Plan Bv7: Balanced Environmental Plan

Objectives

Plan Bv7 strives to return the Lake Ontario-St. Lawrence River System to a more natural hydrologic regime, while limiting impacts to other interests. Since the range of levels and flows that Plan Bv7 produces is closer to the current regulation regime than to unregulated conditions, Plan Bv7 maintains most of the benefits of the current regulation regime. Plan Bv7 builds on Plan B+ developed during the International Lake Ontario - St. Lawrence River Study. Plan Bv7 differs from Plan B+ in that it includes additional rules to maintain navigation and flood reduction benefits on the lower St. Lawrence River (Lake St. Louis to Lake St. Peter) and adjustments to the B+ rules to balance Lake Ontario and lower river levels. The goals of the plan are

- Maintain more natural seasonal level and flow hydrographs on the lake and river.
- Provide stable lake releases.
- Maintain benefits to coastal interests as much as possible while enhancing environmental conditions.
- Maintain benefits to recreational boating as much as possible while enhancing environmental conditions.
- Obtain inter-annual highs and lows required for healthy vegetation habitats.
- Enhance diversity, productivity, and sustainability of species sensitive to water level fluctuations.
- Provide flood and low water protection to the lower St. Lawrence River comparable to Plan 1958-D with Deviations.

The plan uses short-term forecasts and a longer-term index of water supplies in conjunction with the pre-project stage-discharge relationship to determine lake releases. Rules are included to reduce the risk of flooding on the lake and river. Flow limits are applied to prevent river flows from falling too low, to facilitate stable river ice formation, provide acceptable navigation conditions, safe operating conditions for control structures, and controlled week-to-week changes in flows.

Approach

Rule Curves

Lake releases are primarily a function of a sliding rule curve based on the pre-project stage-discharge relationship adjusted to recent long-term supply conditions. The open-water pre-project stage-discharge relationship (in units of m^3/s) is: :

$$preproject\ release = 555.823\left(Lake\,Ontario\ \ level\ \ -0.035-69.474\right)^{1.5}$$

where the 0.035 metre term adjusts the Lake Ontario level (referenced to IGLD 1985) for differential crustal movement fixed to the year 2010[1]. The pre-project relationship is that from Caldwell and Fay (2002), but here the ice retardation effect is not considered.

[1]The year 2010 was selected by the ILOSLRS Plan Formulation and Evaluation Group to compare what pre-project conditions would be near the completion of the Study. The year should be fixed as otherwise there would be a gradual increase in the lake level due to the continual adjustment for glacial isostatic uplift of the lake's outlet.

The flow computed with this equation is then adjusted depending on the recent supply conditions. As water supplies trend above normal, lake releases are increased. As supplies trend below normal, lake releases are decreased.

For supplies above normal (the index is greater than or equal to 7011 m^3/s), the lake release is determined by:

$$outflow_t = preproject\ release + \left[\frac{F\_NTS - A\_NTS_{avg}}{A\_NTS_{\max} - A\_NTS_{avg}} \right]^{P_1} x(C_1)$$

For supplies below normal (the index is less than 7011 m^3/s), the lake release is determined by:

$$outflow_t = preproject\ release - \left[\frac{A\_NTS_{avg} - F\_NTS}{A\_NTS_{avg} - A\_NTS_{\min}} \right]^{P_2} x(C_2)$$

where F_NTS, the supply index, is an index based on the net total supply for the past 52 weeks (48 quarter-months), and A_NTS represents the maximum, minimum and average statistics of the annual net total supply series. The constants C_1 and C_2 determine the rate of flow adjustment to the pre-project release. C_1 is further dependent on the long-term trend in supplies. If the categorical long-term trend indicator is 1 (demonstrating above normal supplies; that is, when the current supply value exceeds 7237 m^3/s) and the confidence indicator is 3 (indicating high confidence in extreme supplies; that is, when the current supply value exceeds 7426 m^3/s), then C_1 is set to 2600 m^3/s, otherwise it is equal to 2200 m^3/s. The value of C_2 is 600 m^3/s. The exponents P_1 and P_2 serve to accelerate or decelerate the rate of flow adjustment. The values of P_1 and P_2 are 0.9 and 1.0, respectively.

Table 1. Plan Bv7 Rule Curve Parameter Values based on Historic Supplies[2].

Climate	***A_NTS_{max}***	***A_NTS_{avg}***	***A_NTS_{min}***
Historic (1900-2000)	8552 m^3/s	7011 m^3/s	5717 m^3/s

The flow is further reduced by 200 m^3/s if the 52 week (48 quarter-month) running lake level mean is less than or equal to 74.6 m IGLD 1985.

Variability of releases from one week (or quarter-month) to the next is smoothed by taking the average of short-term forecasts[3] of releases four weeks (or quarter-months) into the future:

$$outflow = \frac{\sum_{t=1}^{t=4} outlow_t}{4}$$

This averaging also has the impact of accelerating releases during periods of rising lake levels (typically spring), and decelerating releases during periods of falling lake levels (typically fall). Sensitivity analysis indicated that forecasts 4 quarter-months into the future were optimal.

Plan Bv7 also has a rule to reduce the risk of Lake Ontario and St. Lawrence River flooding in the following spring and summer. If the level of Lake Ontario is relatively high then it adds to the rule curve

[2] The rule curve parameters should be updated periodically to account for climate change.
[3] see Lee (2004) for the derivation of the forecast algorithms

flow to reduce the level of Lake Ontario in the fall. It lowers otherwise high Lake Ontario by the onset of winter thus preparing for spring and making temporary lake 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. The rule strives to lower Lake Ontario to 74.8 m by January 1 whenever Lake Ontario level is above 74.8 m at the beginning of September. The rule curve flow is linearly increased by the amount needed to eliminate the storage on the lake above 74.8 m over the remaining time before January 1. A check is made to ensure that the adjusted flow for the first week of September does not exceed that of the last week in August to prevent falling levels affecting Lake St. Lawrence recreational boaters through the Labor Day weekend. The adjusted flow is constrained by the L Limits (see later).

Flow Limits

Several flow limits, adapted from previous plan development, are used in Plan Bv7. If the rule curve flow (described above) falls outside of these limits then the lowest of the maxima, or the minimum limit, as applicable, constrains the rule curve flow.

- M Limit – minimum limit flows to balance low levels of Lake Ontario and Lake St. Louis primarily for Seaway navigation interests. This limit uses a one week (or quarter-month) forecast of Ottawa River and local tributary flows to estimate the inflows to Lake St. Louis, other than those from Lake Ontario.

Table 2. M Limits as used in Bv7.

Lake Ontario level (m, IGLD 85)	Total Flow from Lake St. Louis (m^3/s)	(Approximate Corresponding Lake St. Louis level at Pointe Claire (m IGLD 1985)
> 74.2	6,800	20.64
> 74.0 and ≤ 74.2	6,400	20.50
> 73.6 and ≤ 74.0	6,100	20.39
≤ 73.6	Minimum of (5,770 or pre-project fixed at year 2010)	20.27 or less

In actual operation the flow will be adjusted from day-to-day to maintain the level of Lake St. Louis above the applicable level determined by the Lake Ontario stage.

- L Limit – maximum flows to maintain adequate levels and safe velocities for navigation in the International Section of the river (navigation season) and the overall maximum flow limit (non-navigation season). Maximum releases are limited to 10,700 m^3/s if the Lake Ontario level should rise above 76.0 m during the navigation season and 11,500 m^3/s during the non-navigation season.

Table 3. L Limits as used in Bv7.

Lake Ontario level (m, IGLD 1985)	
For Quarter-Months 13-47 (i.e. Seaway navigation season):	
≤ 74.22	5,950
> 74.22 and ≤ 74.34	5,950+1,333(Lake Ontario level – 74.22)
> 74.34 and ≤ 74.54	6,111+9,100(Lake Ontario level – 74.34)
> 74.54 and ≤ 74.70	7,930+2,625(Lake Ontario level – 74.54)
> 74.70 and ≤ 75.13	8,350+1,000(Lake Ontario level – 74.70)
> 75.13 and ≤ 75.44	8,780+3,645(Lake Ontario level – 75.13)
> 75.44 and ≤ 75.70	9,910
> 75.70 and ≤ 76.00	10,200

> 76.00	10,700
For Quarter-Months 48-12 (i.e. outside Seaway season) all levels	11,500

A final check ensures that the L Limit does not exceed the actual channel hydraulic capacity (in m^3/s) defined as (Lee et al, 1994):

$$channel\ capacity = 747.2(Lake\,Ontario\ \ level\ \ - 69.10)^{1.47}$$

- I Limit – maximum flows for ice formation and stability. During Ice cover formation, either downstream on the Beauharnois Canal or on the critical portions of the International Section, the maximum flow is 6,230 m^3/s. Once a complete ice cover has formed on the key sections of the river, the winter flow constraint prevents the river level at Long Sault from falling lower than 71.8 m. (Note the J limit also applies) This limit may apply in the non-Seaway season whether ice is present or not. This flow limit is calculated using the stage-fall discharge equation for Kingston-Long Sault which includes an ice roughness parameter that must be forecast for the coming period. This limit prevents low levels that might impact municipal water intakes on Lake St. Lawrence, and also acts to limit the shear stress on the ice cover and maintain stability of the ice cover. The I limit also limits the maximum flow with an ice cover present in the Beauharnois and/or international channels to no more than 9,430 m^3/s.

- J Limit – maximum change in flow from one week (or quarter-month) to the next unless another limit takes precedence. Flows are permitted to increase or decrease by up to 700 m^3/s. If the lake is above 75.2 m, and ice is not forming, the flow may increase by up to 1,420 m^3/s from one week (or quarter-month) to the next.

- F limit – maximum flow to limit flooding on Lake St. Louis and near Montreal in consideration of Lake Ontario level. It is a multi-tier rule that attempts to balance upstream and downstream flooding damages by keeping the level of Lake St. Louis below a given stage for a corresponding Lake Ontario level as follows:

Table 4. Lake St. Louis (Pointe Claire) levels corresponding to Lake Ontario levels for limiting lower St. Lawrence River flooding damages (F limits).

Lake Ontario level (m, IGLD 1985)	Pte. Claire level (m, IGLD 1985)
< 75.3	22.10
≥ 75.3 and < 75.37	22.20
≥ 75.37 and < 75.5	22.33
≥ 75.5 and < 75.6	22.40
≥ 75.6	22.48

This limit uses a one week (or quarter-month) forecast of the Ottawa River and local tributary inflows and the following relationship between Lake St. Louis outflows and levels at Pointe Claire:

$$Pte.\,Claire\ level = 16.57 + \left[(R_{Pt.\,Claire}\ \ x\ Q_{L.St.\,Louis}\ / \,604.0)^{0.58}\right]$$

where R is the roughness factor and Q (in m^3/s) is the total flow from Lake St. Louis. In operation the flow will be adjusted from day to day to maintain the level of Lake St. Louis below the applicable level determined by the Lake Ontario stage.

Application of Plan Bv7

Plan Bv7 uses imperfect forecasts of Lake Ontario total supplies, Ottawa River and local tributary flows, ice formation and ice roughness. The water supply forecasts are based on time-series analysis of the historical data as described in Lee (2004). Overall, the statistical forecasts were found to have similar error to those in use operationally. Because the operational methods generally rely upon hydrometeorological data not available for either the historic time series or the stochastic time series, actual forecasts could not be used. However, it was envisioned that operationally, the best available real-time forecasts would be used. In addition, because week ahead forecasts will generally be imperfect, it is expected that in actual operations the flows will be adjusted within the week taking into account the actual ice and downstream inflow conditions to achieve the intent of the Bv7 rules and limits.

Procedure

1. For each of the next four weeks (quarter-months), calculate the Lake Ontario annual net total supply index, forecast the weekly (quarter-monthly) Lake Erie inflow and Lake Ontario net basin supply, Ottawa River and local tributary flows to Lake St. Louis, and ice roughness.
2. For each of the next four weeks (quarter-months), sequentially route the supplies and determine forecasts of lake outflows using the sliding rule curve.
3. Average the next four weeks (quarter-months) forecast releases to determine the next period's release.
4. If the current time period is within September through December inclusive, and Lake Ontario was at or above 74.8 m on September 1 (end of quarter-month 32), then increase the basic rule curve by the amount needed to achieve 74.8 m by January 1, not exceeding the flow in the week before Labour Day (quarter-month 32) in the flow in the Labour Day week (quarter-month 33).
5. Apply the M, L, I, J and F limits. If the plan flow is outside of the maximum of the minimum limits and the minimum of the maximum limits, the appropriate limit becomes the plan flow.

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.

Lee, D., 2004. Deterministic Forecasts for Lake Ontario Plan Formulation. Plan Formulation and Evaluation Group, IJC Lake Ontario-St. Lawrence River Study.

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.