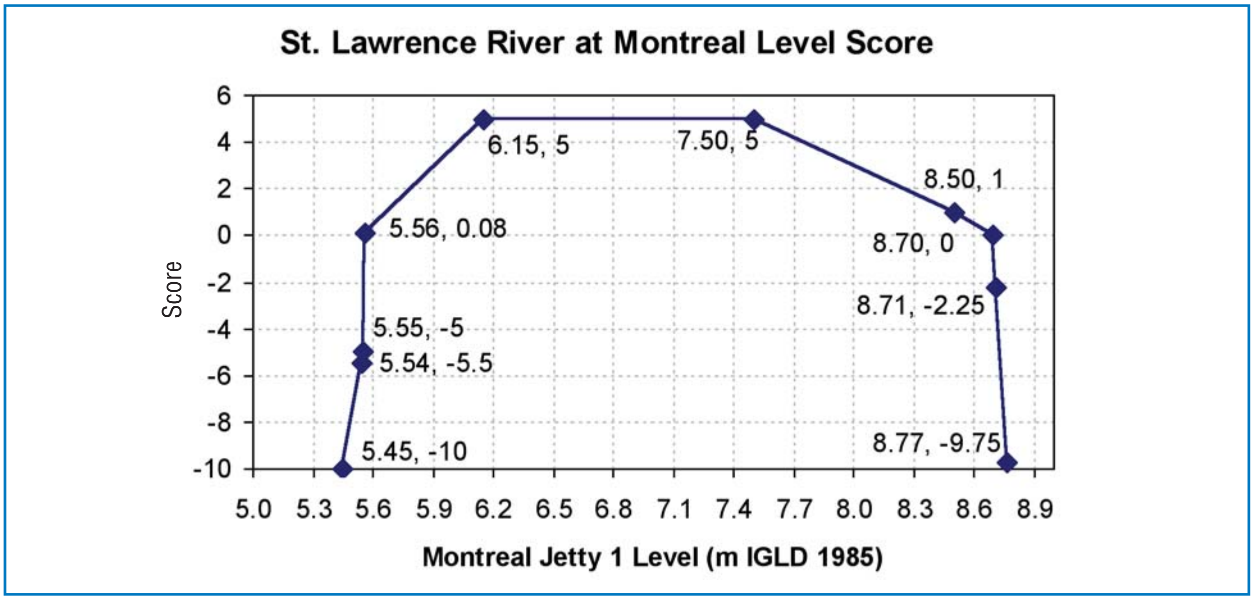


Figure B-28: ***St. Lawrence River at Montreal score***

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.

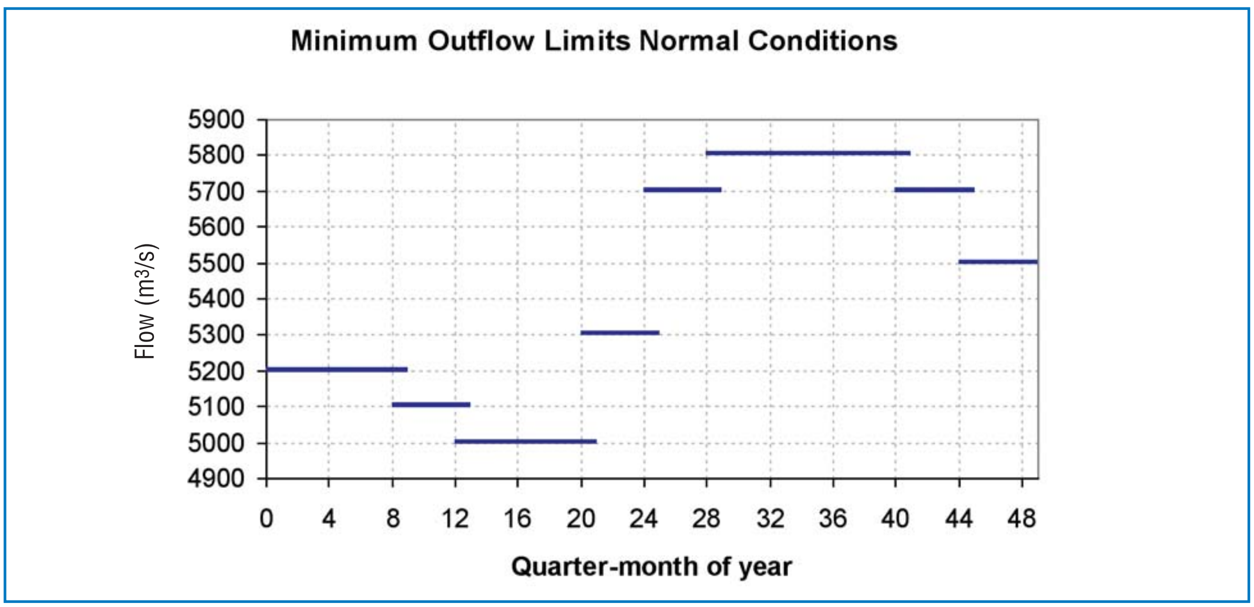


Figure B-29.: Minimum Lake Ontario outflow limits for normal conditions

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.

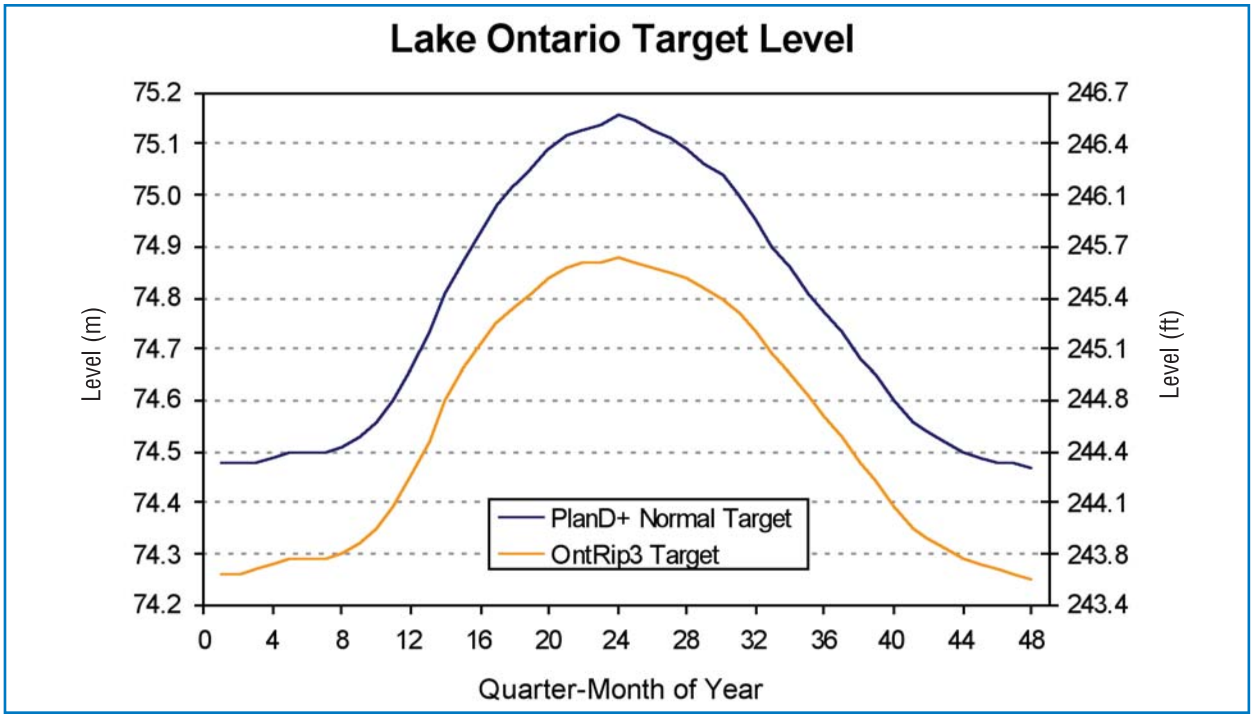


Figure B-30: OntRip3 Lake Ontario target level and Plan D+ normal target level

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.

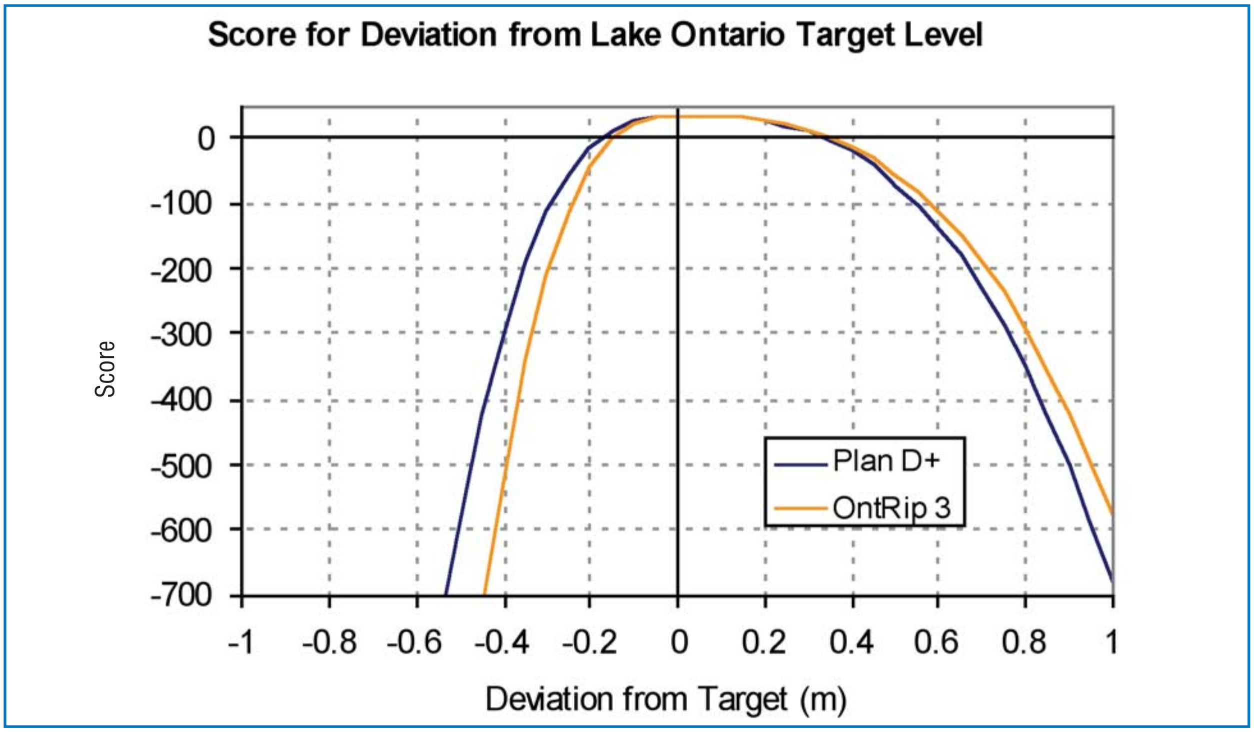


Figure B-31: Lake Ontario score for deviation from target level

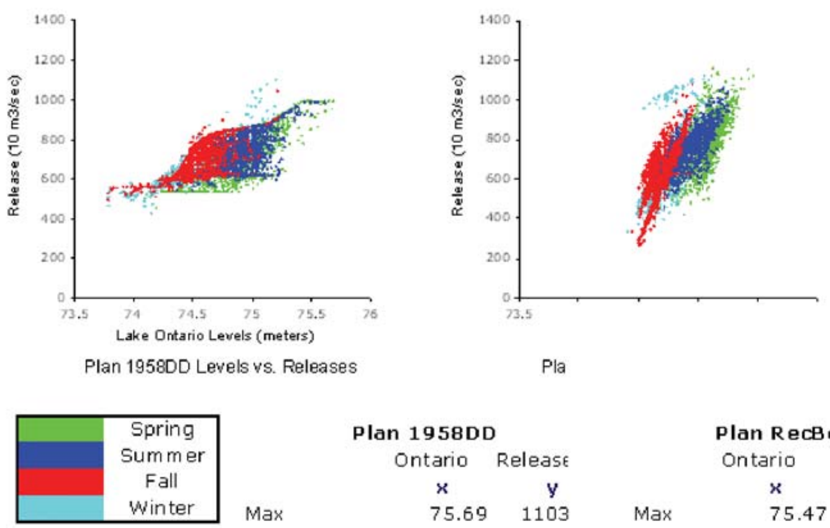
RecBoat: Plan Designed for Recreational Boaters

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).



	Plan 1958DD Ontario x	Release y		Plan RecBoat Ontario x	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.

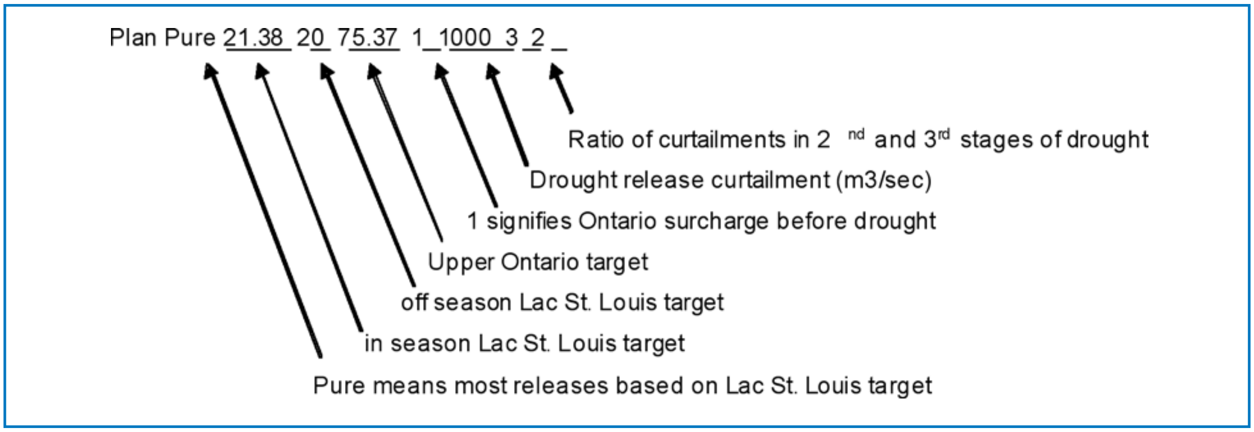


*Figure B-33: **Naming convention for iterations of experimental plans***

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.

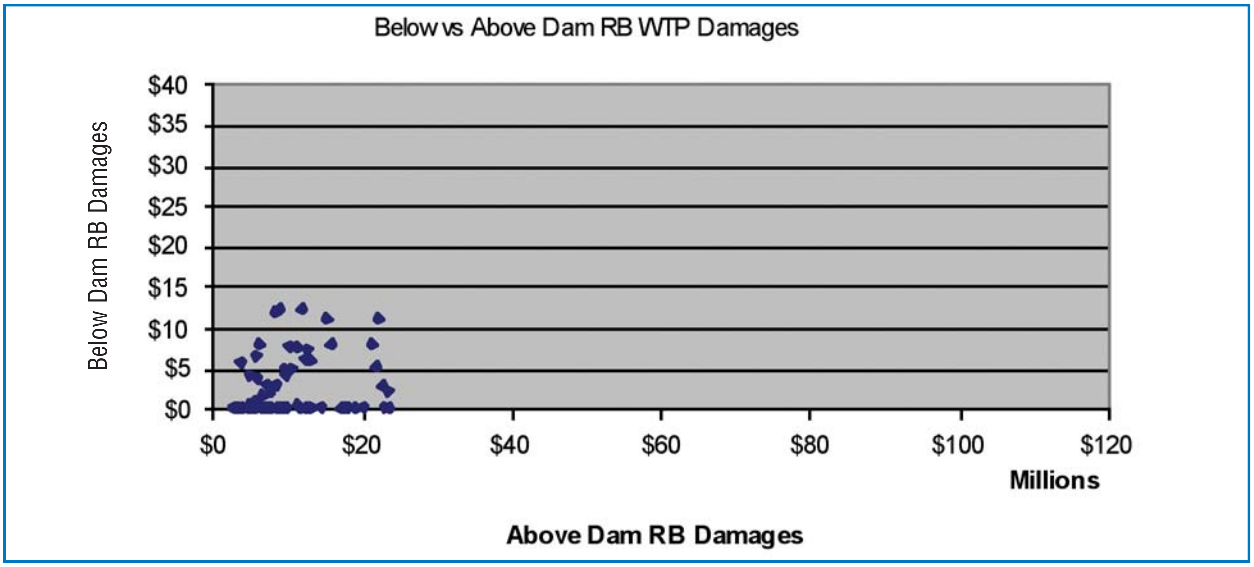


Figure B-34: ***Below versus above dam recreational boating willingness to pay damages***

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

Plan Formulation Team

Mark Lorie (Plan A$^+$)	U.S. Army Corps of Engineers, Ft. Belvoir, VA
Debbie Lee (Plan B$^+$)	U.S. Army Corps of Engineers, Cincinnati, OH
David Fay (Plan D$^+$)	Environment Canada, Cornwall, ON
John Ching	Ontario Power Generation, Toronto, ON
Bill Werick	Culpepper, VA
Yin Fan	Environment Canada, Cornwall, ON
Mike Shantz	Environment Canada, Burlington, ON
Wendy Leger	Environment Canada, Burlington, ON
Paul Yu	U.S. Army Corps of Engineers, Buffalo, NY
Tony Eberhardt	U.S. Secretariat, Buffalo, NY