Great Lakes - St. Lawrence River Adaptive Management (GLAM) Committee

Annex 2:

Supplementary plan review and evaluation information for Lake Ontario and the St. Lawrence River

November 26, 2018

Contents

Cover photo: High water conditions near Fair Haven, New York (photo credit: US Army Corps of Engineers, June 2017)

1.0 Introduction

This Plan Review Annex (**Annex 2**) serves as an in-depth assessment of 2017 conditions on Lake Ontario and the St. Lawrence River, focusing on plan review and evaluation. This Annex 2 provides further information on efforts to review and evaluate the regulation plan. The focus is on water level and flow simulations and not on performance indicator simulations.

The year 2017 provided a unique opportunity to look at various aspects of plan performance under extreme conditions. It should be noted that plan performance must ultimately be assessed under a range of conditions to determine whether overall objectives are being met. The GLAM Committee is acutely aware of the dangers of making premature conclusions based on plan performance in a single year. However, the committee also recognizes the importance of looking at plan performance given the extreme conditions of 2017 to ensure the plan was performing optimally and any lessons learned can be identified for operations under potential future extreme conditions.

2.0 Plan Review and Evaluation

The GLAM Committee intends to analyze the performance of the Lake Superior and Lake Ontario outflow regulation plans on a regular basis to determine how the interplay of nature and regulation rules affected outcomes and, from that, draw conclusions about whether and how the plans can be improved. The analytic framework used in this first GLAM Committee report will also be reviewed and may change over time. This Annex 2 focuses on the Lake Ontario – St. Lawrence River outcomes. The main report offers some assessment of the Lake Superior regulation decisions. In future years, when better tools have been developed for Lake Superior, the GLAM Committee will analyze those outcomes in more depth.

2.1 Overview

The IJC requires the GLAM Committee to support the Great Lakes Boards, particularly the International Lake Ontario – St. Lawrence River Board (ILOSLRB) and the International Lake Superior Board of Control (ILSBC), in the on-going assessment of the regulation plans so they can, "make recommendations to the IJC for modifications to the regulation plans to address what has been learned and/or to address changed conditions of the system.[1]"

The GLAM Committee reviewed the regulation of Lake Ontario and the St. Lawrence River and the performance of Plan 2014 during 2017 in this light. It developed the evaluation process used in this chapter to provide an immediate retrospective review of how Plan 2014 performed during

[1] IJC 2015 Directive to the GLAM Committee

the extreme conditions of 2017, allowing GLAM to further identify and differentiate between the hydrologic conditions that occurred, how Plan 2014 responded to those conditions and the effects each had on water levels and flows throughout the basin.

While this review will generate just one year of information, which in itself is insufficient to fully evaluate regulation plan performance given the uncertainty and variability in water supply conditions from year-to-year and over longer time-spans, the results of this review increase our understanding of the system and can be added to future assessments to support a long-term plan assessment.

The annual review process can assist the GLAM Committee in identifying potential modifications, which may lead to findings that guide future, and more in-depth, plan evaluation activities. Such findings form the basis for a full evaluation that would involve an assessment of all potential regulation plan modifications and comparisons of various alternative regulation strategies, which will be designed in consideration of our evolving understanding of how hydroclimate conditions and impacts of water levels and flows on various interests are changing.

2.1.1 Evaluation framework

Both the International Lake Ontario – St. Lawrence River Study (LOSLRS) and the International Upper Great Lakes Study (IUGLS) assessed potential regulation plan outcomes using a combination of hydrologic/hydraulic models (for simulating water levels and flows), impact assessment models (to estimate potential impacts on various interests, both positive and negative) and a range of potential water supply scenarios, including historical water supplies and simulations of potential future water supply conditions. Acknowledging that water supply conditions are highly variable, unpredictable and uncontrolled, both studies compared the relative impacts of various regulation plans to a baseline condition. Building on the work of these previous studies, the GLAM Committee believes an ongoing and long-term plan evaluation should:

1. Consider plan performance under a range of plausible water supply scenarios;
2. Use net changes from a baseline regulation setting to evaluate the impact of a regulation decision on water levels and flows; and
3. Compare not only water level and flow conditions but also expected impacts, both positive and negative, on various interests throughout the system.

The review of plan performance for a single year, such as 2017 in this report, is an important starting point for building towards a longer-term plan review and can be designed to support a multi-year analysis. The IJC's 2016 Supplemental Orders of Approval require that the effects of the regulation plan on water levels, flows and impacts be reviewed no later than 15 years after the effective date of the Order. The review will assess the extent to which the results predicted by the research and models used to design the regulation plan occurred, and each year's assessment can contribute to that longer-term goal. The single year review provides the opportunity to:

- Analyze how water levels and flows in the Lake Ontario – St. Lawrence River system were influenced by particular hydrologic conditions and the regulation plan in a given year. In this report, the GLAM Committee uses a number of hydrologic conditions scenarios, including actual conditions observed in 2017, as well as a number of modified scenarios to further illustrate the effects of variations in conditions;
- Use net changes from a baseline regulation setting to evaluate the impact of a regulation decision on water levels and flows. In this report, the GLAM Committee uses a number of baselines for comparison to actual results under Plan 2014, including the former regulation plan, pre-project conditions (prior to regulation), and a number of variations to specific Plan 2014 rules and International Lake Ontario – St. Lawrence River Board (ILOSLRB) deviation decisions made during 2017; and
- Allow the GLAM Committee to build towards a multi-year dataset of plan performance under a variety of conditions that provides a better understanding of how outflow regulation compares to the outcomes expected through the available evaluation models.

However, the single-year review also has a number of potential limitations, and as a result, there are several reasons why plan performance should not be based solely on a single year's outcomes alone, including:

1. One year influences the next. Lake Ontario water levels do not return to the same level at the end of every year, so the ending level from the previous year can influence the outcomes in the following year or even subsequent years. Because 2017 was the first year Plan 2014 was used, the GLAM Committee will address this objective in a limited way in this report by considering different start-of-the-year water level conditions. The GLAM Committee will be able to more fully meet this objective in future years.
2. Regulation rules that work well in some years may not work as well in others. For example, because Lake Ontario water supply conditions are highly variable and unpredictable, regulation plans must be expected to perform under a variety of conditions and this includes the possibility of dry or wet futures. Rules that are best at avoiding drought levels might exacerbate flooding in wet years, and vice versa.
3. Impact assessment models and tools were developed for long-term, multi-year assessments, and not all impact assessment tools are property configured to simulate single-year impacts in a comparable way. This is partly because many of the expected positive outcomes of Plan 2014, especially environmental ones, are only expected to be realized after several years, or possibly even decades, as they too depend on water supply conditions.

Despite these potential limitations, the simulations undertaken to assess plan performance in 2017 represent a valuable and important first step in better understanding regulation plan operation and highlighting areas for further investigation of plan impacts using a broader set of water supply conditions.

2.1.2 Operational assessments vs planning simulations

In this report, operational assessment of actual water levels in 2017 are compared to those that would have occurred using Plan 2014 but with:

- Different Hydrologic Conditions in 2017 (2.2), and
- Modified Outflow Regulation Strategies in 2017 (2.3).

A validation of Quarter-monthly Planning Simulations Under 2017 Conditions (2.4) is also provided.

In practice, the ILOSLRB monitors and uses real-time water levels, flows and water supply information from throughout the Great Lakes and St. Lawrence River system as input to make regulation decisions. These decisions are normally made on a weekly basis and according to the rules of Plan 2014. During more critical periods, such as when short-term operational issues arise, or when conditions are rapidly changing within the week, or when the ILOSLRB has authority to deviate from the regulation plan, regulation decisions can occur more frequently.

In contrast, planning simulations, such as those used to design and evaluate Plan 2014 and various alternatives, are used to model and evaluate how regulation plans and decisions are expected to perform over time given the uncertainty and variability in water levels, flows and water supplies that the plans may be faced with. In these simulations, computer programs are developed to simulate, as accurately as possible, how the regulation plan rules will respond to hydrologic conditions. However, as with any model of a real-world process, there are limitations and sources of uncertainty involved. For example, planning regulation models and decisions are made on a quarter-monthly (i.e., 48 quarter-months, or QMs, per year) basis in order to achieve a close approximation of the weekly decisions that are normally made in practice, while also maintaining consistency with available hydrologic data used as input to these models from year-to-year. However, planning models cannot account for shorter-term decisions or changes in hydrologic conditions, in part because many of those decisions are highly uncertain and impossible to accurately represent within a model simulation, and in part because planning models are used to simulate conditions and expected performance over long periods of time (e.g., 100+ years of historical record and 50,000 years of statistically generated records were used in the LOSLRS), making shorter time-steps unfeasible.

The GLAM Committee is charged with comparing actual observations to planned results, so must take the differences between operations and planning into consideration.

In the first two of these three subsections (2.2 and 2.3), water levels and flows were simulated using a "Weekly Operational Simulation" methodology. This methodology most closely reflects the actual conditions – both physical and operational – that occurred and that were considered during the regulation of outflows in 2017. It is a manually intensive approach that involves reviewing conditions week-by-week, and at times day-by-day, throughout the Lake Ontario – St. Lawrence River basin. Actual water supplies and ice conditions, as well as operational considerations (such as hydropower outages, ship requests, boat haul-outs, Seaway transits, downstream flooding concerns, etc.) are reviewed to determine if operational adjustments or deviations from the plan-prescribed flow might have been necessary. The effects of these factors on flows and levels is assessed, and then regulated outflows from Lake Ontario are computed, along with water levels throughout the Lake Ontario – St. Lawrence system, and recomputed when necessary (e.g., if levels exceed critical values). As a result, this week-by-week methodology most closely reflects the conditions that would have occurred in 2017 under various alternatives and is the closest representation of actual weekly operations conducted by the ILOSLRB. Further background on operational adjustments and deviations is provided in the sidebar on the next page.

In the third sub-section (2.4), water levels and flows in 2017 were simulated using a "Quarter-monthly Planning Simulation" approach, rather than the "Weekly Operational Simulation" methodology described above. The quarter-monthly plan simulations were employed during the LOSLRS and subsequent IJC efforts to evaluate and compare the effects of different regulation plans. This is a simpler methodology to employ because water levels and flows are simulated on

UNDERSTANDING OPERATIONAL ADJUSTMENTS AND DEVIATIONS

Operational adjustments are those flow changes necessary to address inaccurate forecasts employed by the plan internally (to set the tentative flows each week) or short-term changes in conditions within the week, and so, are consistent with, and accounted for, in the design of the plan. For example, adjustments may be needed to successfully manage ice formation, downstream flood flows, or ensure adequate river depth for Seaway transits, such as when inflows are not accurately forecast, or ice begins to form mid-week and/or during periods of relatively high flows as intended by the plan. Note that in the past, the ILOSLRB would, through deviations from Plan 1958-D, often provide similar adjustments to flows to achieve similar objectives, so in this way the new plan functions in much the same way. However, with operational adjustments under Plan 2014, no offsetting, compensatory restoration is necessary following operational adjustments, so they are distinguished from deviations and separate records are maintained.

Minor deviations which may be necessary for contingencies such as hydropower maintenance, assistance for commercial vessels, boat haul-outs, emergencies, etc., were also considered and were restored by equivalent offsetting adjustments from the plan flows as soon as conditions permitted. Thus, cumulative impacts and changes to the balance of the plan's benefits were minimized.

In addition, as per the IJC's December 8, 2016 Directive on Operational Adjustments, Deviations and Extreme Conditions, major deviations from the plan may be allowed when levels of Lake Ontario rise above or below a set of established Lake Ontario threshold levels considered in the weekly Plan 2014 simulation. As detailed in the IJC's directive, the high thresholds are those levels that are exceeded 2 percent of the time and the low thresholds are defined as the levels exceeded 90 percent of the time as determined by the full stochastic generation (50,000 years of stochastically generated water supplies based on historical climate trends – refer to section 2.4.2.4) of lake levels with Plan 2014, linked to the quarter months in which those levels occur. The 2 and 90 percent exceedance thresholds were flagged within the weekly Plan 2014 code, and whenever simulated levels rose above or fell below these limits, careful consideration was given to whether the ILOSLRB may have decided to allow major deviations from Plan flow, and whether such deviations would have been possible and to what extent under the simulated conditions at the time. Consideration was given to both upstream and downstream conditions, the amount by which the thresholds were exceeded, the time of year, ice or other conditions, etc.

a quarter-monthly (i.e., four quarters per month, 48 per year) basis, rather than weekly, and the simulations are completed exclusively using computer programs, rather than manually working through the simulation from week-to-week/day-to-day (as in the weekly operational simulations).

However, in contrast to the weekly operational simulations, the quarter-monthly plan simulations require additional simplifications and assumptions that need to be made regarding the actual conditions – both physical and operational – that occur in any given year. In reality, outflow regulation occurs on a weekly (not quarter-monthly) basis and conditions are more dynamic and variable from week-to-week and from day-to-day than can be typically captured in a quarter-monthly computer simulation.

As an example, whereas in reality and in the weekly operational simulations, ice can be forming or not and flows can and are adjusted according to Plan 2014 on a daily or hourly basis, the computer models for the quarter-monthly simulations must be provided with input as to whether ice is forming or not during each QM of winter, and then corresponding Plan 2014 flows are computed and maintained for that entire QM. As a result, quarter-monthly simulation results may less-closely reflect reality than the weekly operational simulations. Nonetheless, significant efforts are made to accurately model these types of variable conditions and limit the effects that these or any such simplifications or assumptions may have on the quarter-monthly simulation results.

Furthermore, any such simplifications or assumptions are applied consistently to each regulation plan simulated, including Plan 2014 and the baselines used for comparison. As such, these quarter-monthly simulations offer a fair means of comparing the results for various plans using readily available and coordinated datasets at a computational time step that facilitates such simulations and are the current basis for the GLAM Committee's responsibilities related to ongoing review and evaluation of regulation plans.

Finally, because the quarter-monthly plan simulations were employed to evaluate and compare the effects of different regulation plans during the development of Plan 2014 and are expected to continue to be used for long-term evaluations of regulation plans going forward, comparing actual conditions in 2017 to how they would have been simulated using the quarter-monthly plan simulations (i.e. assessing "model error") is an important step in the GLAM Committee's longer-term plan review effort as it supports the improvement of the baseline simulation process. Reviewing the simulation approaches and assessing the underlying assumptions helps to ensure that the simulations represent actual conditions to a satisfactory degree of accuracy for use in plan evaluation and comparison. The information will help in the review of decisions made in the past and support future decision making.

2.2 Effects of Hydrologic Conditions in 2017 for Lake Ontario and the St. Lawrence River

Weekly operational simulations of water levels and flows were completed using various modifications to the observed hydrologic conditions that occurred in 2017. The modifications represent minor changes (or perturbations) of uncontrolled natural factors and the results of these simulations help to better define the effects that each of the hydrologic factors had on the extreme water levels and outflows in 2017.

The simulations include analyses of the effects of:

- St. Lawrence River ice conditions (2.2.1);
- spring water supplies (in this case April and May), including the multiple heavy precipitation events that occurred across the basin and resulted in record net total supplies (NTS; the net amount of water entering the lake) to Lake Ontario and record Ottawa River flows into the St. Lawrence River (2.2.2); and
- a higher Lake Ontario level at the start of 2017 (2.2.3).

This section is strictly focused on simulating conditions using the rules of Plan 2014 and does not include any modified regulation scenarios. In this manner, actual observations serve as the baseline, and results demonstrate how alternative hydrologic conditions could have led to different water level and flow outcomes from what were observed. These simulations can be considered sensitivity analyses of the hydrologic factors considered.

2.2.1 The impact of ice conditions on levels and flows

In practice, the ILOSLRB must monitor winter weather conditions and adjust Lake Ontario outflows to facilitate the formation of a safe and stable ice cover. While every year is unique, in most winters historically, the formation of ice has occurred in three sequential steps with varying dates: ice formation begins when weather turns cold enough, ice has fully formed and remains stable, and ice disappears as the weather warms. However, St. Lawrence River ice conditions during the period of January to March 2017 did not follow a simple sequence; rather they were highly unusual as a result of highly variable winter temperatures. This section assesses how different 2017 water levels could have been with different St. Lawrence River ice conditions.

As ice starts to form in the critical areas of the St. Lawrence River, which include the Beauharnois Canal and Lake St. Lawrence, outflows must be temporarily reduced to facilitate the formation of a safe and stable ice cover. Reducing outflows slows the current and reduces the stress that this puts on the ice cover, and this helps reduce the risk that a newly formed, fragile ice cover could collapse, jam up the river channel, and potentially cause damage. In addition, fast moving water with frigid temperatures generates what is known as frazil ice, i.e., ice crystals suspended in water that is too turbulent to freeze solid. Frazil ice can also result in ice jams along the St. Lawrence River, which can cause flooding and property damages. Prior to regulation, ice jams occurred frequently in the St. Lawrence River. If one were to occur today, the ice-clogged channel would reduce outflows significantly and for an extended period, potentially causing immediate flooding upstream along portions of Lake St. Lawrence and the St. Lawrence River, and leading to rapidly declining levels in the St. Lawrence River downstream of the jam. Ice jams also limit the ILOSLRB's ability to vary flow until the jam dissipates.

In contrast, by carefully monitoring ice conditions and temporarily reducing flows when necessary, the ILOSLRB creates flow conditions that help form a stable ice cover. Once the ice cover has formed and as the ice cover strengthens, the ILOSLRB can safely increase outflows. The flow management strategies employed during ice formation are built into the rules of Plan 2014, specifically the "I-limit" (i.e., maximum flow for ice formation). These rules were developed from past ILOSLRB operational ice management practices that were employed under the previous regulation plan. In other words, managing flows according to ice conditions is required under any regulation plan and the implementation of the new regulation plan did not change how this occurs. Furthermore, it is important to note that ice forms when weather conditions dictate; the management of outflows does not cause ice to form or prevent it from forming, rather it simply helps ensure that the ice forms in a safe and stable manner.

As described in section 5.2 of the ILOSLRB report ("Observed Conditions and Regulated Outflows in 2017"), ice began to form in the Beauharnois Canal during the first week of January 2017, which is about an average start date for this location, and outflows were reduced accordingly. However, unseasonably mild temperatures followed in January and February, with multiple fluctuations above and below freezing. As a result, ice went from forming to thawing multiple times, and it never fully formed in the Beauharnois Canal during this period, when it normally does. In March, two of the coldest stretches of weather observed all winter occurred. This allowed ice to begin reforming in the Beauharnois Canal, and required further flow reductions in March, something never required previously.

Simulations of seven different ice scenarios were completed and compared to actual water levels and flows from the January to March 2017 period (Figure 2-1). The scenarios include ice conditions during four recent years (2002, 2008, 2012, and 2014), a "no-ice" simulation, and two "average ice" simulations, one representing average ice conditions from 1960-2016 and the other an average of just recent years (2007-2016). In addition, all scenarios use the same actual observed water supply conditions in order to isolate the effects of ice conditions on water levels and flows in 2017.

The analyses (Figure 2-1) show that the unusual ice conditions experienced in 2017 played a small part in raising water levels compared to other hydrologic factors. Even under an unlikely scenario where ice did not form and no outflow reductions were required for managing ice conditions, water levels would have been at most 12 cm (4.72 in) lower by the end of March. In comparison, water levels rose 60 cm (23.6 in) during the January to March period overall, as a result of the generally above-average water supply conditions during this period.

Under more typical ice condition scenarios, the effects of ice conditions on water levels in 2017 would have been less than 12 cm (4.72 in). This is demonstrated by those simulations that used the actual ice conditions observed in a number of recent years, such as 2008, 2012, and 2014. Each of these simulations resulted in water levels that were lower than actual levels by the end of March. This is because in these more "typical" ice formation scenarios, ice formed in the critical areas of the St. Lawrence River over a one to four week window and once formed, did not melt, allowing the Lake Ontario outflow to be gradually increased.

For the 2008 scenario, outflows would have needed to be reduced in December through the beginning of January owing to an ice jam at Valleyfield Bridge in the Beauharnois Canal. Record-high air temperatures then broke up much of the ice cover, allowing outflows to be increased. Ice began reforming in the Beauharnois Canal in late-January, requiring outflows to be reduced again. Once the ice cover stabilized, outflows could gradually be increased beginning in February. No other outflow reductions would have been required for ice management thereafter. Lake Ontario water levels would have been 5 cm (2.0 in) lower by the end of March if ice conditions like those in 2008 were experienced in 2017.

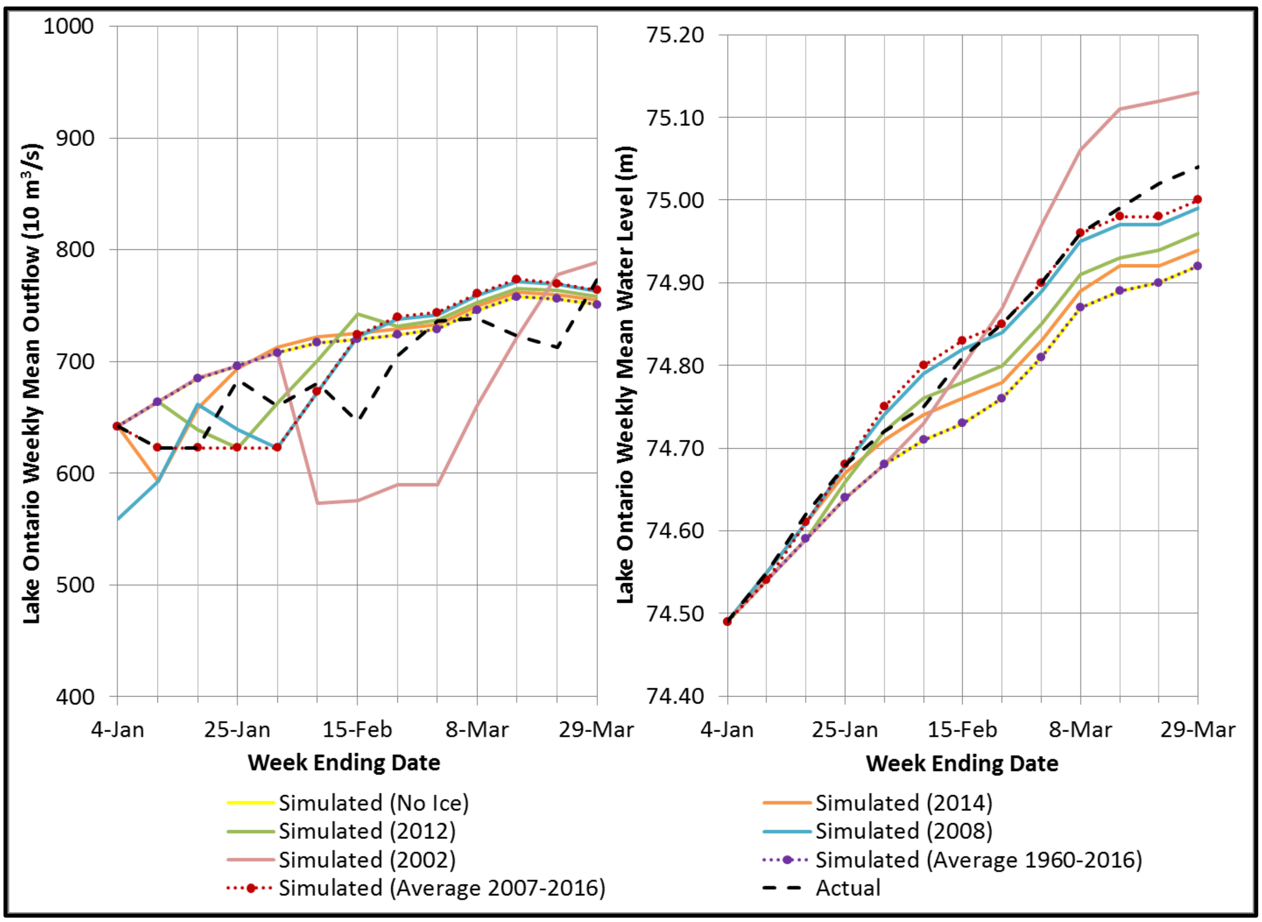

Figure 2-1: Lake Ontario outflows and water levels under various simulated St. Lawrence River ice conditions.

In 2012, ice formed in the Beauharnois Canal in mid-January and outflows could have been increased beginning in late January. Lake Ontario water levels would have been 8 cm (3.2 in) lower by the end of March if ice conditions like those in 2012 were experienced in 2017.

For the 2014 scenario, ice formation in the Beauharnois Canal was complete by the beginning of January and had started to form on Lake St. Lawrence. However, a hanging ice dam at Sparrowhawk Point would have required outflows to be reduced temporarily until frazil ice generation dissipated. No other outflow reductions would have been required for ice management thereafter. If ice conditions like those in 2014 were experienced in 2017, Lake Ontario water levels would have been 10 cm (3.9 in) lower by the end of March.

Only the 2002 ice condition simulation resulted in higher than 2017 water levels by the end of March. Similar to the conditions that occurred in 2017, ice conditions in 2002 were operationally challenging. During the winter of 2002, mild temperatures delayed the onset of ice formation until the beginning of February when a storm brought freezing rain and ice pellets as well as very strong winds, which broke an ice boom in the Beauharnois Canal. Conditions remained challenging and almost all ice booms in the Beauharnois Canal were reported broken by mid-February. This required outflows to be reduced throughout much of February. Ice never fully formed, and it was only after the ice began to dissipate that outflows could be increased. As a result, in the simulation of the 2002 ice scenario, outflows would have had to be reduced under Plan 2014 for almost a month in February and early March to manage ice formation, and the relatively high inflows that were observed in 2017 would have led to a more rapid rise in Lake Ontario levels during that period than what actually occurred. If ice conditions like those in 2002 were experienced in 2017, Lake Ontario water levels would have been 9 cm (3.5 in) higher than they actually were by the end of March.

Finally, to supplement the scenarios analyzed for specific years, scenarios of “average” ice conditions were conducted. Two scenarios were chosen to represent average conditions following a review of ILOSLRB records, which suggested that the ice conditions that occurred during the entire period of record (1960-2016) appeared to be significantly different from those that have occurred during just the past ten years (2007-2016). In more recent years, records indicate that ice has taken longer to form in critical areas of the St. Lawrence River than it did in the past. ILOSLRB staff have indicated that this finding, and in particular the causes, are highly uncertain: notably, records of ice conditions themselves are not homogenous and were not maintained at the same level of accuracy and detail historically as they have been in more recent years. This could explain some of the apparent differences in ice conditions. Nonetheless, the more recent records are considered more accurate, and the recorded differences match anecdotal observations that recent years’ ice conditions have been more challenging, and it is these types of challenging ice conditions that would have the greatest impact on regulation of outflows and water levels. Furthermore, given the potential that a trend towards warmer temperatures in winter may continue to impact ice conditions and outflow regulation in the future, the apparent change in ice conditions observed in ILOSLRB records still suggests a plausible scenario that can be considered in evaluating regulation plans.

Notwithstanding the uncertainties noted above, the simulation of "average" ice conditions based on the recent period of record (2007-2016) resulted in outflows and water levels similar to the 2008 scenario, and Lake Ontario water levels would have been 4 cm (1.6 in) lower by the end of March. Interestingly, the simulation of "average" ice conditions using the entire period of record (1960-2016) resulted in outflows and water levels equivalent to the "no ice" scenario, which represents a situation in which no outflow reductions were required to manage ice conditions in January through March. The reason for this is that under the "average" (1960-2016) scenario, outflow reductions would have been required in December, but by the beginning of January, outflows would not have been restricted by ice conditions and could have been steadily increased throughout the remainder of winter.

2.2.2 The relative impact of water supplies in different time periods

Section 5.3 of "Observed Conditions and Regulated Outflows in 2017", as well as the hydroclimate section within the main GLAM Committee report, illustrate the extreme hydrologic conditions observed in April and May 2017 across the Lake Ontario and Ottawa River basins and how those extreme conditions collectively contributed to the extreme water levels that were observed throughout the system. The GLAM Committee simulated seven alternative inflow scenarios (depicted in Figure 2-2 and described in Table 2-1) and compared the resultant water levels to what actually occurred in 2017. The simulations helped determine the role that individual storms played in the increase in supplies and water levels.

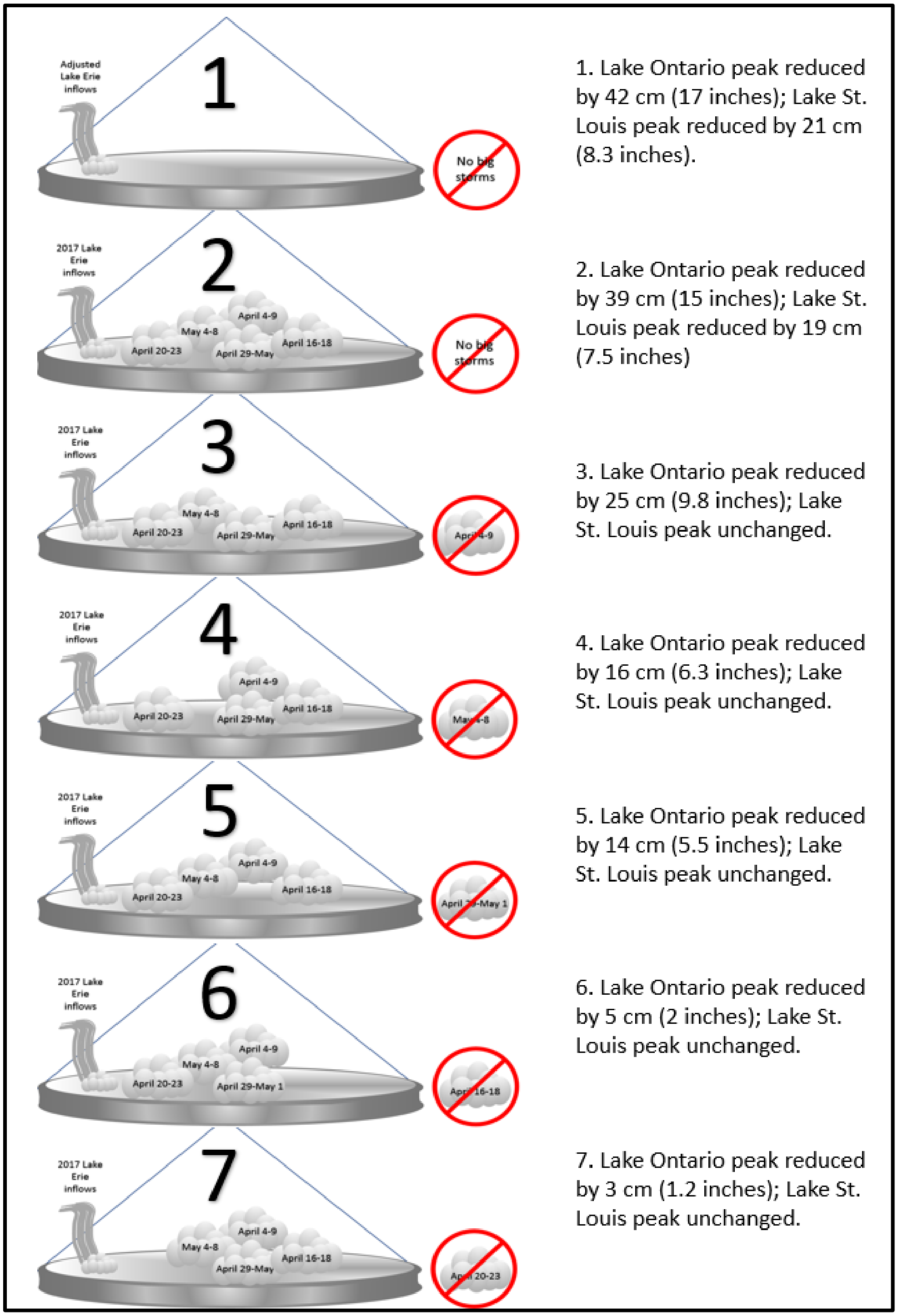

Figure 2-2: Impacts on water levels from seven alternative inflow scenarios

Table 2-1: Description of seven alternative inflow scenarios used for simulations

Inflow Scenarios	**Description**
1. Simulated (no significant storms with adjusted Erie flows)	A simulation of conditions had the most significant April and May storm events not occurred (April 4-9, April 16-18, April 20-23, April 29-May 1, May 4-8) and with Lake Erie flows also adjusted (reduced) accordingly
2. Simulated (no significant storms with actual Lake Erie flows)	A simulation of conditions had the most significant April and May storm events not occurred (April 4-9, April 16-18, April 20-23, April 29-May 1, May 4-8) and with actual Lake Erie flows from 2017
3. Simulated (without April 4-9 storm)	A simulation of actual 2017 water supplies with the exception of the April 4-9 storm
4. Simulated (without May 4-8 storm)	A simulation of actual 2017 water supplies with the exception of the May 4-8 storm
5. Simulated (without April 29-May 1 storm)	A simulation of actual 2017 water supplies with the exception of the April 29-May 1 storm
6. Simulated (without April 16-18 storm)	A simulation of actual 2017 water supplies with the exception of the April 16-18 storm
7. Simulated (without April 20-23 storm)	A simulation of actual 2017 water supplies with the exception of the April 20-23 storm
P2014 Actual	Actual 2017 water supplies

Alternative Net Basin Supply (NBS) sequences to Lake Ontario were created by reducing the portions of the actual 2017 sequence to remove the increases in supplies from the most significant storm events that occurred in April and early May. For example, the adjusted supplies for the "no significant storms" scenarios (Scenarios 1 and 2) are compared to the actual 2017 supplies in Figure 2-3. These adjusted sequences were then used to simulate the outflows and water level conditions that would have resulted had the most significant April and early May storm events not occurred. Similarly, the effects of the record-high Ottawa River flows on Lake Ontario and the St. Lawrence River were also considered by adjusting the local inflow to Lake St. Louis (which for modelling purposes is computed as the residual of measured Lake St. Louis outflows minus Lake Ontario outflows and includes that portion of the Ottawa River that enters at Lake St. Louis). The local inflows to Lake St. Louis were manually adjusted to values that were slightly above average (1960-2016) in order to simulate downstream levels at Lake St. Louis that would have resulted had the most significant April and early May storm events not occurred (Figure 2-3) in the Ottawa River basin. In Scenario 1, adjustments to Lake Erie flows were also made to account for the fact that many of the same storms that impacted Lake Ontario and the St. Lawrence River also passed through the Lake Erie basin and raised levels and outflows as a result. Lake Erie flows were adjusted by reducing the increases in Lake Erie outflows immediately following each of the major storm events.

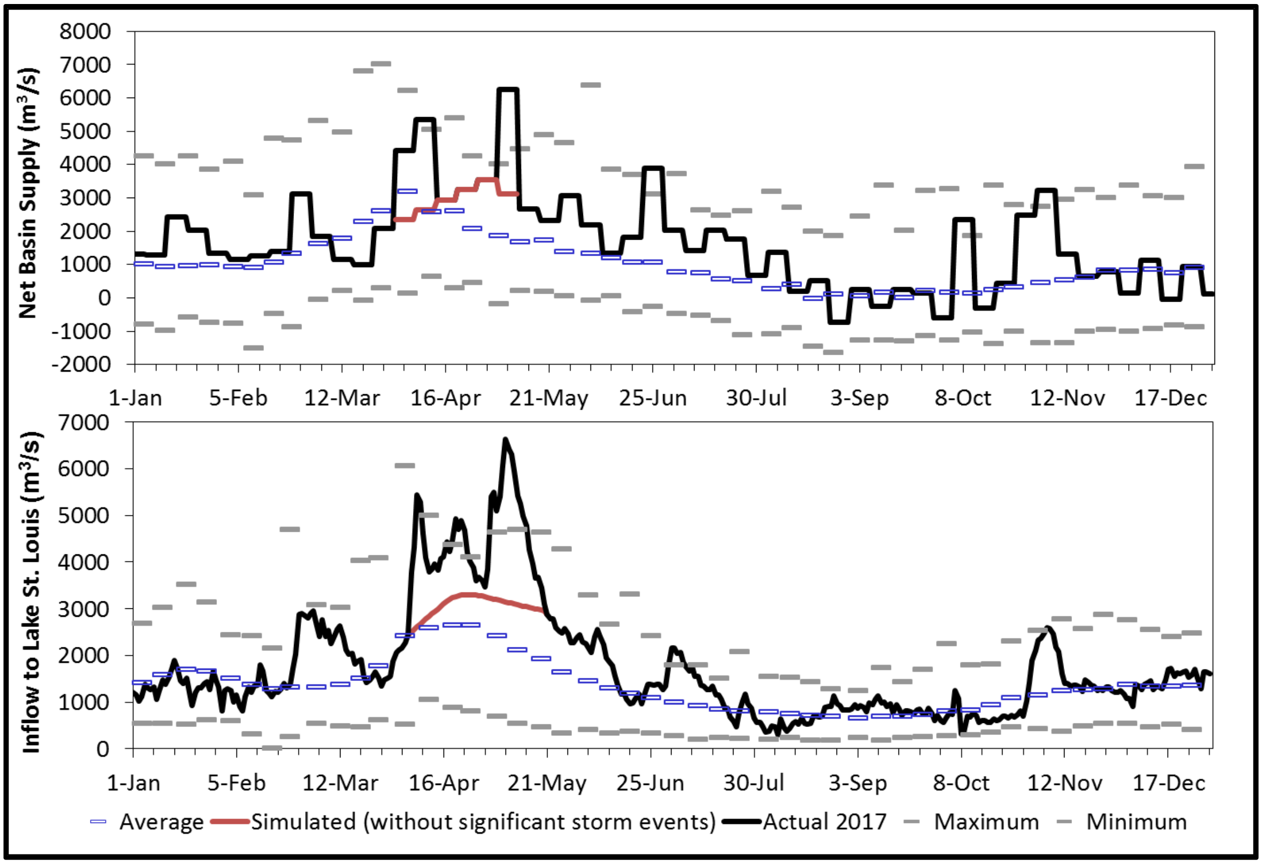

Figure 2-3: Illustration of how NBS to Lake Ontario (top) and inflows to Lake St. Louis (bottom) were reduced to simulate outflows and water levels that would have resulted had the most significant April and early May storm events not occurred.

To maintain consistency with ILOSLRB operations and decisions during the spring of 2017, in this section and in all of these scenarios, the rules of Plan 2014 were followed. This included application of the Plan 2014 maximum F-limit whenever it applied, or following the adjusted rule curve flow. For those scenarios that Lake Ontario water levels exceeded the defined Plan 2014 criterion H14 high threshold levels, granting the ILOSLRB authority to deviate from Plan 2014, it was assumed that the ILOSLRB would have continued applying the F-limit rules of Plan 2014, just as they did from the end of April and most of May 2017. Individual scenarios are described in Table 2-1 and the results are illustrated in Figure 2-4.

The simulation results demonstrate that the three significant storm events on April 4-9, May 4-8 and April 29 to May 1 account for approximately 55 cm (22 in), or over half of the overall water level rise of 80 cm (32 in) that occurred on Lake Ontario during the April to May period. Each of these storms brought widespread, heavy precipitation across the Lake Ontario, St. Lawrence

River and Ottawa River systems. Taken separately, had even just one of these major storm systems missed the area, peak Lake Ontario water levels would have been approximately 14 to 25 cm (5.5 to 9.8 in) lower. Two additional storms on April 16-18 and April 20-23 brought lesser amounts of precipitation to the Lake Ontario basin and were centered further downstream near the lower St. Lawrence River and Ottawa River basin. These two smaller storms accounted for an additional approximately 3 to 5 cm (1.2 to 2.0 in) of the water level rise on Lake Ontario, respectively. Removing all five of these major storms as simulated in Scenarios 1 and 2 reduced the peak Lake Ontario level by 42 cm (16.5 in) and 39 cm (15.4 in), respectively. The additional 3 cm (1.2 in) lowering in Scenario 1 was because Lake Erie inflows were reduced to reflect the fact that some of these storms also raised Lake Erie levels. Lake Erie levels and outflows were above-average throughout the year and brought significant volumes of water into the Lake Ontario – St. Lawrence River system throughout the spring. Nonetheless, these simulation results show that the additional effects the spring storms had on NBS to Lake Ontario, and inflows to Lake St. Louis, were much more significant in raising Lake Ontario water levels than the effects these same storms had on further raising Lake Erie levels and hence outflows from Lake Erie into Lake Ontario. Given the unpredictability of spring weather conditions, particularly extreme events as were seen in 2017, these disproportionate effects are an important consideration for the GLAM Committee in terms of regulation plan development and evaluations.

Lower NBS, combined with lower inflows to Lake St. Louis, would have modified the outflows prescribed by Plan 2014. Because the amount of water entering Lake Ontario and Lake St. Louis was reduced for all of these scenarios, outflows from Lake Ontario would not have needed to be reduced as significantly in April and May in the simulations to maintain Lake St. Louis levels at or below the applicable Plan 2014 F-limits. This creates an additive effect: Lake Ontario water levels are lowered both because the inflows to Lake Ontario are reduced and because the plan can now allow higher outflows while still maintaining levels of Lake St. Louis below plan limits. It should be noted that in most scenarios, while Lake Ontario's peak level was reduced by the removal of certain significant storms, the peak Lake St. Louis level ended up being comparable to the actual peak that occurred in 2017. This is because in all but Scenarios 1 and 2, the simulated Lake Ontario water level eventually rose above 75.60 m (248.03 ft) which corresponds to a level of 22.48 m (73.75 ft) on Lake St. Louis (the top tier of the F-limit). Therefore, in Scenarios 3-7, outflows would have been managed and the same peak Lake St. Louis level would have eventually been reached and maintained in accordance with the F-limit.

Comparing the impacts from each individual storm, removal of the April 4-9 storm (Scenario 3) would have had the greatest impact on peak Lake Ontario and Lake St. Louis levels. When only the April 4-9 storm was eliminated from the simulation (and NBS and inflows to Lake St. Louis were otherwise kept the same as what actually occurred in 2017) the peak Lake Ontario level would have been 25 cm (9.8 in) below the actual 2017 peak level. Under this scenario, outflows would not have needed to be reduced as significantly in April to maintain Lake St. Louis levels below F-limit values, and would have instead followed the adjusted rule curve outflows until the week ending April 26. Lake Ontario levels would have remained below 75.40 m (247.4 ft) through the end of April. Lake St. Louis would have also been maintained lower than actual levels in April, but still would have peaked at levels comparable to actual peak 2017 levels in May due to the extremely high Ottawa River flows and the similarly extreme wet conditions on Lake Ontario, which would have increased Lake Ontario levels to above 75.60 m (248.0 ft) by mid-May. At levels above 75.60 m (248.0 ft), outflows would have been adjusted to maintain levels at 22.48 m (73.75 ft) on Lake St. Louis, the highest tier of the F-limit.

Removal of each of the May 4-8 (Scenario 4) and April 29-May 1 (Scenario 5) storms also significantly reduced peak Lake Ontario water levels in the simulations. The removal of the May 4-8 storm resulted in peak Lake Ontario water levels 16 cm (6.3 in) below actual peak levels, while the removal of the April 29-May1 storm resulted in Lake Ontario water levels that were 14 cm (5.5 in) lower than actual peak levels. When either of the May 4-8 or April 29-May 1 storm events are removed from the simulation, Lake St. Louis levels would still have been comparable to actual 2017 levels because outflows would have been adjusted to maintain the same F-limit tiers.

The removal of the April 16-18 or April 20-23 storms (Scenarios 6 and 7) from the simulations had little impact on peak Lake Ontario water levels as these storms brought lesser amounts of precipitation to the Lake Ontario basin and were centered further downstream near the lower St. Lawrence River and Ottawa River basin. Peak Lake Ontario levels were 5 cm (2.0 in) lower than the actual 2017 peak when the April 16-18 storm was removed and 3 cm (1.2 in) lower when the April 20-23 storm was removed. Again, these differences would not have been enough to keep Lake Ontario below 75.60 m (248.0 ft), and therefore peak levels on Lake St. Louis would have been comparable to actual 2017 levels because the same F-limit tiers would have been targeted.

These simulations may do more than satisfy curiosity about the relative importance individual storms had in raising water levels. They show the additive effect of a series of extreme precipitation anomalies in one year. The NBS patterns observed in 2017 can be compared to wet years in the inflow sequences that have been used to evaluate regulation plans (refer to section 2.4.2.4 of this report).

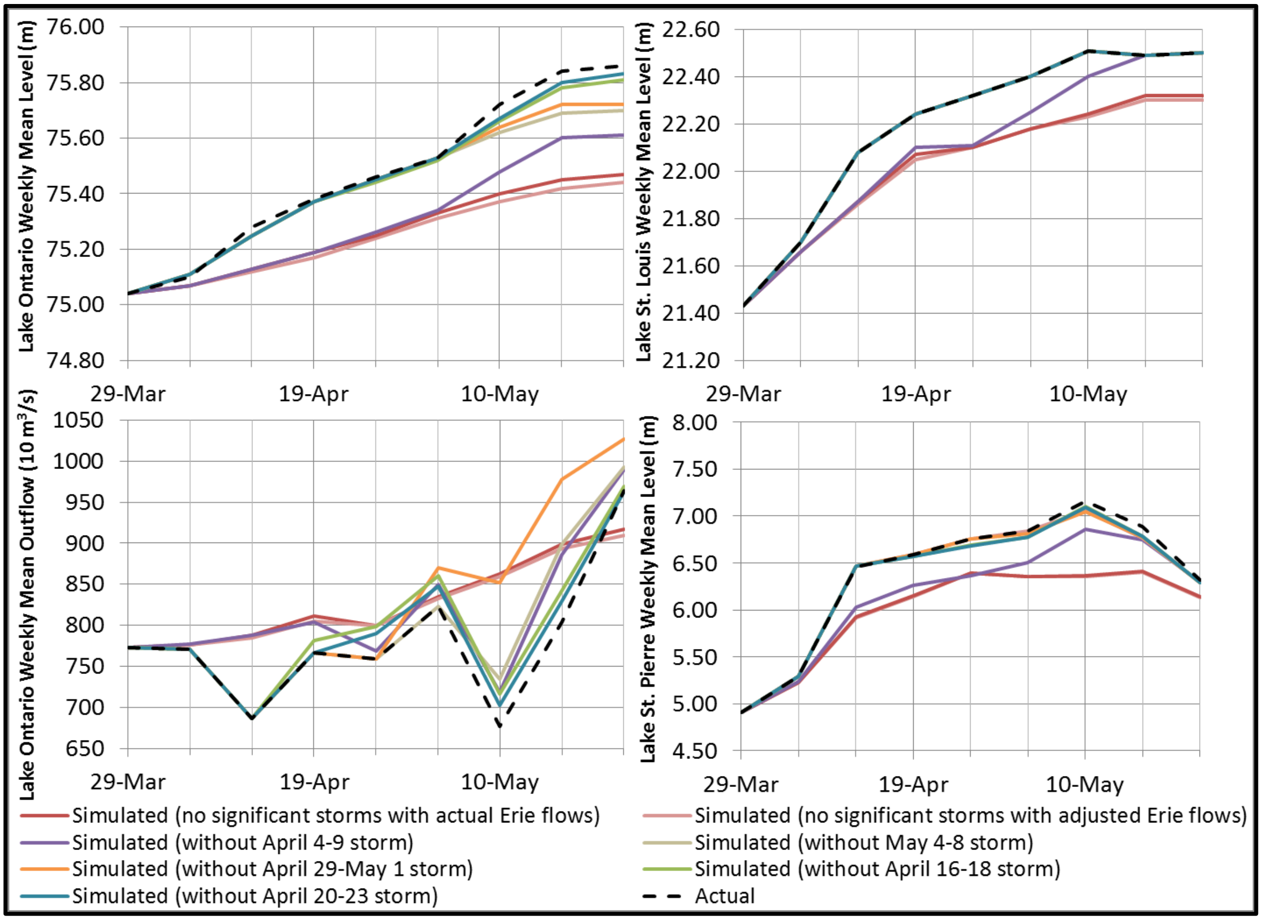

Figure 2-4: Lake Ontario outflows, Lake Ontario water levels, Lake St. Louis water levels and Lake St. Pierre water levels under various alternative spring water supply scenarios

2.2.3 The impact of higher Lake Ontario water levels at the start of 2017

In 2016, the fall and early winter levels of Lake Ontario were close to average, but they were set under the old regulation Plan 1958-DD; had Plan 2014 been in effect during this period, how would the water levels that occurred later in 2017 been affected?

Plan 2014 was implemented operationally on January 7, 2017, but prior to its implementation, water levels and flows under Plan 2014 had been simulated by ILOSLRB staff on behalf of the IJC continuously from 2001 to the end of 2016. At the end of the simulation, Lake Ontario levels were 10 cm (3.9 in) higher than the actual Lake Ontario levels on December 30, 2016. For the purposes of this review, the GLAM Committee continued to simulate Plan 2014 for 2017 assuming Plan 2014 was implemented in 2001 and with Lake Ontario levels starting 10 cm (3.9 in) higher to determine how much effect a higher starting level would have had on peak 2017 water levels. The results are shown in Figure 2-5.

The simulation shows that the initial 10 cm (3.9 in) difference would have been gradually reduced over time. The peak Lake Ontario level would have been 4 cm (1.6 in) higher than the actual peak observed in 2017, and levels would have been only 2 cm (0.8 in) higher by the end of the 2017. There are several reasons for this gradual reduction, but all are related to the fact that because water levels would have started the year higher, the Plan 2014 prescribed outflows would have also generally been higher when this was possible. First, during the first week of January 1-6 (when Plan 1958-D remained in effect), ice had yet to begin forming. Plan 1958-D had a rule that specified a maximum outflow of 6230 m^3/s (220,000 ft^3/s) at the beginning of January to facilitate ice formation whether ice was forming or not, whereas Plan 2014 only reduces flows when ice is indeed forming and so flows instead would have been set to the higher adjusted rule curve value that week. Moreover, during the week ending January 27, and on a handful of days between February 27 and April 4, ice conditions did not restrict outflows and a higher adjusted rule curve flow would have been released owing to the higher Lake Ontario level. On all other days through the winter, outflows would have been comparable to actual flows and operationally adjusted according to ice conditions.

Next, because the simulated Lake Ontario level was higher when Lake St. Louis started to rise and the F-limit was first imposed, the initial Lake St. Louis level that was maintained and the corresponding F-limit outflows that were released would have been higher. In other words, because the F-limit is a tiered rule that depends on the level of both Lake Ontario and Lake St. Louis, and because Lake Ontario would have been higher earlier on, higher tiers of the F-limit would have also been targeted at Lake St. Louis a few days earlier and Lake Ontario outflows would have been slightly higher than actual outflows on several days between April 7 and May 4. The slightly higher simulated outflows would have resulted in a gradual convergence of the simulated and actual Lake Ontario levels over time. By May 5, the actual Lake Ontario level had risen above 75.60 m (248.0 ft) and outflows were increased to maintain a level of 22.48 m (73.75 ft) (highest F-limit tier) at Lake St. Louis. At this point, outflows under this simulation would have matched actual outflows and the Lake Ontario level would have been just 4 cm (1.6 in) higher than the actual level. Higher starting levels on Lake Ontario would not have increased the peak level of 22.48 m (73.75 ft) maintained at Lake St. Louis since this is the highest tier of the F-limit.

Finally, as per actual conditions, it was assumed for this simulation that the ILOSLRB would have conducted major deviations by continuing to follow the F-limit rules until the Ottawa River flows subsided, and then increased outflows to 10,400 m^3/s (367,000 ft^3/s) on June 14. It was further assumed that the ILOSLRB would have reduced flows in accordance with the L-limit beginning on August 8, consistent with actual operations to maintain safe conditions for navigation. The L-limit is set according to the level of Lake Ontario, and in this simulation, since Lake Ontario levels would have been higher, higher outflows would have been released in accordance with the L-limit. Similar to actual conditions, Lake Ontario water levels would have fallen below the Criterion H14 high thresholds by September 1 and it was assumed that the ILOSLRB would have returned to Plan 2014 specified flows, which continued to be set in accordance with the L-limit. Again, since Lake Ontario levels would have been 3 cm (1.2 in) higher, higher outflows would have been released in accordance with the L-limit, and this would have continued to gradually cause simulated levels to converge with actual levels of Lake Ontario. Outflows slightly higher than actual outflows would have been released through the remainder of the year until operational adjustments were required for ice management, when outflows would have matched actual flows once again.

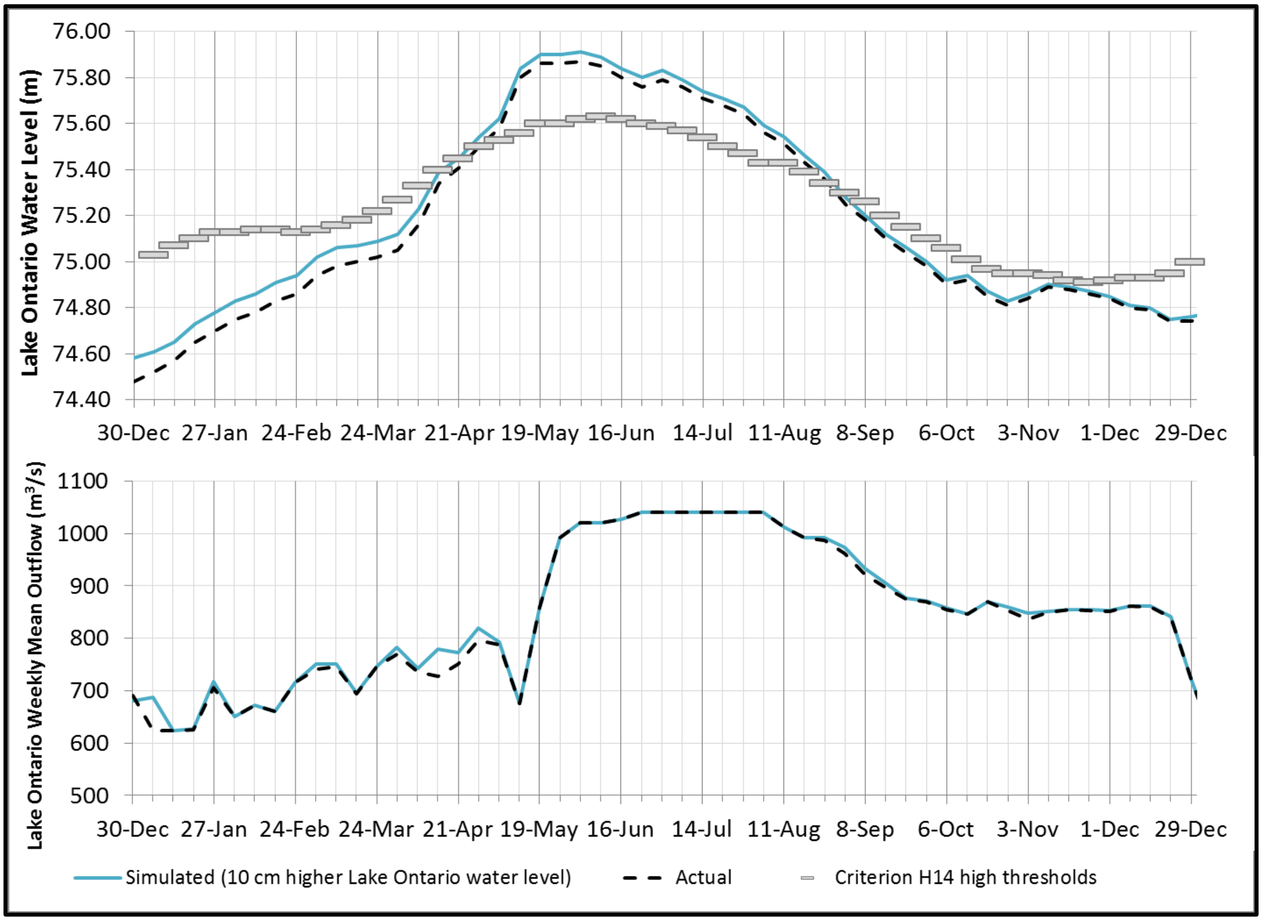

Figure 2-5: Simulated Lake Ontario levels and outflows in 2017 based on a 10 cm (3.9 in) higher Lake Ontario at the start of 2017 compared to actual levels and outflows

2.3 Effects of Modified Outflow Regulation Strategies in 2017

In addition to the simulations of variations in hydrologic conditions presented in section 2.2, a second set of weekly operational simulations of water levels and flows were conducted to illustrate the potential impacts of modified outflow regulation strategies. In these scenarios, the actual hydrologic conditions observed in 2017 were used for each simulation and then alternative outflow regulation scenarios were developed and applied to simulate the outflows that would have been released and the water levels that would have occurred throughout the system, given those conditions.

The simulations of modified outflow regulation strategies include:

- Modifying the rules balancing flooding above and below the dam (2.3.1)
- Modified Criterion H14 High Trigger Levels (2.3.2)
- Modifying rules balancing navigation safety and coastal impacts (2.3.3)
- Alternative Major Deviations (2.3.4)
- Regulation Plan 1958-D with "Actual" Operational Deviations (2.3.5)
- Pre-project Water Levels and Outflows (2.3.6)

2.3.1 Modifying the rules balancing flooding above and below the dam

The F-limit rules of Plan 2014 are used to prescribe maximum outflow limits to manage flooding and erosion impacts on Lake St. Louis in consideration of Lake Ontario levels and are meant to be a means of balancing impacts upstream and downstream of the Moses-Saunders dam. A further description of the F-limit is provided in Section 4 of the ILOSLRB report "Observed Conditions & Regulated Outflows in 2017".

In these simulations, several modifications were made to rules of Plan 2014 during the spring, including the F-limit rules (those internal to Plan 2014 are outlined in Table 2-2) meant to balance high water impacts, in order to assess their sensitivity with regards to levels and flows. First, two extreme scenarios (Scenarios 1 and 2) were simulated wherein the F-limit rules were not followed and instead Lake Ontario outflows were simulated to assess what would have been required to maintain levels of Lake Ontario below 75.37 m (247.3 ft) and 75.50 m (247.7 ft) and the impact this would have had on levels downstream in the St. Lawrence River. Next, several simulations (Scenarios 3-6) involved minor modifications to some of the different tiers within the F-limit, again, in order to assess the impacts on levels upstream and downstream. Finally, Scenarios 7 and 8 were used to simulate the effects on outflows and the levels of Lake Ontario if Lake St. Louis' maximum level was maintained at a peak level of 22.33 m (73.26 ft) and 22.48 m (73.75 ft), respectively.

It is important to note that some of the modifications made to the rules and used to develop alternative simulations may not be beneficial to some interests, might contradict the principles of balancing flooding upstream and downstream, and may not even have been physically or operationally possible at times in 2017. These are simply "what-if" scenarios to illustrate how water levels and flows may have differed by modifying outflows (see Table 2-3 for scenario descriptions). Several scenarios would have resulted in exacerbated flooding or prolonged flooding, either upstream on Lake Ontario or downstream on the St. Lawrence River. Also, results of each of these scenarios must be considered without the benefit of hindsight. It is impossible to say how much confidence the ILOSLRB would have needed with respect to forecasted flood levels on Lake Ontario prior to agreeing to a modified outflow which would alter the flooding impacts on the St. Lawrence River, and vice versa.

Table 2-2: Lake St. Louis levels (measured at Pointe Claire) corresponding to Lake Ontario levels for balancing upstream and downstream flooding damages (F limits).

Lake Ontario Water Level	***Lake St. Louis (at Pointe Claire) Water Level***
< 75.30 m (247.05 ft)	**22.10 m (72.51 ft)**
≥ 75.30 m (247.05 ft) and < 75.37 m (247.28 ft)	**22.20 m (72.83 ft)**
≥ 75.37 m (247.28 ft) and < 75.50 m (247.70 ft)	**22.33 m (73.26 ft)**
≥ 75.50 m (247.70 ft) and < 75.60 m (248.03 ft)	**22.40 m (73.49 ft)**
≥ 75.60 m (248.03 ft)	**22.48 m (73.75 ft)**

Water levels expressed in meters/feet International Great Lakes Datum (IGLD) 1985

Table 2-3: Description of F-limit scenarios used for simulations

F- Limit Scenarios	**Description**
1. Simulated (Maintain LO ≤ 75.37 m (247.28 ft))	Outflows are managed to maintain Lake Ontario levels at 75.37 m (247.28 ft) or lower, with Lake St. Louis levels unconstrained
2. Simulated (Maintain LO ≤ 75.50 m (247.70 ft))	Outflows are managed to maintain Lake Ontario levels at 75.50 m (247.70 ft) or lower, with Lake St. Louis levels unconstrained
3. Simulated (No 22.20 m (72.83 ft) or 22.40 m (73.49 ft) tiers)	Only three tiers are used. There are no intermediate tiers of 22.20 m (72.83 ft) or 22.40 m (73.49 ft). The lowest tier remains the same, the 22.33 m (73.26 ft) tier applies for Lake Ontario levels of 75.30 m (247.05 ft) to 75.37 m (247.70 ft), 22.48 m (73.75 ft) applies for higher Lake Ontario levels.
4. Simulated (No 22.10 m (72.51 ft) or 22.20 m (72.83 ft) tiers)	The bottom two tiers are removed. Lake St. Louis water levels are maintained at 22.33 m (73.26 ft) up to a Lake Ontario level of 75.50 m (247.70 ft) , the top two tiers remain the same
5. Simulated (Start 22.48 m (73.75 ft) tier at 22.40 m (73.49 ft) tier)	The bottom three tiers remain the same, Lake St. Louis level is maintained at 22.48 m (73.75 ft) at a Lake Ontario level of 75.50 m (247.70 ft) or higher
6. Simulated (No 22.40 m (73.49 ft) tier)	The 22.40 m (73.49 ft) tier is not used. Lake St. Louis levels are maintained at 22.33 m (73.26 ft) until the Lake Ontario level is above 75.50 m (247.70 ft).

7. Simulated (Maintain LSL at 22.33 m (73.26 ft))	Outflows are managed to maintain Lake St. Louis levels at 22.33 m (73.26 ft) (no other tiers)
8. Simulated (Maintain LSL at 22.48 m (73.75 ft))	Outflows are managed to maintain Lake St. Louis levels at 22.48 m (73.75 ft) (no other tiers)
9. Actual	Actual F-limit operations as shown in Table 2-2

As expected, Scenarios 1 and 2 would have resulted in the greatest reduction in water levels upstream on Lake Ontario but also at the expense of the greatest increase in water levels downstream of the dam at Lake St. Louis (Figure 2-6). It is important to note that the ILOSLRB did not have the authority to conduct the major deviations that would have been required to maintain Lake Ontario levels at or below 75.37 m (247.28 ft) or 75.50 m (247.70 ft). These scenarios are simply meant to illustrate what extreme outflows would have been required in these situations and the impacts elsewhere in the system.

Given the extreme hydrologic conditions that actually occurred in 2017, to maintain Lake Ontario levels at 75.37 m (247.28 ft) in the simulation (51 cm (1.7 ft) below the actual peak in 2017), outflows would have needed to exceed those prescribed by the adjusted rule curve of Plan 2014 beginning on April 1, 2017 with the first three weeks defined by the J-limit (maximum flow change from week-to-week). Outflows then would have needed to be set to 10,200 m^3/s (360,000 ft^3/s) on April 16 through the end of May. These extremely high Lake Ontario outflows, combined with the extremely high flows out of the Ottawa River system, would have resulted in Lake St. Louis levels peaking at 23.39 m (76.74 ft), 91 cm (3 ft) above the highest Plan 2014 F-limit tier of 22.48 m (73.75 ft) that was targeted in 2017 during the peak of the spring flooding. In addition, Lake St. Lawrence levels at Long Sault would have dropped to 72.07 m (236.45 ft) (53 cm (1.7 ft), well below Plan 2014 L-limit threshold of 72.60 m (238.19 ft), and this would have required implementation of mitigation measures or suspension of commercial navigation in the St. Lawrence River.

In Scenario 2, maintaining Lake Ontario levels at or below 75.50 m (247.70 ft), or 38 cm (1.2 ft) below the actual peak in 2017, would have required outflows to exceed those prescribed by the adjusted rule curve of Plan 2014 beginning on April 1, 2017 with the first week defined by the J-limit (maximum flow change from week-to-week), and would have required outflows to be set in accordance with the L-limit rules through the end of May. In this scenario, Lake St. Louis levels would have peaked at 23.23 m (9.2 in), 75 cm (2.5 ft) above highest Plan 2014 F-limit tier of 22.48 m (73.75 ft). It is also important to note that the simulated levels of Lake St. Louis when maintaining Lake Ontario at these much lower levels may be inaccurate owing to the fact that the stage-discharge relationship at Lake St. Louis has not been developed or validated with such extremely high flows and levels that would have been observed under these scenarios. In short, the simulated water levels are potentially too high as water would be spilling outside of the channel and flooding the surrounding land area under such extreme conditions.

A number of more modest changes to the Plan 2014 F-limit rules were also simulated. Scenarios 3 – 6, which involved minor modifications to the F-limit rules (Figure 2-6), including removal of intermediate tiers or more immediate increases in Lake St. Louis level (but no increase in the actual peak Lake St. Louis levels), would have resulted in differences in peak Lake Ontario water levels of 5 cm (2 in) or less.

Scenarios 7 and 8 involved the most significant changes to the F-limit and resulted in the largest changes in Lake St. Louis levels as a result. Of all scenarios tested, Scenario 7, which maintained Lake St. Louis at a maximum of only the 22.33 m (73.26 ft), would have provided the most significant protection to Lake St. Louis and more than the F-limit currently provides. Under this scenario, lower outflows from Lake Ontario would have been required beginning on May 5 to maintain Lake St. Louis levels at 22.33 m (73.26 ft). As a result of the lower flows, Lake Ontario would have peaked at a level that was 6 cm (2.4 in) higher than the actual peak observed at the beginning of June. In contrast, Scenario 8, which involved a modified F-limit with Lake St. Louis maintained at only the single, highest tier level of 22.48 m (73.75 ft), illustrates the effects of providing more significant protection to Lake Ontario than the F-limit currently provides. Under this scenario, it would have been possible to release higher Lake Ontario outflows (rule curve) than actually occurred (F-limit) in early April without exceeding 22.48 m (73.75 ft) at Lake St. Louis. Starting April 16, flow adjustments would have been required to maintain 22.48 m (73.75 ft) thereafter, though in general these outflows also would have been higher given the higher level maintained at Lake St. Louis. As a result, Lake Ontario would have been 10 cm (3.9 in) lower by the beginning of June, but flooding downstream along the St. Lawrence River would have been prolonged as the maximum level (22.48 m (73.75 ft)) would have occurred as early as April 16, 19 days prior to actual conditions.

Scenario 7 demonstrates that levels could have been maintained 15 cm (5.9 in) lower at Lake St. Louis had Lake Ontario been allowed to rise 6 cm (2.4 in) higher than its actual peak, while Scenario 8 demonstrates that changes to the F-limit could have lowered Lake Ontario levels 10 cm (3.9 in) by prolonging, but without raising, the peak Lake St. Louis levels. These scenarios help demonstrate how the F-limit balances high water upstream and downstream and how modifications to the F-limits would alter that balance at the expense of upstream or downstream conditions. Furthermore, while Scenario 8 may suggest that Lake Ontario could have been reduced without increasing the peak levels that eventually occurred downstream on Lake St. Louis, this is an example of a rule change that looks better in hindsight and modification of the F-limit in this way would have severe impacts in other years. For example, had outflows been increased to maintain Lake St. Louis at 22.48 m (73.75 ft) in mid-April but then the subsequent extreme precipitation events in late April and early May not happened, the ILOSLRB would have induced flooding around Lake St. Louis that would not have otherwise occurred. These modified releases would have been required well before the ILOSLRB had any reliable forecast of those later storms, so the ILOSLRB would have had to trade certain flooding on Lake St. Louis and further downstream in the St. Lawrence River for a reduction in risk of uncertain flooding on Lake Ontario, a decision that would have had mixed effects in 2017, but only negative impacts in most years.

It is important to remember that the primary driver of high water levels in 2017 was the extreme precipitation on both the Lake Ontario and Ottawa River basins. Outside of the extreme outflows that would have been required to constrain Lake Ontario water levels while leaving water levels at Lake St. Louis unconstrained, the most significant difference in Lake Ontario water level in any of the modified F-limit simulations was 10 cm (3.9 in). Even in that scenario, outflows would have been increased such that levels on Lake St. Louis would have been near record-high levels as early as 19 days before the maximum levels actually occurred in 2017 and before Lake Ontario had reached or was even predicted to reach critical levels. Since two- to four-week precipitation forecasts remain highly unreliable, it would be difficult for the ILOSLRB to decide to set Lake St. Louis to flood levels earlier than as prescribed by the F-limit rules (if granted the authority) given the possibility that extreme Lake Ontario levels may or may not transpire.

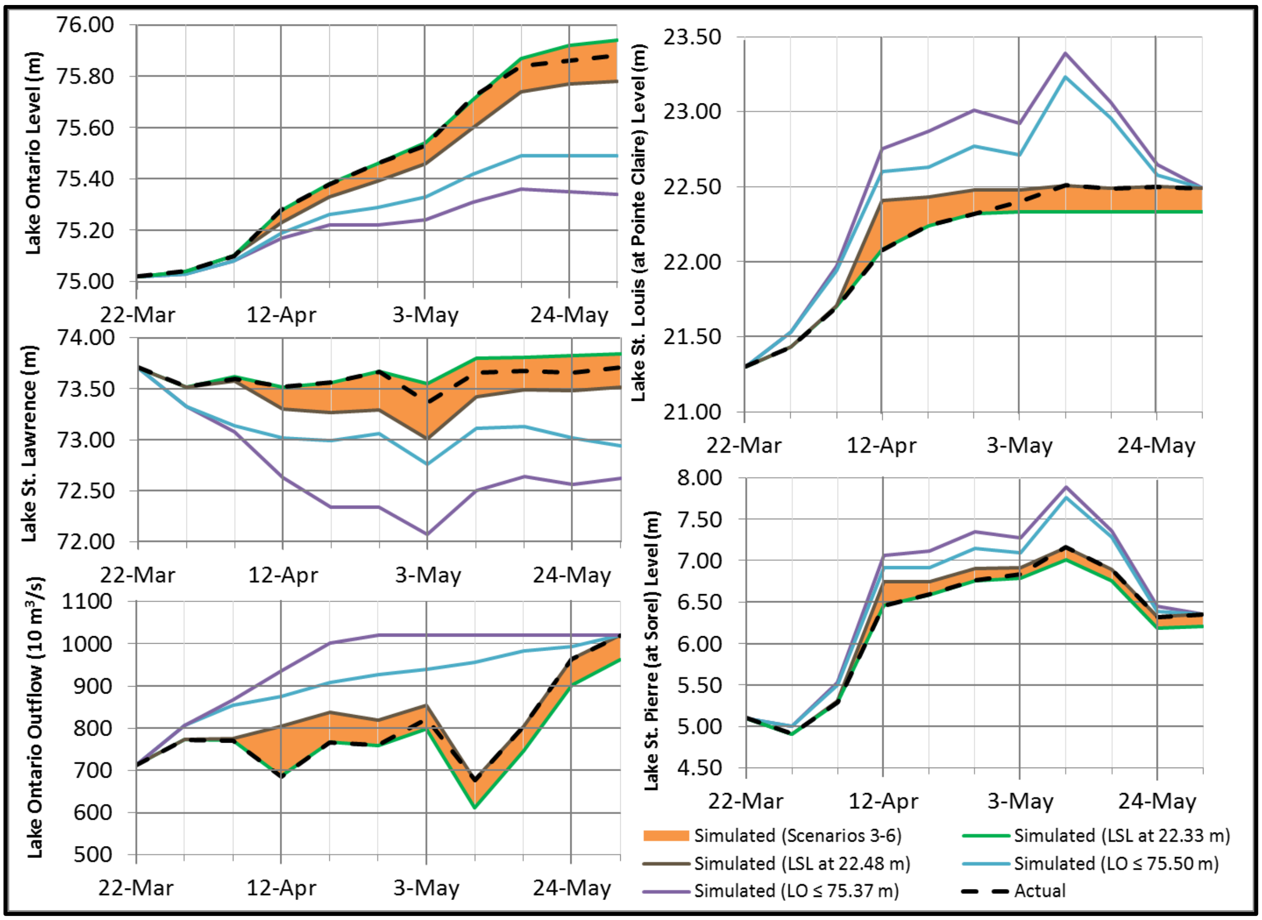

Figure 2-6: Simulated Lake Ontario outflows, Lake Ontario water levels, Lake St. Lawrence water levels, Lake St. Louis water levels and Lake St. Pierre water levels based on modified F-limit rules compared to actual outflows and water levels in 2017

2.3.2 Modified criterion H14 high thresholds

The criterion H14 high water level thresholds that allow the ILOSLRB to conduct major deviations from the rules set in Plan 2014 are those levels that would be expected to be exceeded two percent of the time. Many expressed concern in 2017 that the trigger levels were too high, meaning the ILOSLRB would have to wait too long to deviate from Plan 2014, resulting in higher than necessary Lake Ontario levels. The IJC evaluations of Plan 2014 during its development showed that deviating from Plan 2014 rules tends to shift the balance of benefits in Plan 2014 over the long-term. Often this shift in balance involved a reduced risk of damages to coastal areas at the expense of eliminating other benefits of the Plan, including to the environment. However, given the concerns expressed in 2017, the GLAM Committee elected to simulate alternative trigger levels to better understand the coastal benefits that could have been gained.

As background, criterion H14 is a condition of the December 8, 2016 Order that states, "In the event that Lake Ontario water levels reach or exceed high levels, the works in the International Rapids Section shall be operated to provide all possible relief to the riparian owners upstream and downstream…The high [and low] water levels at which this criterion applies, and any revisions to these levels, shall be subject to the concurrence of Canada and the United States and shall be set out in a Commission directive to the ILOSLRB." The IJC's Directive on Operational Adjustments, Deviations and Extreme Conditions sets out these values (in Table 1 therein) on a quarter-monthly basis (i.e., four quarters per month, 48 per year). Values were established based on simulation of the rules of Plan 2014 for the 50,000 years stochastic series. Each high threshold or "trigger" level represents the lake level exceeded in two percent of the 50,000 years of simulation.

Three potential modifications were considered to the criterion H14 high water level thresholds. The first two scenarios simulated criterion H14 high water level thresholds based on levels that would be expected to be exceeded five and ten percent of the time, in lieu of the two percent exceedance values currently used for the criterion H14 high thresholds. The third scenario tested was a one foot (~30 cm) lowering of each of the 48 high threshold values contained in Table 1 of the directive. This was an arbitrary, significant reduction in these values to allow a simple assessment of their sensitivity with regards to levels and flows.

It is important to note that the criterion H14 high threshold scenarios tested may not necessarily be beneficial to some interests and may even contradict certain overall objectives of water management in the system. These are simply "what-if" scenarios at this point in time and constitute major modifications to the regulatory regime, which would require a more complete analysis for multiple indicators over a longer time period using various hydrologic scenarios to evaluate the effects on all interests.

The simulations showed that only the most extreme lowering of trigger levels (by one foot or about 30 cm) would have had any effect on 2017 levels, and even those were modest, as peak Lake Ontario levels would have been lowered 6 cm (2.4 in) at the most. Thresholds one foot (~30 cm) lower than the 2% triggers correspond to levels that would be expected to be exceeded approximately 20% of the time. If Plan 2014 used criterion H14 high water level triggers based on these levels, a substantial portion of the environmental benefits of Plan 2014 would be eliminated and there would be consequences for shipping and recreation in some years.

Interestingly, simulations using the five and ten percent exceedance values would not have resulted in any difference in Lake Ontario water levels in 2017. This is assuming the ILOSLRB would have made similar decisions as it did when operating under criterion H14 in 2017, and continued to follow the F-limit as per actual operations to balance upstream and downstream flooding damages when they were granted major deviation authority. The ten percent high thresholds would have been exceeded in early April (Figure 2-7), three weeks before the actual criterion H14 high thresholds were reached, but by this time Plan 2014 flows were already following the F-limit and the ILOSLRB continued to do so throughout the 2017 event. It is unlikely that given the high Ottawa River flows and flooding that was already occurring in the lower St. Lawrence River at that time, that the ILOSLRB would have decided to greatly increase outflows simply because a lower high trigger threshold was reached on Lake Ontario. Similarly, the five percent high thresholds would have been exceeded one week later than the ten percent high thresholds, and two weeks before the actual criterion H14 high thresholds were reached (Figure 2-7). Again, it is unlikely that the ILOSLRB would have decided to undertake additional major deviations at that time and likely would have continued to balance upstream and downstream flooding damages by releasing flows in accordance with the F-limit.

In the simulation of criterion H14 high threshold levels modified 1 foot (~30 cm) lower (Figure 2-7), Lake Ontario water levels would have exceeded the high threshold levels in mid-February 2017 instead of the end of April. Given high-water impacts had yet to occur and there was no indication that they would, and based on past operations as recently as 2016, when the ILOSLRB had discretionary authority to deviate from Plan 1958-D but did not use it under similar scenarios, it seems highly unlikely that the ILOSLRB would have conducted major deviations at that time. Nonetheless, if the ILOSLRB did decide to deviate at this time, this would have allowed for higher flows and major deviations during short periods when ice conditions allowed (i.e. February 27 to March 5 and March 11, between necessary flow reductions in accordance with the I-limit) and prior to the high water levels beginning in April (i.e. March 25 to April 5, until flow reductions were required in accordance with the F-limit to balance upstream and downstream flooding damages). The simulation assumed that the ILOSLRB would have conducted major deviations by following the Plan 2014 J-limit instead of the adjusted rule curve flow during these periods. The J-limit ensures more consistent and predictable flows for hydropower operators and complements the I-limit by ensuring relatively consistent conditions for ice management. Simulated daily flows were about 320 to 1,070 m^3/s (11,300 to 37,800 ft^3/s) higher than actual values between February 27 and April 5 (Figure 2-7). Despite the unlikelihood that outflows would have been managed in this way had outflows been increased in this manner, Lake Ontario levels would have been 6 cm (2.4 in) lower at the beginning of June.

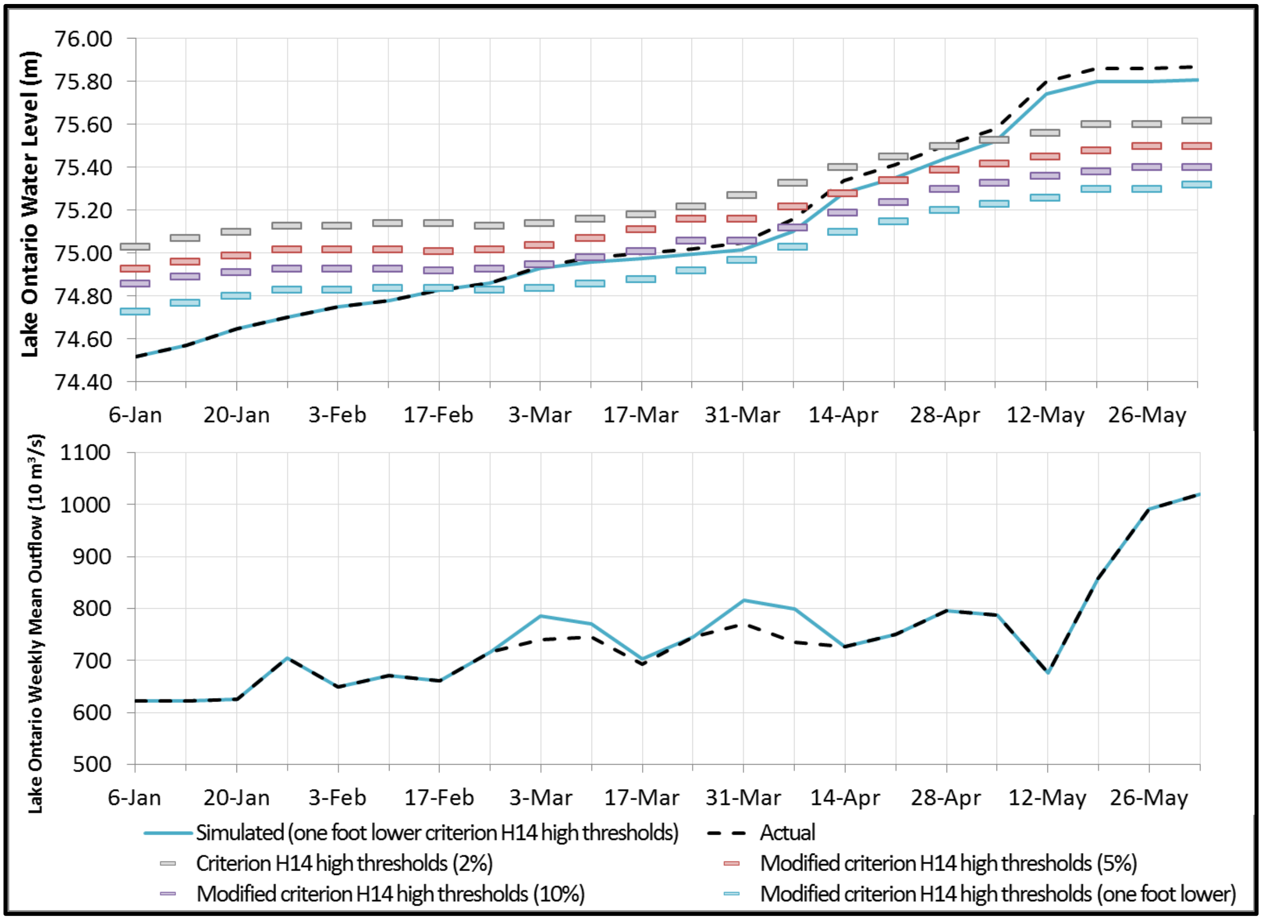

Figure 2-7: Simulated Lake Ontario water levels and outflows based on modified criterion H14 high thresholds compared to actual water levels and outflows in 2017

2.3.3 Modified rules balancing navigation safety and coastal impacts

The ILOSLRB had authority to conduct major deviations from the end of April to the beginning of September 2017. During that time, the maximum amount of water possible was released from Lake Ontario while considering the balancing of high water impacts upstream and downstream and the continued operation of commercial navigation through the St. Lawrence Seaway. After Lake Ontario levels fell back below the criterion H14 high threshold levels in September of 2017, outflows remained high and were largely constrained by the Plan 2014 maximum L-limit. In other words, the adjusted rule curve flow was higher than the maximum L-limit flow that was considered safe for navigation, so the L-limit applied. Simulations were conducted to determine what the impact would have been if the ILOSLRB had the authority (and chose to use it) to slightly increase L-limit flows. It is not known how the increased flows used in the simulations would have impacted the navigation industry (e.g. increased risks for ships, requirements for mitigation measures, etc.) and that would need to be considered at a later date if further investigation of the L-limit was deemed appropriate.

Two scenarios were tested by increasing the plan-prescribed L-limit flows by up to an additional i) 200 m^3/s (7,100 ft^3/s) and ii) 300 m^3/s (10,600 ft^3/s). The impacts to water levels and outflows of these scenarios are illustrated in Figure 2-8. In both scenarios, the modified L-limit flow was applied from August (when flows were first reduced below 10,400 m^3/s (367,000 ft^3/s)) through to when ice limits were applied in December. Consistent with the Plan 2014 L-limit rules, weekly mean Lake St. Lawrence levels at Long Sault Dam were maintained at or above 72.60 m (238.19 ft). Application of this aspect of the L-limit rule required the modified L-limit flows to be increased by lesser amounts (i.e., increases of less than 200 m^3/s (7,100 ft^3/s) and 300 m^3/s (10,600 ft^3/s)) in two weeks and seven weeks of the +200 m^3/s (7,100 ft^3/s) and +300 m^3/s (10,600 ft^3/s) simulations, respectively.

Had up to 200 m^3/s (7,100 ft^3/s) more than the L-limits been released, water levels would have been 8 cm (3.2 in) lower by the end of December (Figure 2-8). Had up to 300 m^3/s (10,600 ft^3/s) more than the L-limits been released, water levels would have been 10 cm (3.9 in) lower by the end of December (Figure 2-8). Note that because the L-limit is a function of Lake Ontario water levels, the effects of any strategy that increases the L-limit flow are greater at the start of the simulation and decrease over time. The reason is that higher outflows earlier on drop the water level of Lake Ontario somewhat faster, and as the lower Lake Ontario level continues, this results in lower outflows being possible later in the simulation.

As with the other simulations, only water levels and flows are considered here. Further investigation is required to determine what benefits and tradeoffs these increases in flows and reduced levels would have to Lake Ontario shoreline riparians and other interest groups such as commercial navigation or environmental considerations. For example, it may have been beneficial to both shoreline riparians and commercial navigation interests if more water had been released earlier, which would have shortened by a small amount the period that the L-limit was applied and/or reduced the risk of low Lake St. Lawrence levels later in the season.

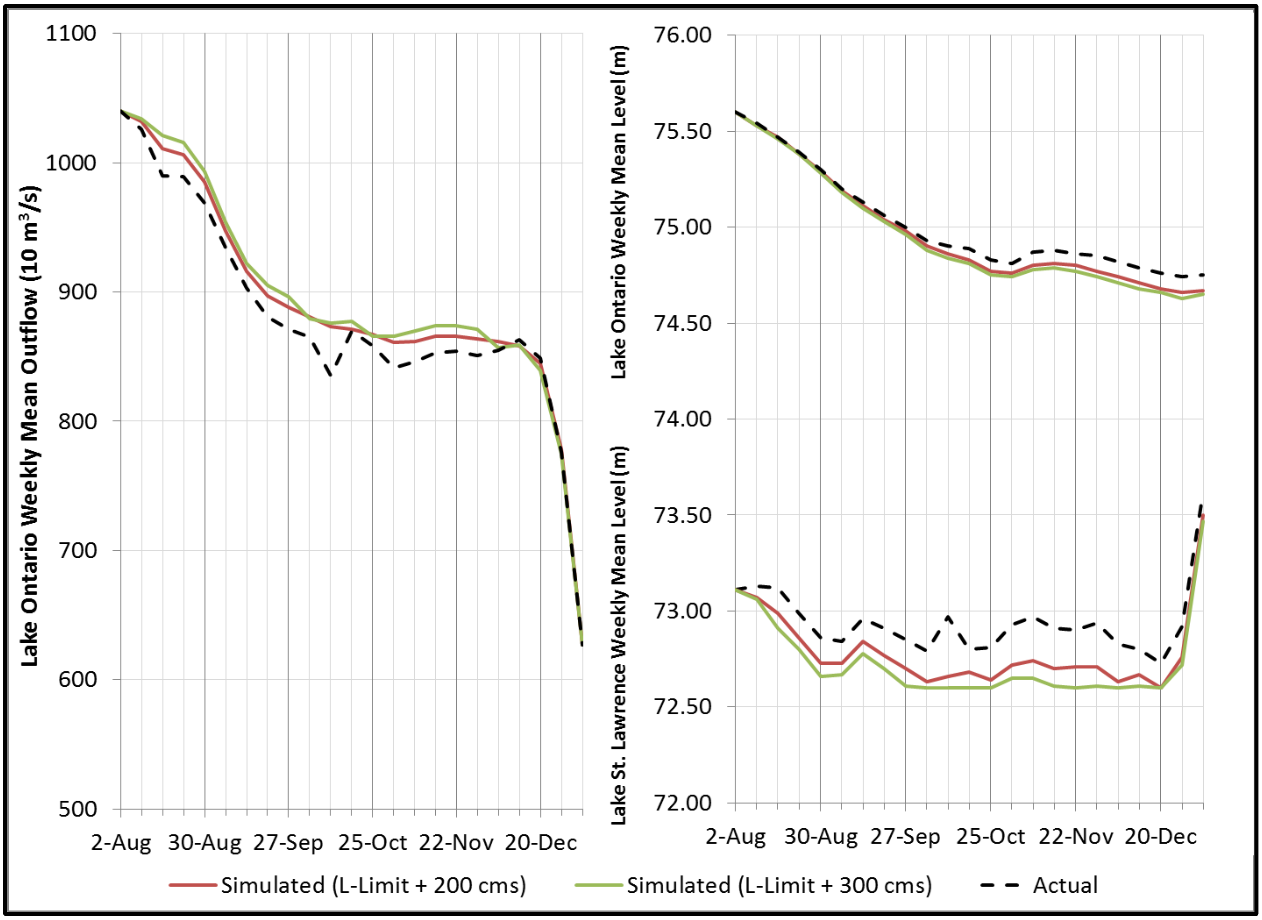

Figure 2-8: Simulated Lake Ontario outflows, Lake Ontario water levels and Lake St. Lawrence water levels based on modified L-limit flows compared to actual outflows and water levels in 2017

2.3.4 Alternative major deviations

Throughout the high-water period of 2017, and more specifically during the period from the end of April through the beginning of September when water levels exceeded the Plan 2014 criterion H14 high threshold levels, the ILOSLRB conducted major deviations and outflows were set in consideration of balancing upstream and downstream flooding impacts while maintaining safe conditions for navigation in the St. Lawrence River. From June 14 to August 8, 2017 outflows were maintained at 10,400 m^3/s (367,000 ft^3/s), the highest sustained outflow on record. Despite these record-high flows, there remains interest in understanding the potential impacts on water levels and flows had higher outflows been maintained. It is important to note that these preliminary simulations do not outline the potential impacts to various interests throughout the system, including the impacts on commercial navigation, to shoreline interests below the Moses-Saunders dam, or to hydropower interests, boaters or the environment upstream of Moses-Saunders on Lake St. Lawrence, where levels would have been reduced significantly had releases exceeded 10,400 m^3/s (367,000 ft^3/s) on an ongoing basis. Section 5.4 of the "Observed

Conditions and Regulated Outflows in 2017" report includes additional information on the ILOSLRB's considerations for maintaining record-high outflows in 2017 and the potential impacts of exceeding 10,400 m^3/s (367,000 ft^3/s). These simulations are simply meant to illustrate potential impacts to levels if alternative major deviations were conducted in 2017.

Three alternative major deviation scenarios were simulated and compared to actual conditions: a simulation of explicit application of Plan 2014 flows with no major deviations in 2017, and two extreme simulations of major deviations which demonstrate the effects of maximum possible outflows that may have been physically possible in 2017. Each of the latter two of these scenarios included increasing outflows to maximum channel capacity (up to 11,500 m^3/s (406,000 ft^3/s)) in mid-June (instead of 10,400 m^3/s) 367,000 ft^3/s, and they are differentiated by the fact that one scenario returns to Plan 2014 flows when levels fall below criterion H14 high threshold levels, while the other continued to release the maximum outflows through the end of the year (until flow reductions were required for ice management). It should be noted that the ILOSLRB did not have authority to deviate in this manner (i.e., continuing to deviate after levels of Lake Ontario had fallen below criterion H14 levels), but this extreme scenario demonstrates the maximum outflows possible within physical limits of the system. Note that in both of these simulations, the top tier of the F-limit was respected and Lake St. Louis levels were maintained at or below 22.48 m (73.75 ft) and it was also ensured that Lake St. Lawrence levels were maintained above 71.80 m (235.6 ft) to protect water intakes (consistent with an aspect of the Plan 2014 I-limit).

These scenarios would have had little or no effect on flood damages around Lake Ontario, but they would lower end-of-year levels, possibly reducing water levels and the risk of a potential repeat of high water conditions in 2018. Given high water conditions did not occur in 2018, any potential benefits of either strategy would not have been realized. In other years, such lowering could induce drought conditions and damages. In all years, these extreme strategies would likely cause substantial damages to many sectors both above and below the dam.

As expected, the most extreme simulation of maximum channel capacity flows through the end of the year resulted in the largest impact on water levels. In this scenario, Lake Ontario water levels would have been 45 cm (1.5 ft) lower by the end of December (Figure 2-9). The extreme flows (if feasible on a sustained basis) would have maintained Lake St. Louis at flood stage longer (Figure 2-9) and would have exceeded flows that were considered the maximum for safe commercial navigation during 2017 operations with the expectation that St. Lawrence Seaway and all international shipping on the Great Lakes would have to be shut down for the year. Extremely low levels on Lake St. Lawrence would also be expected. See section 5.4 of the "Observed Conditions and Regulated Outflows in 2017" report for additional details on the potential adverse effects.

The alternative major deviation scenario that was simulated (applying outflows of up to 11,500 m^3/s (406,000 ft^3/s) until water levels fell below the criterion H14 high threshold levels) would have resulted in Lake Ontario water levels that were 15 cm (5.9 in) lower at the beginning of September, but only 7 cm (2.8 in) lower by the end of December. This is because the higher flow releases earlier in the summer would lower the lake faster, resulting in lower water levels by September. This lower water level would have resulted in lower outflows starting in September because the L-limit is a function of lake levels. That is, given the lower Lake Ontario levels, the maximum safe flow for navigation would have had to be lower than actual flows were after this point, and this would have begun to offset the effects of the higher flows earlier on, causing the resulting effects on water levels to converge. The maximum difference in simulated Lake Ontario levels for this scenario compared to actual conditions is 20 cm (7.9 in) in early August (Figure 2-9). In this scenario, there is an unknown trade-off because the high flows would have more rapid relief to Lake Ontario riparians, but would have prolonged downstream flooding, caused low levels on Lake St. Lawrence, and likely resulted in the suspension of commercial navigation in the St. Lawrence Seaway during that period.

Had the ILOSLRB not conducted any major deviations (i.e. if the ILOSLRB had followed the Plan 2014 rules explicitly during the period when they had deviation authority), Lake Ontario levels would have been 15 cm (5.9 in) higher at the beginning of September. In contrast to the deviation scenarios above, those higher levels would have allowed higher than actual flows (while maintaining safe navigation) after September. Because of this, and similar to the deviation scenarios, the resulting effects on water levels tend to converge, and as a result, Lake Ontario levels would have been only 8 cm (3.2 in) higher than actual levels by the end of December.

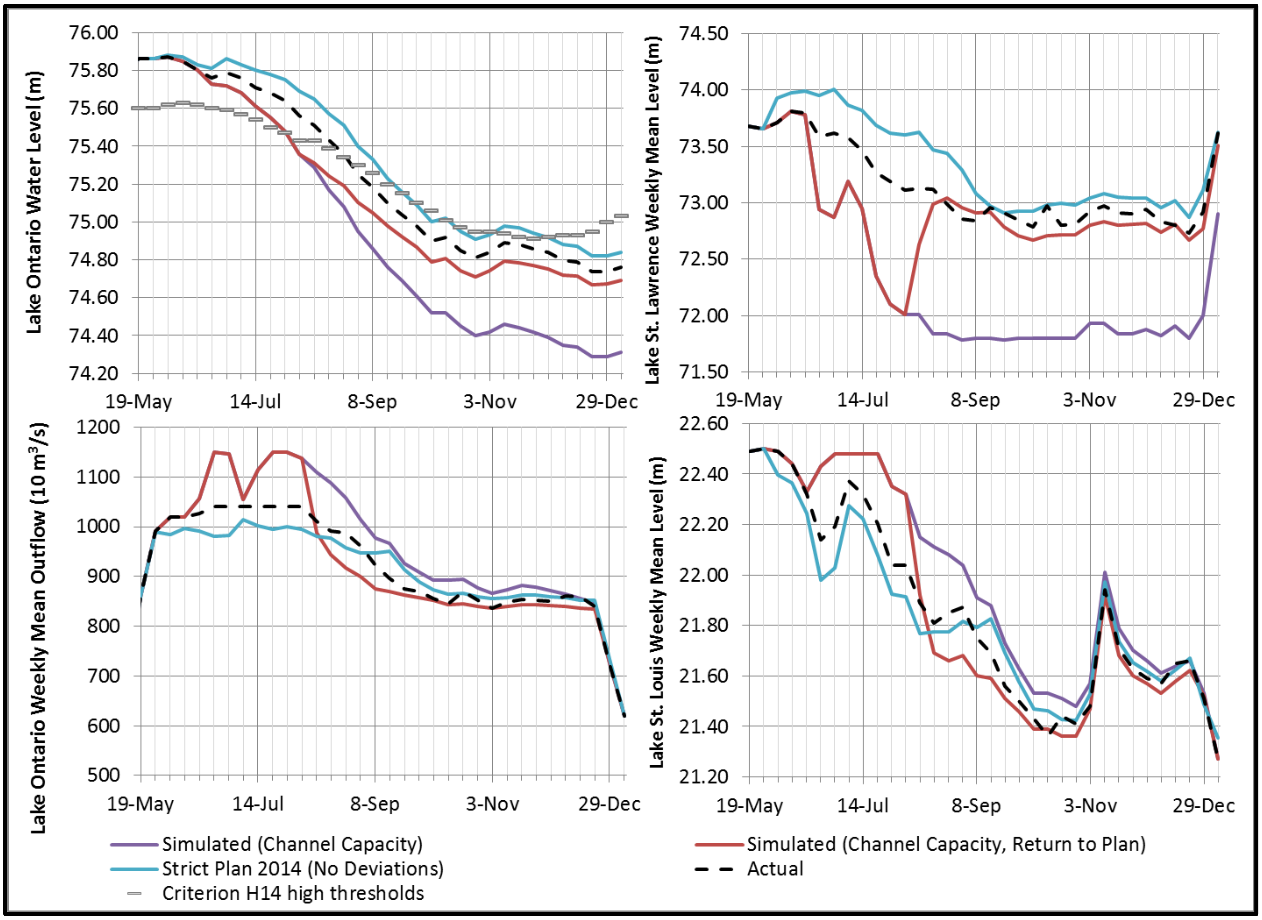

Figure 2-9: Simulated Lake Ontario outflows, Lake Ontario water levels, Lake St. Lawrence water levels and Lake St. Louis water levels based on modified major deviation scenarios

2.3.5 Regulation plan 1958-D with "actual" operational deviations

Since Plan 2014 was only implemented as of January 7, 2017, there is considerable interest in understanding what conditions would have been like had the previous regulation plan (Plan 1958-D with deviations) remained in operation. It is important to note that decisions of the previous International St. Lawrence River Board of Control were critical to the application of Plan 1958-D with deviations and simulating the potential decisions that the ILOSLRB made or may have made under the old regulation plan cannot be done with exact certainty. Despite these uncertainties, there is a high degree of confidence in the simulation of 1958-D with "actual" operational deviations for 2017 for three reasons: first, as this was the first year of Plan 2014's implementation, both plans would have started the year at exactly the same level; second, the extreme hydrologic conditions in 2017 often dictated flows that could be released, and this would have largely been the case under both plans; and third, the maximum flow limitations within Plan 2014 that were employed throughout most of 2017 were designed based on similar limitations under Plan 1958-D and operations of the ILOSLRB under Plan 1958-D, including deviations that were often necessary to achieve similar outcomes (e.g. to balance upstream and downstream flooding impacts and to maintain safe conditions for navigation).

Figure 2-10 compares the actual Lake Ontario outflows and water levels in 2017 to the Plan 1958-D prescribed outflows and water levels that would have occurred in 2017 had the ILOSLRB followed the Plan 1958-D rules strictly, without deviating (dotted grey series). The simulated outflows and water levels that could have occurred in 2017 under operation of Plan 1958-D with deviations are indicated by the shaded orange series. Outflows (and therefore water levels) would have been nearly identical under Plan 1958-D with deviations in 2017. Specific time periods where outflows could have differed are denoted with letters **A** through **E** in Figure 2-10 and described below.

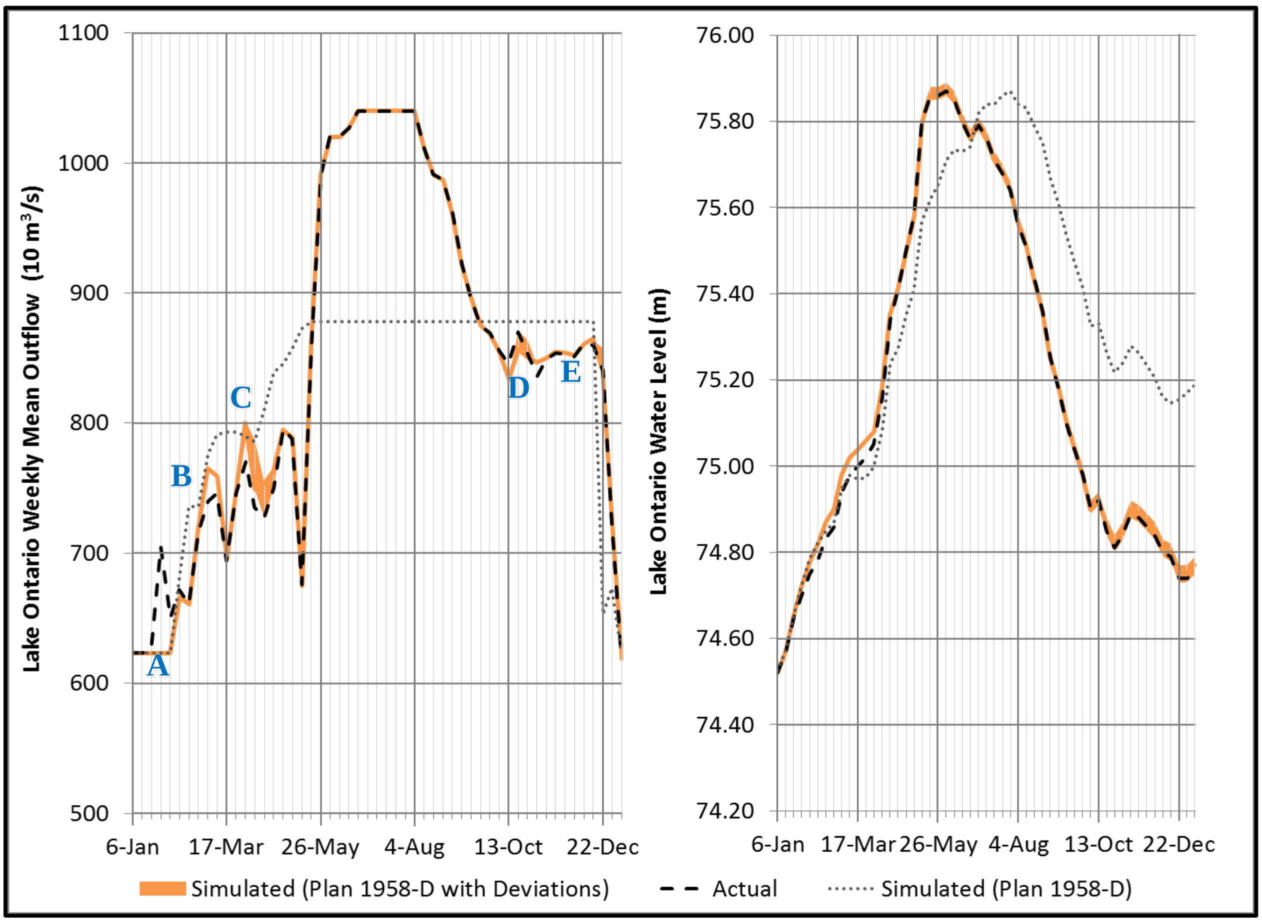

Figure 2-10: Simulated Plan 1958-D with deviations (shaded orange series) and simulated Plan 1958-D prescribed outflows and water levels (dotted grey series) compared to actual outflows and water levels in 2017

In January, Plan 1958-D typically specified a maximum flow of 6230 m^3/s (220,000 ft^3/s) to allow for ice formation (even when ice was not actually forming) while Plan 2014 allows for a higher flow until ice formation actually begins (**A**). It is unlikely that the ILOSLRB would have decided to deviate from Plan 1958-D and release flows above 6230 m^3/s (220,000 ft^3/s) in

January, given that there was no indication that conditions would be extremely wet later in the spring and the level of Lake Ontario was slightly below the long term average. As further evidence, as recently as in 2016, the ILOSLRB did not deviate under similar conditions. The Plan 1958-D prescribed flow would have been higher than the Plan 2014 prescribed flow during the weeks ending March 3 through March 17 (**B**), and there would have been limited opportunities during this period to release these higher flows. Otherwise, the same outflow adjustments would have been required for ice management, but these would have been considered deviations from Plan 1958-D. The ILOSLRB likely would have released flows greater than the Plan 1958-D prescribed outflows in the short period between March 25 and April 5, after ice conditions in the St. Lawrence River no longer limited the outflows, and before the onset of the Ottawa River freshet (**C**).

The Plan 2014 F-limit is largely based on how the ILOSLRB used to operate under Plan 1958-D during the spring Ottawa River freshet. During those periods, the ILOSLRB would normally deviate from Plan 1958-D, as it did not include an F-limit, in order to balance upstream and downstream high water levels and impacts. So, beginning April 5, it was assumed that the ILOSLRB would have deviated from Plan 1958-D prescribed outflows, as it had in the past and, in a similar manner to how outflows were operationally adjusted under the Plan 2014 F-limit, to balance upstream and downstream flooding damages.

Based on the results of this Plan 1958-D simulation, the level of Lake Ontario would have peaked within +/- 2 cm (0.8 in) of the actual peak in June 2017. As the ILOSLRB had authority to deviate from Plan 2014 by this point, it was assumed that thereafter, the ILOSLRB operating under Plan 1958-D would have also deviated and released the same record-high outflows through much of the summer. The ILOSLRB likely would have come to the same consensus to decrease outflows to maintain safe conditions for navigation beginning on August 8. As per actual operations in 2017, the ILOSLRB likely would have allowed a similar deviation from Plan 1958-D in October to facilitate removal of boats and other equipment on Lake St. Lawrence (**D**) and a similar test of flows above the maximum L-limit in December (**E**). Beginning on December 25, it was assumed that the ILOSLRB would have decreased flows to facilitate ice formation, as ice had started forming in the Beauharnois Canal.

Based on the results and uncertainties of this simulation, by the end of 2017, the level of Lake Ontario would have been within +/- 3 cm (1.2 in) of the actual level had the ILOSLRB been operating under Plan 1958-D instead of Plan 2014.

2.3.6 Pre-project water levels and outflows

A simulation was conducted to compare actual levels and outflows in 2017 to pre-project conditions (Figure 2-11). Pre-project conditions were simulated using a natural stage-discharge relationship, in other words, the natural conditions that existed prior to the control structures being constructed on the St. Lawrence River. Under pre-project conditions, the level of Lake Ontario would have continued rising and not peaked until the first week of July, reaching a level about 18 cm (7.1 in) higher than it actually did in 2017 and exceeding the 76.00 m (249.3 ft) mark. The extremely high water levels would have persisted well into the fall and winter with water levels ending the year as much as 76 cm (2.5 ft) higher than actual levels in 2017. On the lower river, Lake St. Louis water levels would have peaked about 53 cm (1.7 ft) higher. This could have resulted in catastrophic damages on both Lake Ontario and the St. Lawrence River.

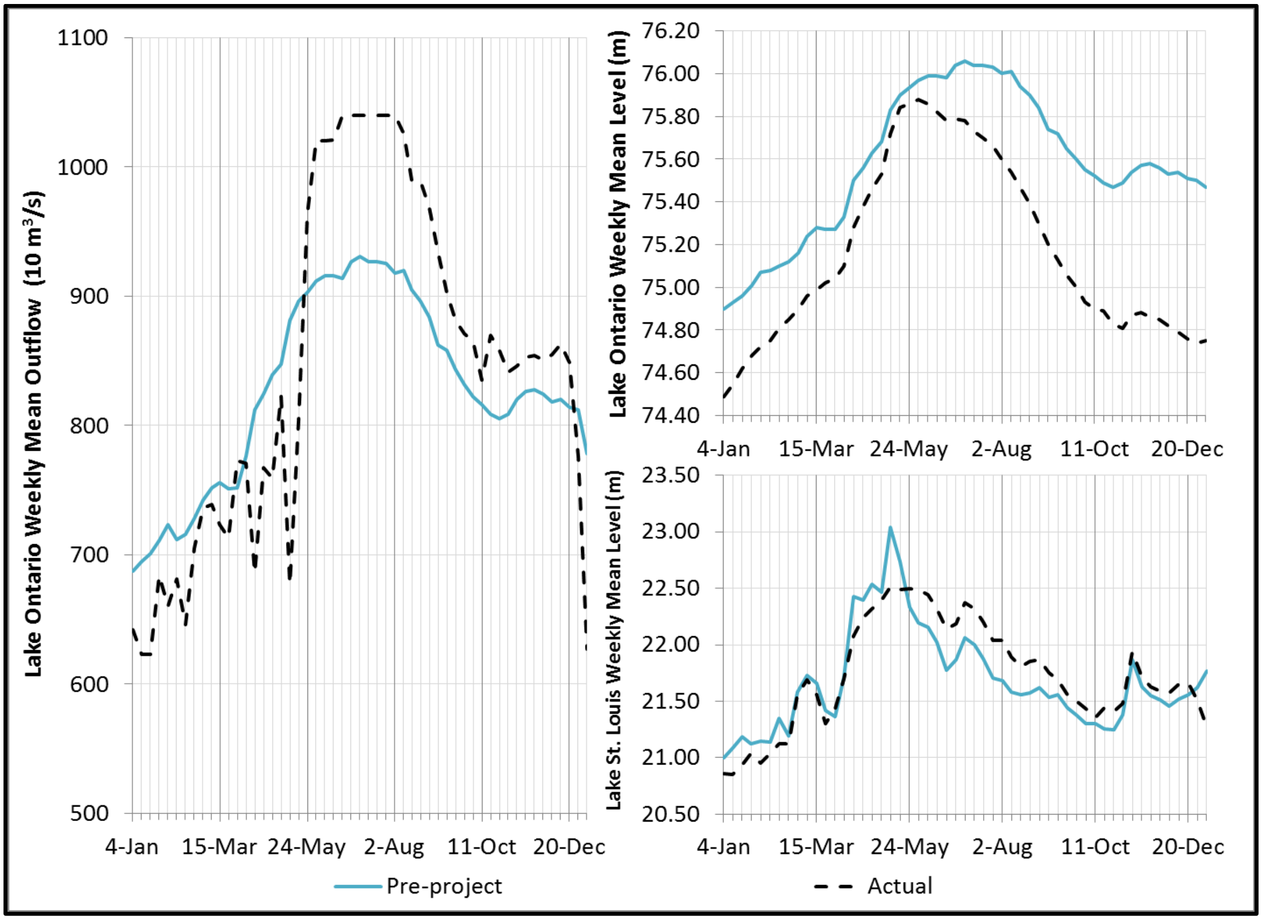

Figure 2-11: Simulated pre-project Lake Ontario outflows, Lake Ontario water levels and Lake St. Louis water levels compared to actual water levels and outflows in 2017

2.4 Validation of Quarter-monthly Plan Simulations Under 2017 Conditions

2.4.1 Background

Plan 2014 was designed and tested using simulation models, which are computer programs developed to simulate, as accurately as possible, how the regulation plan rules will respond to hydrologic conditions. However, as with any model of a real-world process, there are limitations and sources of uncertainty involved, and it is necessary to simplify or generalize some inputs that the ILOSLRB considers in actually operating the plan. In this section, the GLAM Committee considers what effects these have on simulated water levels and flows, and whether these generalizations bias or degrade the evaluation of regulation plan performance. These generalizations are necessary when attempting to simulate conditions within such a complex system and have important benefits in plan evaluation.

For example, simulations for Lake Ontario were conducted on a quarter-monthly (i.e., four quarters per month, 48 per year) basis, which provides a simplified representation of actual regulation operations, which occur on a weekly basis. Quarter-monthly time series of hydrologic conditions (e.g., water supplies, ice indicators, roughness factors) were used as inputs to the model and simulated flows and water levels were outputs from the model. It is important to evaluate regulation plans using a wide range of hydroclimate conditions that capture more possibilities than what has been observed historically because future conditions are uncertain but will most certainly be different from what occurred in the past. Therefore, during the LOSLRS and thereafter, statistical analysis was performed to develop a time series of 50,000 years of stochastically generated water supplies and tributary flows to test regulation plans, allowing for more robust evaluations and producing better plans more capable of dealing with what may occur in the future. These scenarios of hydroclimate conditions are run through computer models that also simulate the plan rules and regulated outflows that would occur, as well as the water levels throughout the system, given such conditions. But as another generalization, in practice, deviations from the plan reflect a consensus reached by the ILOSLRB after discussion, but to evaluate Plan 2014 and Plan 1958-DD using such extended time series of hydrologic conditions, algorithms capturing the essential logic of the ILOSLRB is required. Furthermore, while daily or even hourly flow data, ice conditions and shipping issues are considered by the ILOSLRB in its weekly operations, it is essential that these within-week permutations be simplified or managed statistically to allow practical simulation runtimes.

The GLAM Committee is charged with comparing actual observations to planned regulation plan results, so must take the differences between operations and planning models into consideration, and consider the accuracy with which models represent reality, and determine what may be lost by using these generalizing techniques, and whether it is significant.

Furthermore, as part of its charge, the GLAM Committee is to help the IJC Great Lakes Boards including the ILOSLRB and the ILSBC with improved understanding of the system and to address future conditions. A key question the GLAM Committee is to address is whether future water supplies will be different from those used to test the current management of levels and flows. In the LOSLRS it was recognized that the future will not be a repeat of the past; especially when it comes to the weather that drives the water supplies in the Great Lakes-St. Lawrence River system. The previous LOSLRSB and the IJC acknowledged that even without the effects of increased greenhouse gases in the atmosphere, we could be confident that there will be periods of higher and lower water supplies sometime in the future due to the natural variation in climate. Therefore, the LOSLRSB chose to test all alternative regulation plans using a stochastically generated supply sequence to evaluate their hydraulic range and economic benefits.

Unlike past studies that had often assumed a certain stationarity to climate and assumed what had happened in the past was a good reflection of the future, the LOSLRS attempted to look beyond the past and attempted to identify alternative future hydroclimate sequences that may be possible. It did this by generating a large 50,000 year sequence of stochastically generated supplies to each of the Great Lakes, the Ottawa River and other downstream tributary flows. While this stochastic time series was based on the statistical characteristics of the twentieth century supplies (LOSLRS, 2006), it generated a greater range of conditions to test regulation plans and included several more extreme wet and dry events than had occurred historically. The stochastic hydrology model included important probabilistic relationships between the supplies from one year to the next, their seasonal patterns and their QM to QM correlations (LOSLRS, 2006). Important statistical properties of the system were preserved such as the mean, standard deviation and the probability that wet or dry conditions would occur in the various drainage basins at the same time. For the most part, the stochastic supply sequence was used to assess differences in average annual benefits between alternative regulation plans.

As such, this chapter provides a review of 2017 conditions in light of both model uncertainty and also in consideration of how observed water levels and hydroclimate conditions compared to those used in the development and evaluation of the regulations plans, and what this might mean for future evaluations.

2.4.2 2017 validation

The extraordinary conditions in 2017 provide an opportunity to not only study the effects of the different regulation plans, but also validate portions of the models used to simulate regulation plan performance over time.

By comparing actual conditions in 2017 to how they would have been simulated using the quarter-monthly plan-evaluation code, the tools themselves can be assessed, to ensure they represent actual conditions to a satisfactory degree of accuracy for use in plan evaluation and comparisons, both to review decisions made in the past and to support decisions that may be made in the future. "Model error" can readily be illustrated and described in this manner, and the significance of any errors can be assessed, immediately in the case of 2017, but also in terms of recommendations for future study and in preparation for future evaluation activities.

Five specific factors were reviewed, including:

1. **Ice Conditions (2.4.2.1):** Highly variable ice conditions occurred in 2017. Further review is needed as to how 2017 ice conditions (formation and stability) relate to historical conditions used to evaluate regulation plan alternatives.
2. **Simulation of Lake St. Louis Water Levels (2.4.2.2) in Plan 2014:** Given extreme water levels throughout the system in 2017, it was determined that further validation of the simulated Lake St. Louis levels is required.

3. **Simulation of Lake Ontario Levels (2.4.2.3):** How the Lake Ontario water level in 2017 compares with the water level simulated from the 50,000 year stochastic hydrologic time series.
4. **Water supplies (2.4.2.4):** The water supplies in April and May 2017 exceeded those that had occurred during the historical period of record 1900-2008 used to evaluate regulation plans. How do they compare to other water supply scenarios used in plan evaluation, including the 50,000 year stochastic scenarios? Climate change scenarios need to be updated for this analysis and that will be done in the future.
5. **Ottawa River flows (2.4.2.5):** Similar to above, record flows were set in 2017, how do these compare to other scenarios used in plan evaluation? Also, how does the combination of high water supplies to Lake Ontario and high Ottawa River flows compare to the plan evaluation time series?

Each of the five concerns listed are discussed in separate sections, below.

2.4.2.1 Ice conditions

In simulations of regulation plan performance, including the quarter-monthly simulations, a number of assumptions and simplifications are made to describe ice processes in the St. Lawrence River, and this has a direct effect on the resulting outflows that would be released under such conditions. In this section, simulations are used to quantify how these simplifications distort 2017 water level simulations. The section also considers whether the time series used to simulate ice conditions in the St. Lawrence River in regulation planning simulations accurately reflects historical conditions and whether this provides an acceptable indicator of future conditions that may occur for the purposes of plan evaluations, or whether it should be modified to reflect recent observations that include longer ice periods with multiple formation periods and/or limited ice cycles in a given year.

The main challenge in the quarter-monthly simulation of 2017 conditions was how to select the "ice status indicators" (ISI) to define ice conditions in the critical sections of the St. Lawrence River at each QM from January through March. The ISI is a simple means of identifying when ice is forming or not in the St. Lawrence River, and is used by the quarter-monthly regulation models when setting appropriate outflows through the winter months.

The ISI are defined as follows:

- ISI = 0 if there is no ice in critical sections
- ISI = 1 if ice is forming in critical sections
- ISI = 2 if ice is fully formed and stable

If there is no ice (ISI = 0) then there are no ice-related limitations applied to outflows from Lake Ontario under any regulation plan. Likewise, if ice is fully formed and stable, the QM simulation code does not apply ice-related limitations (though it does check for critically low levels of 71.8 m (235.56 ft) on Lake St. Lawrence and if necessary, limits flows to maximum values to maintain this level. This, however, was not necessary in 2017). However, if ice is forming in critical sections of the St. Lawrence (ISI=1), then the QM simulation code requires that the Lake Ontario flow be a maximum of 6230 m^3/s (220,000 ft^3/s) or less for at least two QMs.

This simplified approach results in two challenges for simulating 2017 conditions:

- First, ice went from forming to thawing multiple times in 2017 and on very few occasions did these processes last for a full QM or longer, making it impossible at times to identify and apply a single ice status indicator to a full QM; and
- Second, it was not necessary to limit outflows to the maximum of 6230 m^3/s (220,000 ft^3/s) at all times that ice was forming, particularly later on in March 2017, when the ILOSLRB (in consultation with its Operations Advisory Group, which has the primary responsibility for monitoring of ice conditions) was able to release somewhat higher outflows; however, it was also not possible to increase flows to the much higher rule curve or J-limit flows that would have otherwise been prescribed.

The combination of highly variable ice conditions and limited flexibility to prescribe outflows when ice was forming made it impossible to precisely model actual ice conditions and effects on flows in the quarter-monthly simulation. Instead, after carefully reviewing ice conditions, actual flow changes, and correspondence from winter 2017, two alternative scenarios were created to model both the least and most restrictions that would have been caused by actual 2017 ice conditions within the restrictive framework of the planning model:

- Scenario 1 (the least ice limitations): In this scenario, ISI was set equal to 1 (ice forming) for QM 1, 2 and 6 only, which is when flows were in fact restricted to 6230 m^3/s (220,000 ft^3/s) due to ice (although actual flows were slightly higher than this overall). At times in 2017 that ice was forming for only a partial QM and flows higher than 6230 m^3/s (220,000 ft^3/s) were able to be released, the ISI was set equal to 0 (no ice forming).
- Scenario 2 (the most ice limitations): In this scenario, ISI was set equal to 1 (ice forming) during QM 1 to 7 and QM 9 to 11, which are all QMs when flows were restricted to varying degrees due to ice formation.

These two alternative ice status indicator sequences were used to simulate Plan 2014 and 1958-DD. In the first scenario (least ice limitations), a comparison was made between these simulations and actual QM Lake Ontario outflows and Lake Ontario and Lake St. Louis levels (Figures 2-12 to 2-14). With no ice restrictions applied in QM 3 - 5 in scenario 1, both simulated Plan 2014 and Plan 1958-DD allow similar higher Lake Ontario outflow than what was actually possible in reality. In reality, during some of QM 4 and 5 ice was forming and restricting outflows, though not as low as 6230 m^3/s (220,000 ft^3/s). In the first scenario, simulated flows are reduced again during QM 6 and 7 for simulated Plan 1958-DD and Plan 2014, but then allowed to increase in March to outflows that were much higher than were possible under actual conditions due to the fact that ice was forming during extreme cold weather in March. In reality, actual outflows were also increased substantially and were maximized depending on ice conditions and were well above the normal “ice forming” value of 6230 m^3/s (220,000 ft^3/s), but actual flows did not reach the high flows simulated under either Plan 1958-DD or Plan 2014 during this period, and the simulated high flows for those plans would not have been possible without significant risk of ice complications, including a possible ice jam in the Beauharnois Canal.

As a result, scenario 1, with the least ice restrictions, is not an accurate representation of reality. Ice formed throughout the first three months of 2017, however it did not always fully limit outflows to 6230 m^3/s (220,000 ft^3/s); at times higher outflows than this were possible, but the much higher flows simulated under both regulation plans would not have been possible throughout much of 2017.

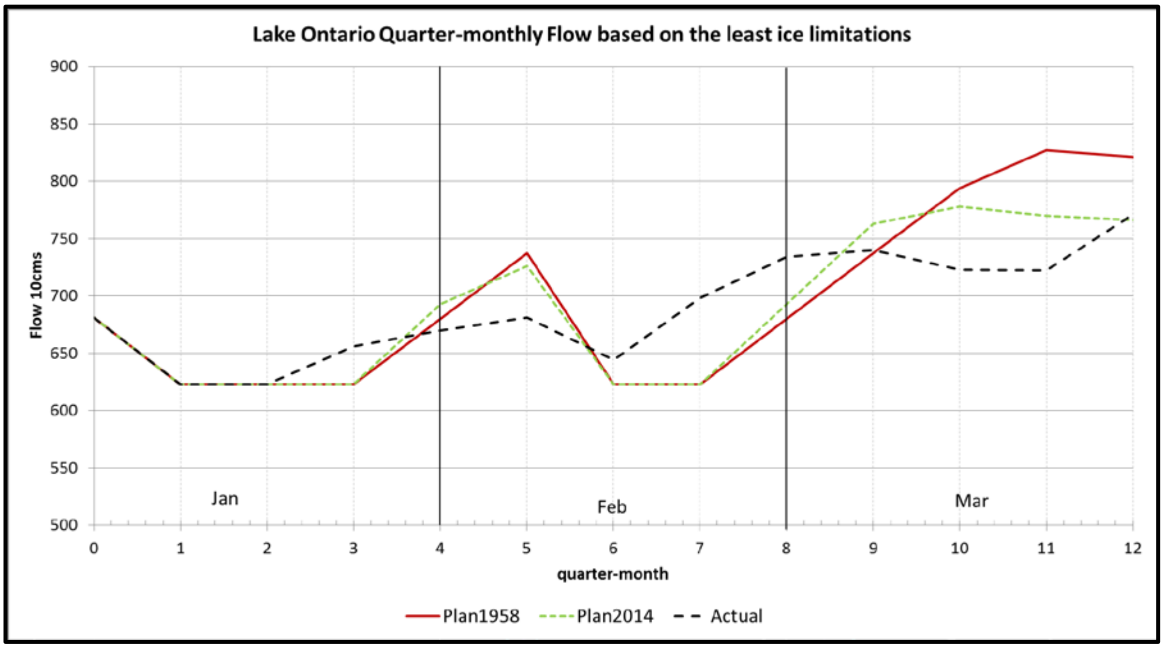

Figure 2-12: Lake Ontario quarter-monthly outflows simulated with less ice limitations than actually occurred in 2017 (Scenario 1). Simulated outflows under both Plan 2014 and Plan 1958-DD would have been lower at times, but higher overall than what was actually possible during the winter of 2017.

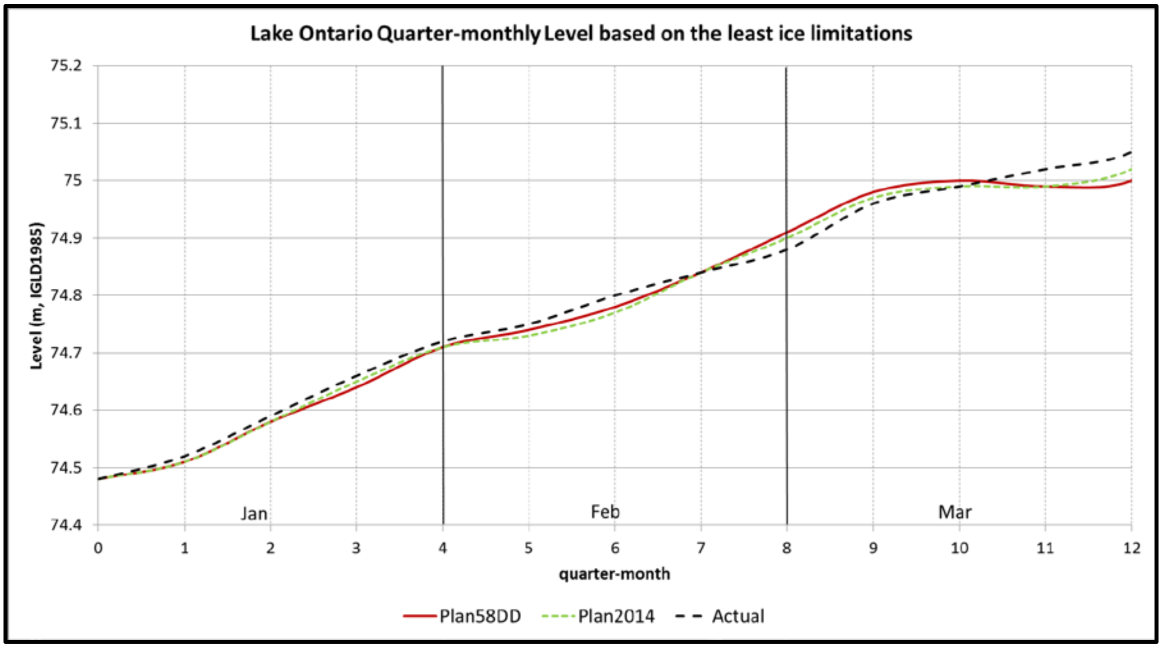

Figure 2-13: Lake Ontario quarter-monthly levels simulated with less ice limitations than actually occurred in 2017 (Scenario 1). Since both the Plan 2014 and Plan 1958-DD simulations allowed overall higher outflows than would have been possible in reality, simulated Lake Ontario levels under both regulation plans are below actual levels by the end of March.

To simulate Plan 1958-DD outcomes, the simulation code uses a modified version of the Plan 1958-D maximum P limit, developed to represent the deviations the ILOSLRB typically employed under similar circumstances to prevent downstream flooding by assuming a maximum Lake St. Louis flow for certain Lake Ontario levels (ILOSLRSB, Annex 3 B, 2006). For example, if Lake Ontario's level is below 75.20 m (246.72 ft), the maximum P limit flow could be obtained as the difference between a Lake St. Louis flow of 11,500 m^3/s (406,000 ft^3/s) and the flows entering the St. Lawrence between Lake St. Louis and the outlet at Moses-Saunders Dam (i.e., SLON). If the Lake Ontario level is above 75.20 m (246.72 ft) but less than 75.45 m (247.54 ft), the same method is employed, but Lake St. Louis flow would be a maximum of 12,400 m^3/s (438,000 ft^3/s). If the Lake Ontario level is above 75.45 m (247.54 ft), the P limit is determined by combining the Plan 1958-D P limit and using a Lake St. Louis flow of 12,400 m^3/s (438,000 ft^3/s). This "rule" within the Plan 1958-DD code results in a similar water level response as the F-limit within Plan 2014; however, with this method, there are no explicit rules in the simulation code to limit the Lake St. Louis level, only the outflow from Lake St. Louis. As a result, the simulated quarter monthly Lake St. Louis levels can exceed expected values. For example, in the simulation of ice conditions in scenario 1, Lake St. Louis levels during QM 18 (second QM of May) reached 22.73 m (74.57 ft) in the Plan 58-DD simulation, which is higher than actual quarter-monthly levels reached in 2017 and higher than the ILOSLRB would likely have allowed had it been actually operating under Plan 1958-D given similar conditions.

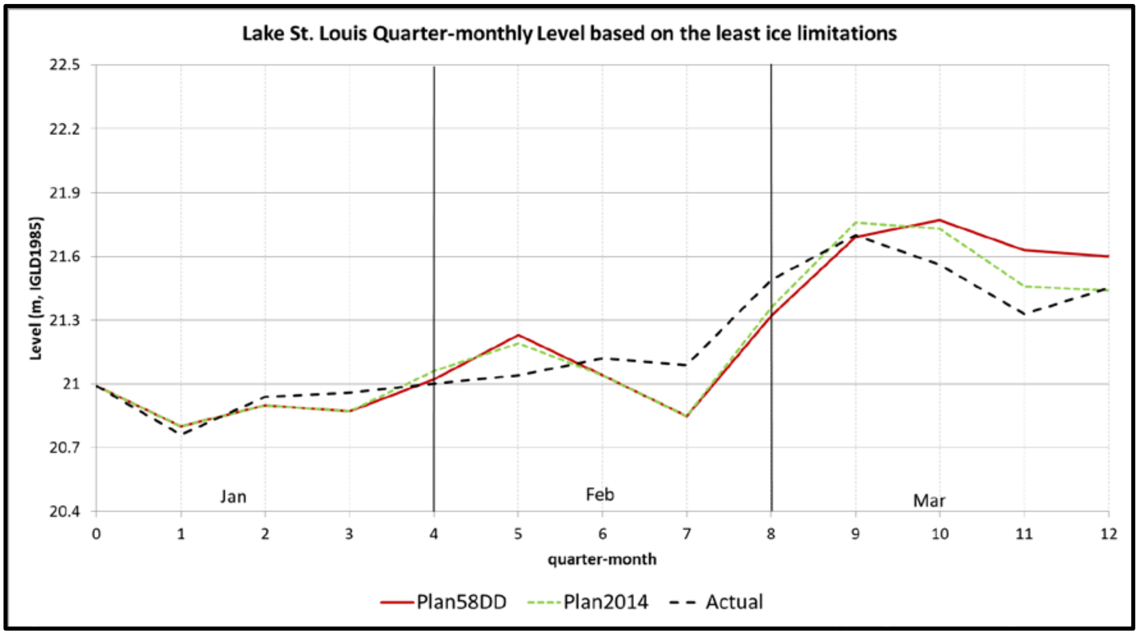

Figure 2-14: Lake St. Louis quarter-monthly levels simulated with less ice limitations than actually occurred in 2017 (Scenario 1). Since both the Plan 2014 and Plan 1958-DD simulations allowed overall higher outflows than would have been possible in reality, simulated Lake St. Louis levels under Plan58-DD is above actual levels at the end of March.

In Scenario 2 (the most ice limitations), it was assumed that ice was forming during QM 1 to 7 and QM 9 to 11, which are all QMs when flows were restricted to varying degrees due to ice formation in 2017. In this case, with ice assumed to be forming through most of the first 11 QMs of 2017 (i.e., January through the 3rd QM of March), the flow is restricted to 6230 m^3/s (220,000 ft^3/s) during this period under both regulation plans. However, in reality higher flows were possible at times, even when ice was forming, especially in March. As a result, in this scenario, the QM simulation of both Plan 2014 and 1958-DD underestimate the potential outflows for much of the January to March period and result in higher peak Lake Ontario water levels than actually occurred (16 cm (6.3 in) and 6 cm (2.4 in) higher than actual levels, respectively).

The following plots (Figure 2-15 to 2-17) are from scenario 2.

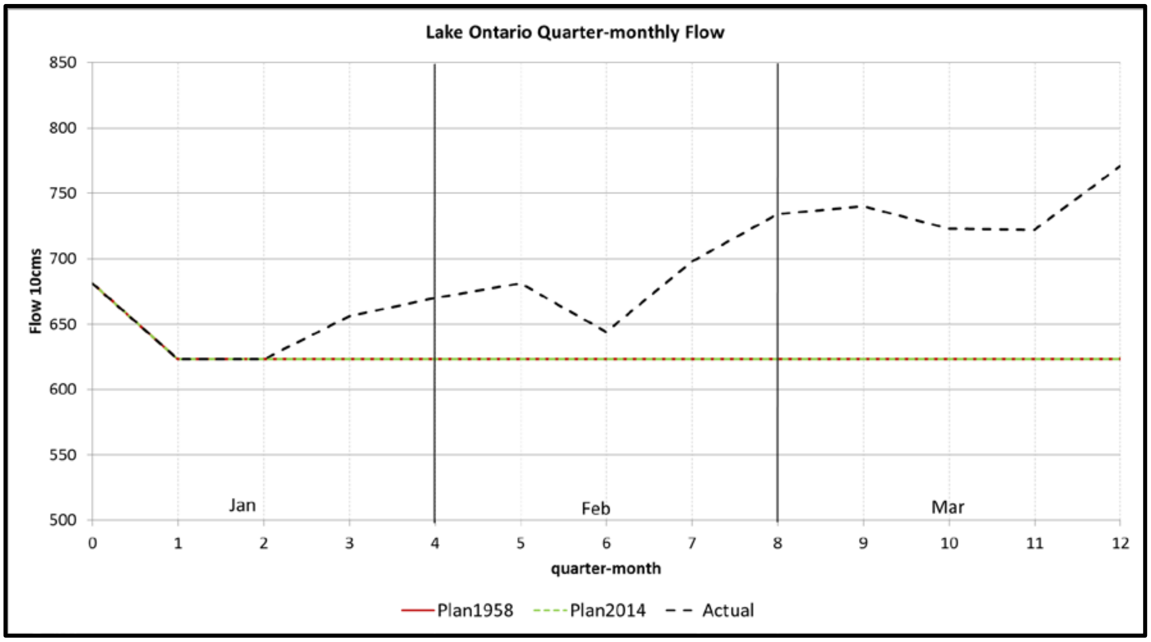

Figure 2-15: Lake Ontario quarter-monthly outflows simulated with greater ice limitations than actually occurred in 2017 (Scenario 2). Simulations of both Plan 2014 and Plan 1958-DD are restricted to lesser outflows throughout the winter than what was actually possible.

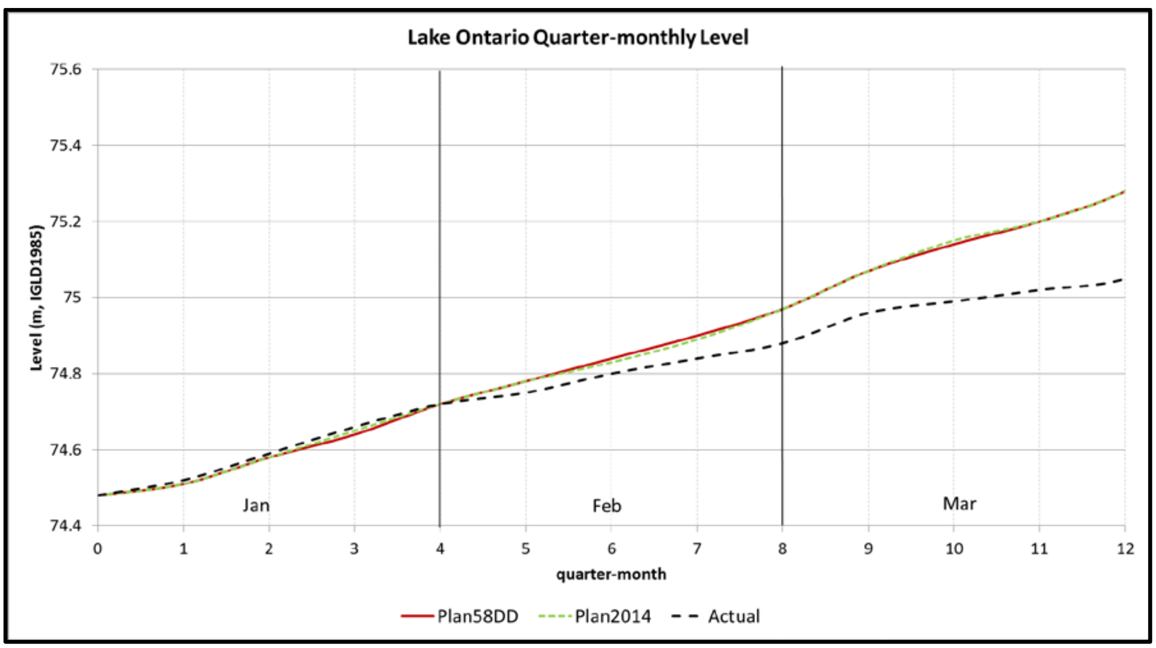

Figure 2-16: Lake Ontario quarter-monthly levels simulated with greater ice limitations than actually occurred in 2017 (Scenario 2). Since both the Plan 2014 and Plan 1958-DD simulations were restricted to lower outflows than what was possible in reality, simulated Lake Ontario levels under both regulation plans are above actual levels throughout winter.

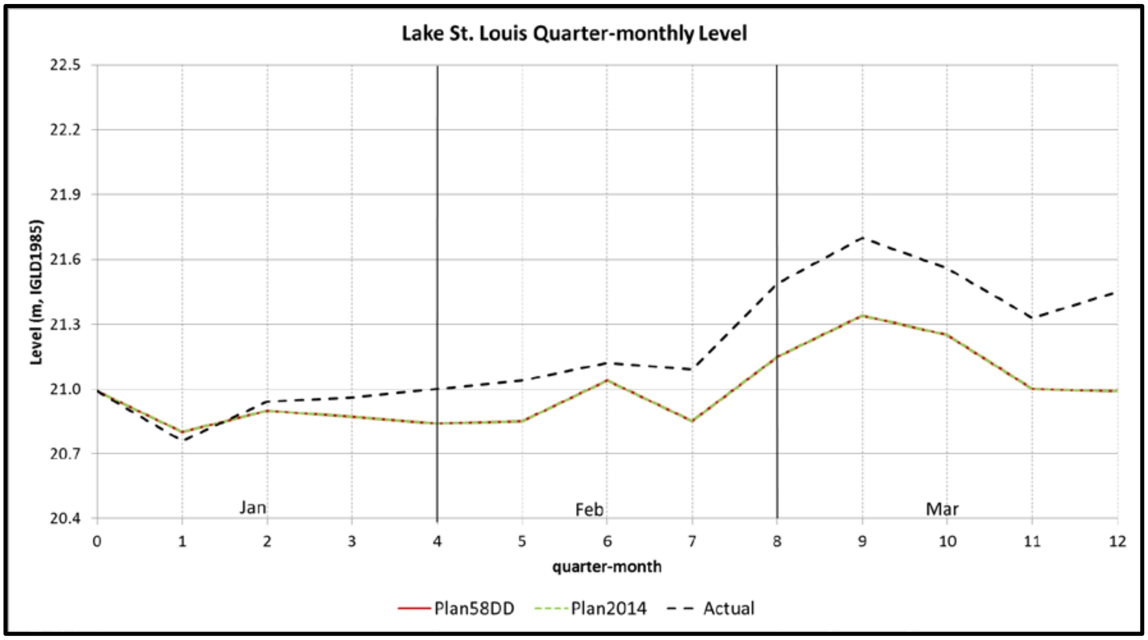

Figure 2-17: Lake St. Louis quarter-monthly level simulated with greater ice limitations than actually occurred in 2017 (Scenario 2). Since both the Plan 2014 and Plan 1958-DD simulations were restricted to lower outflows than what was possible in reality, simulated Lake St. Louis levels under both regulation plans are below actual levels throughout winter.

In summary, a key finding from the QM vs. weekly simulation comparison is that ice conditions observed in 2017 were more dynamic than can be simulated with the current quarter-monthly code. The quarter-monthly code is more restrictive and allows less flexibility in terms of managing outflows during winter than can occur under actual operations. This discrepancy affects simulated water levels under both Plan 2014 and Plan 1958-DD.

A review of the historical ice records (and also the stochastic dataset generated from it) used to evaluate Lake Ontario regulation plans shows how unique 2017 ice conditions were in comparison to past years.

- Not one year in the historical time series shows ice forming, stopping and then reforming (i.e., ISI=1 to 0 to 1), yet in 2017 there were 5 such periods (although when these are quantified on a quarter-monthly basis, it is less than 5 cycles, as some of the fluctuations observed in 2017 were a short duration).

- Furthermore, during the periods when ice was forming in 2017, particularly in February and March, it was possible to release more than the normal “safe” ice flow (ISI = 1) of 6230 m^3/s (220,000 ft^3/s); ice formation was not complete during these periods (i.e., not ISI = 2), yet in consultation with the Operations Advisory Group, it was determined that flow could be safely increased. However, there is no means currently available in the quarter-monthly plan evaluation tools to allow for this incremental increase in flows.

Moreover, it was observed that since about 2000, ice conditions appear from the ISI to have been very different than the full 1900-2008 period used to evaluate regulation plans (Figure 2-18). In particular, the duration of ice formation is much longer. With a few exceptions, ice formation used to almost always take approximately 1 or 2 QM to complete, at least according to the ISI records, while in more recent years it seems to require 2 QM at a minimum and often many more than this. A maximum of 8 QM of ice formation occurred in 2001, but 2017 may be considered longer depending on what is considered to be the period when ice was forming (for example, is ice only considered to be forming when flows were no more than 6230 m^3/s (220,000 ft^3/s), as in the first ice scenario described earlier in section 2.4.2.1?). Because the duration of ice formation has increased, the duration of fully formed ice (which allows flows to be increased) has decreased, and this has implications for the amount of water that can be released during winter months under any regulation plan.

These preliminary findings require further verification. It is possible that some of the findings are indeed real, but some may also be related to a discrepancy in how the ice indicators were established in the historical records vs. the more recent past (10 to 20 years). However, given the limited information currently available for the development of this annual report, a more detailed investigation of the simulation of ice formation conditions should be considered a priority. If the preliminary findings are correct, then there have been significant changes in ice conditions during the last 20 years and using the full historical period of record to evaluate regulation plans may not be an accurate representation of present day. If the findings are not real and simply a discrepancy in how the ice indicators were established, it suggests that the ice information used in the plan evaluation may not be representative of current operational reality. Most importantly, if the stochastic ice status indicator time series chronically underestimates the duration of ice restricted flows, the simulations may produce lower Lake Ontario water levels than may be possible in reality. Recalling that the extremely unique ice conditions in 2017 were found to be responsible for at most 12 cm (4.7 in) of the total rise in Lake Ontario, and also recalling that Plan 2014 has self-correcting tendencies, as illustrated when using higher start of the year Lake Ontario levels (2.2.3 Higher Lake Ontario Water Level at the Start of 2017), the induced error in peak water levels from any discrepancy in the representation of ice conditions in planning models may be small. Nonetheless, a review of potential impacts is warranted.

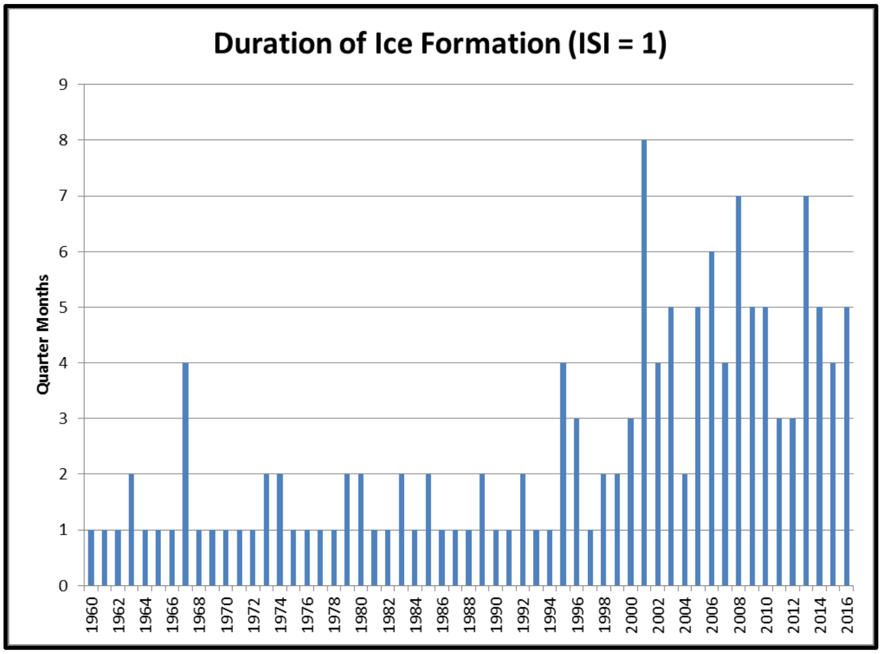

Figure 2-18: Duration of ice formation indicator based on or inferred from available historical records and used in quarter-monthly regulation planning models

2.4.2.2 Simulation of Lake St. Louis levels in Plan 2014

During the summer of 2017, a review of the quarter-monthly simulation results for Plan 2014 revealed significant discrepancies in Lake St. Louis water levels in a small number of scenarios as a result of an error in how those levels were calculated in these simulations.

For the Plan 2014 quarter-monthly simulations, it was found that the quarter-monthly F-limit calculation was not applied correctly in the model code when Lake Ontario water levels were above 75.75 m (248.52 ft). Recall that the Plan 2014 F-limit is a multi-tiered rule that attempts to balance high water conditions upstream and downstream by ensuring levels of Lake St. Louis are maintained below certain thresholds depending on the level of Lake Ontario. To accomplish this in the simulation model, a stage-discharge relationship is used to determine the Lake St. Louis outflow corresponding to each of the F-limit tiers, this flow is reduced by the Ottawa River and local tributary flows, and then the remainder is used to set the Lake Ontario outflow accordingly. However, an error was identified whereby the Lake St. Louis outflow was multiplied by a factor of 10 within the model whenever Lake Ontario was above 75.75 m (248.52 ft), which allowed the Lake St. Louis level to rise substantially and effectively removed any level of protection from this area of the system. The result is that there are discrepancies with simulated water levels in some of the most extreme wet scenarios of the stochastic Plan 2014 results from the LOSLRS. Historical results from the LOSLRS were not affected by this coding issue since simulated quarter-monthly Lake Ontario levels in the historical simulation (and in fact, actual historical levels, prior to 2017) had never rose above 75.75 m (248.52 ft). This is also likely what kept the coding error from being identified until now. With the code correction, for the stochastic simulation, the maximum simulated Lake Ontario level is changed from 76.62 m (251.38 ft) to 76.66 m (251.51 ft) (increase of 4 cm (1.6 in)), while the maximum Lake St. Louis level is reduced from 23.33 m (76.54 ft) to 22.81m (74.84 ft) (decrease of 52 cm (20.5 in)).

In 2017, the extreme water supplies exceeded historical observations and actual and simulated levels of Lake Ontario rose above 75.75 m (248.52 ft). As a result, the issue in the model code applied to this scenario and there were small differences with the simulated Lake Ontario outflows and Lake Ontario and Lake St. Louis levels between the original version and the updated code (Figure 2-19 and 2-21).

For Lake Ontario flow at QM 21, the F-limit is applied in the corrected code, while in the old code, the L-limit was applied. Since the F-limit flow is lower than the L-limit flow, the Lake Ontario levels at QM 21 are the same, but 1-2 cm (0.4 – 0.8 in) higher for the subsequent QMs. The correction ensures Lake St. Louis levels were maintained below 22.48 m (73.75 ft) as had been intended.

It should be pointed out that the Lake St. Louis level could be higher than 22.48 m (73.75 ft) if the Lake Ontario level is much higher than 75.75 m (248.52 ft) in the quarter-monthly simulation. As a “best guess” at estimating how the ILOSLRB might regulate under criterion H14 during periods of high water upstream and downstream, the plan formulators during the LOSLRS devised a method in the Plan 2014 QM code that linearly extends the actual F-limit rule (by way of deviations) and states that the Lake St. Louis level could be raised higher than 22.48 m (73.75 ft). For example, if the Lake Ontario level is 75.88 m (248.95 ft), the Lake St. Louis level could reach 22.53 m (73.92 ft). But it should be clearly understood that this is not part of the Plan 2014 rule and that even when deviating from the plan, the ILOSLRB is not obligated and may not regulate outflows in this way. It is recommended that the correction to the code be maintained and that there be further investigation regarding the implications of the quarter-monthly simulation of Lake St. Louis levels for Plan 2014 due to the potential effects this may have on stochastic plan evaluations. This may include re-running the full stochastic evaluations using the SVM to determine the implications for the calculation of the performance indicator results.

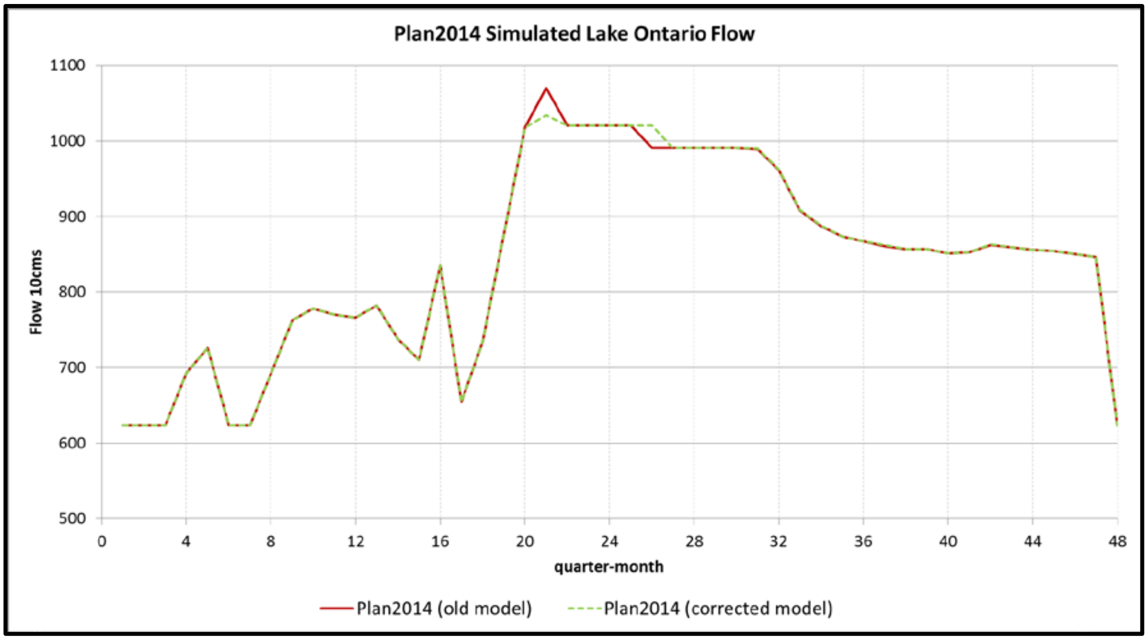

Figure 2-19: Lake Ontario simulated quarter-monthly flows in 2017 comparing results of the old and corrected F-limit calculation. With the F-limit corrected, it is applied in lieu of the L-limit and outflows are reduced slightly for a short period at the start of June in the simulation.

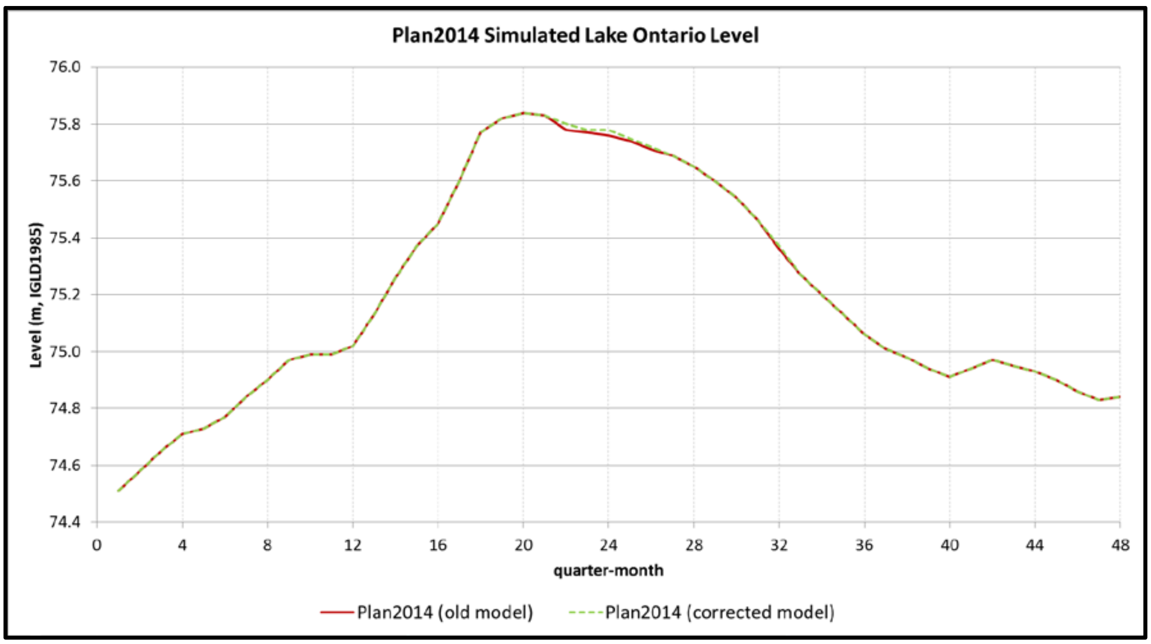

Figure 2-20: Lake Ontario simulated water levels in 2017 comparing results of the old and corrected F-limit calculation. With the F-limit corrected and outflows reduced slightly at the start of June, simulated Lake Ontario levels are slightly higher in the weeks that follow.

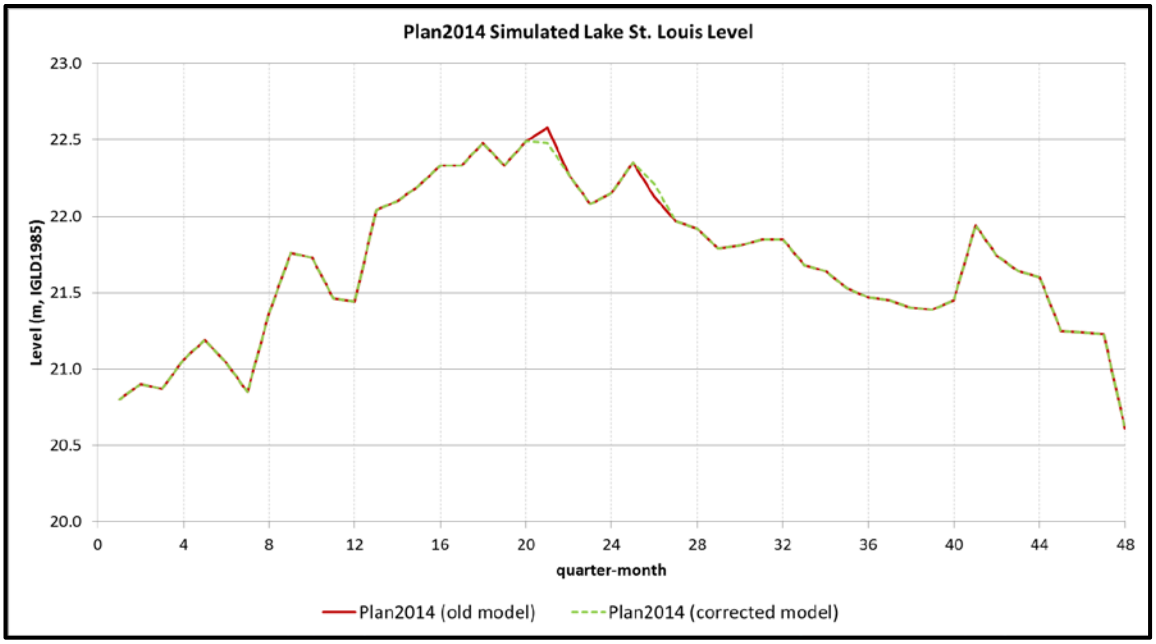

Figure 2-21: Lake St. Louis simulated water levels in 2017 comparing results of the old and corrected F-limit calculation. With the F-limit corrected and outflows reduced slightly at the start of June, simulated Lake St. Louis levels are maintained around 22.48 m (instead of rising well above).

2.4.2.3 Simulation of Lake Ontario levels

In this section, the extreme Lake Ontario water levels that occurred in 2017 are compared with the water levels simulated from the 50,000 year stochastic hydrologic time series in order to better understand the rarity of the event and how it compares to the expected probability that such events would occur as was evaluated during the development and evaluation of Plan 2014.

In May 2017, Lake Ontario's level reached 75.88 m (248.95 ft), which was above the highest water levels recorded at any time since 1918. It was 6 cm (2.4 in) above the record high of 75.82 m (248.75 ft) at the beginning of the 1st QM of June, set in 1952, and 15 cm (5.9 in) above the record high May monthly mean of 75.73 m (248.46 ft), set in May 1973.

Comparing it to the full 50,000 year stochastic simulated time-series (Figure 2-22 to 2-24), the levels in May, June, July and August of 2017 were all above those of the 1% exceedance level in the stochastic series (i.e., they occurred in less than 1 of every 100 years), indicating that 2017 conditions would rarely be expected according to the simulation results. However, actual levels were still considerably below (78 cm or 2.6 ft.) the maximum simulated level found in the stochastic series used to test the regulation plans during the LOSLRS, indicating that even more extreme scenarios than seen in 2017 were tested in the evaluation of Plan 2014.

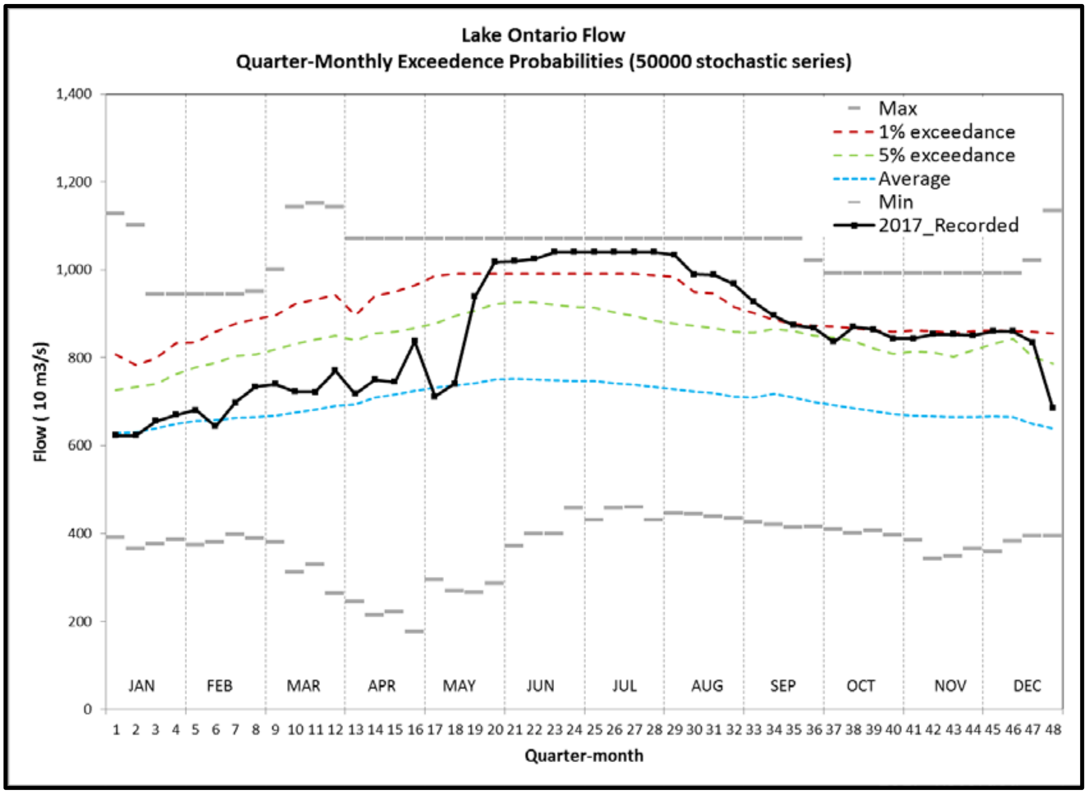

Figure 2-22: Lake Ontario outflow comparing 2017 with the full stochastic series

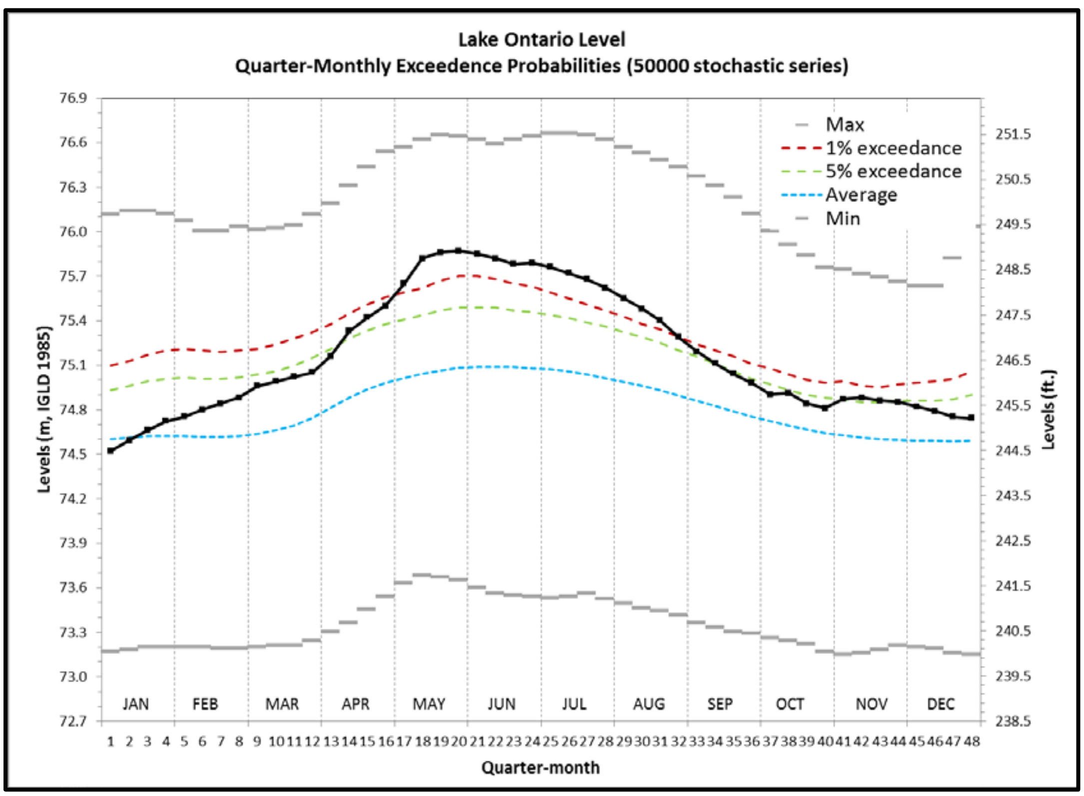

Figure 2-23: Lake Ontario water levels comparing 2017 with the full stochastic series range

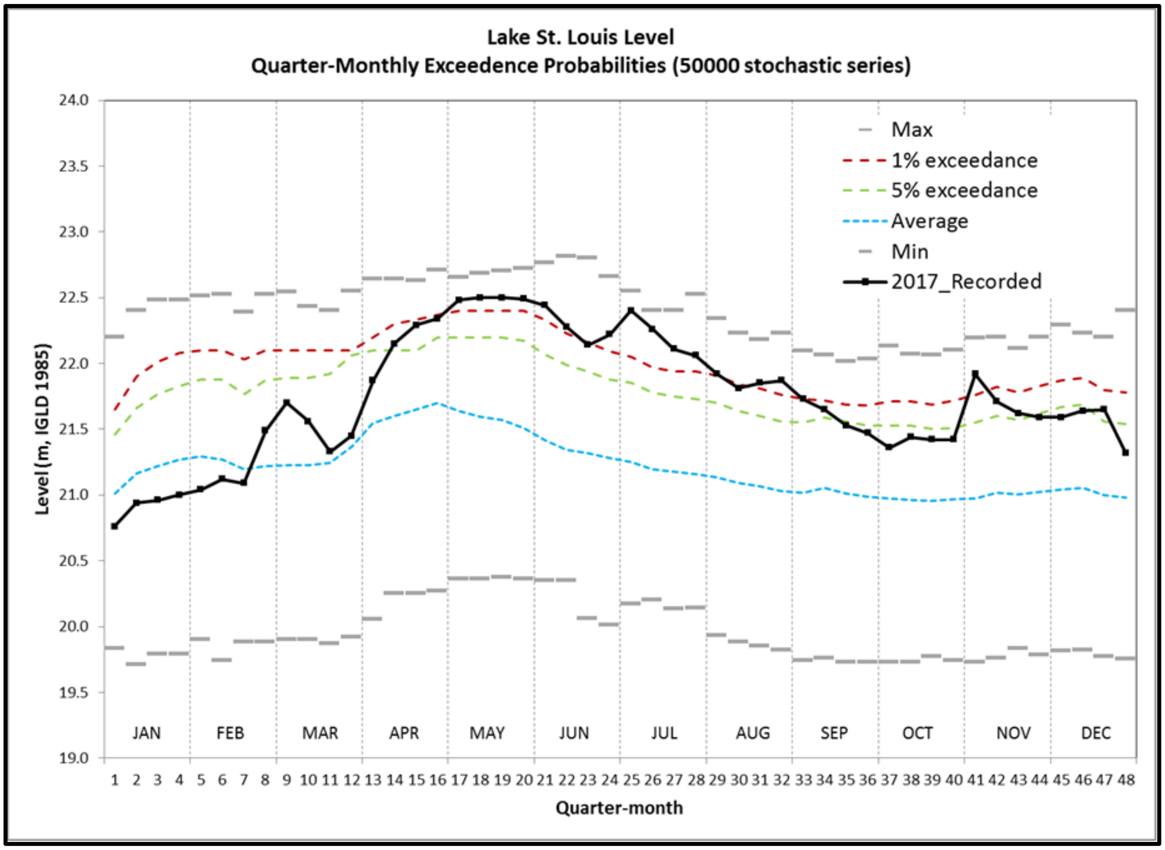

Figure 2-24: Lake St. Louis water levels comparing 2017 with the full stochastic series range

2.4.2.4 Water supplies

Similar to the previous section, in this section, the extreme Lake Ontario water supplies that occurred in 2017 are compared with the water supplies in the 50,000 year stochastic hydrologic time series.

The actual NTS in QM 17 (the first quarter of May), QM 23 (the third quarter of June) and QM 41 (the first quarter of November) of 2017 exceeded those that had occurred during the historical period of record 1900-2008 used to evaluate regulation plans, as shown in Figure 2-25.

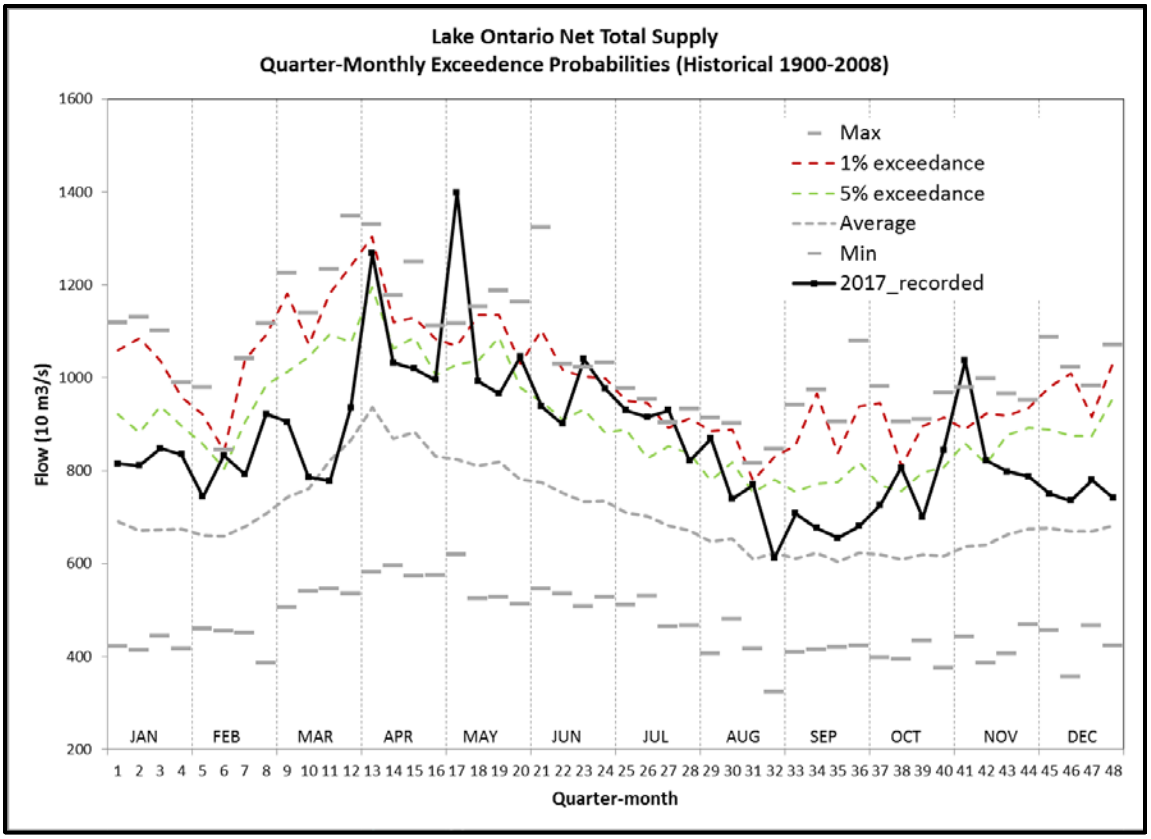

Figure 2-25: Lake Ontario net total supplies for 2017 compared with the historical water supply sequence

The NTS at QM 17 also exceeded the maximum observed in that QM in the full 50,000 year stochastic series (though this is in part by chance, as other QMs in April and May show higher supplies in the 50,000 year stochastic series) (Figure 2-26).

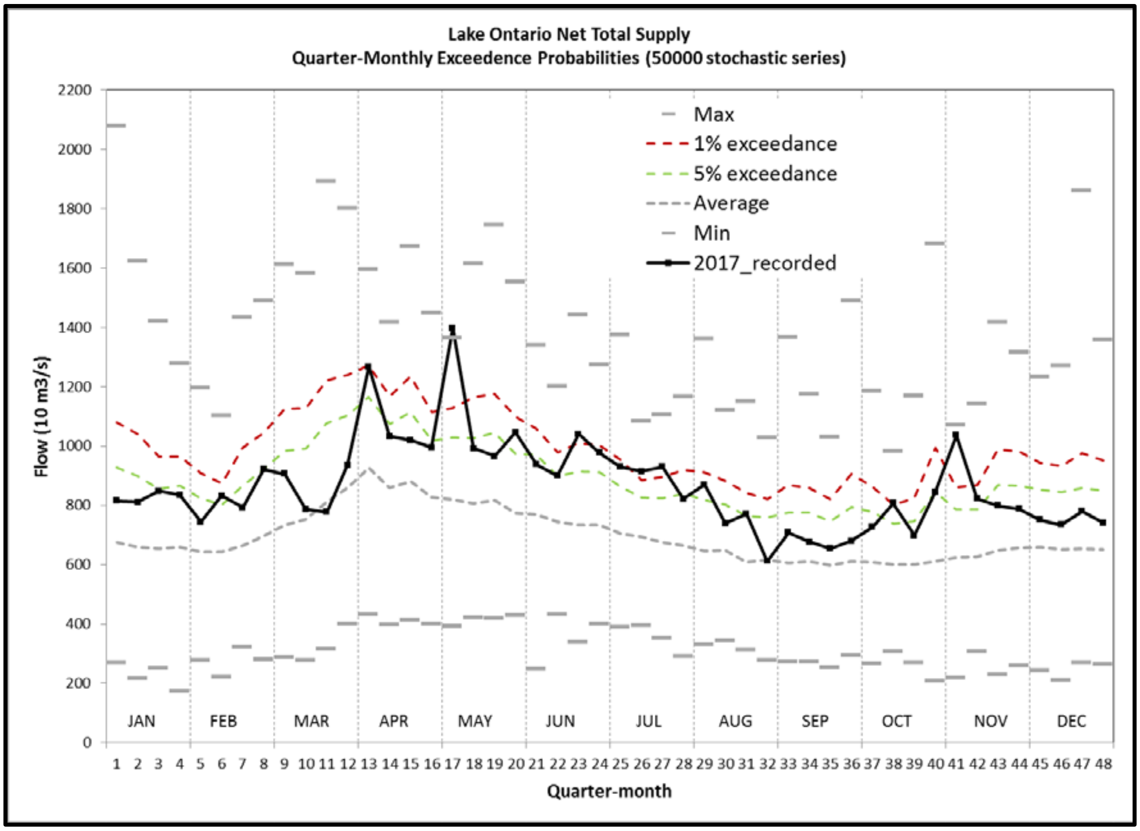

Figure 2-26: Lake Ontario net total supplies for 2017 compared with the full stochastic water supply sequence

The stochastic NTS include even wetter periods and produce peak water levels about 0.8 m (2.6 ft) higher than 2017 levels. One concern is whether the 2017 supplies support the consideration that high inflow years could be more common in the future. The stochastic supplies were developed by ensuring that key statistical parameters, including the mean and standard deviations, were similar to those of the historical record. With 50,000 years of record, this provides a wider range of possible conditions to test regulation plans, while maintaining some level of consistency with what has occurred in the past and may occur in the future. However, if climate is changing, the mean and standard deviations would not be expected to remain the same. During the LOSLRS, many climate modelers expected higher temperatures to increase evaporation and for that to lower lake levels despite increased storminess, but a review of climate models during the IUGLS showed that climate models do not consistently predict that increased evaporation will draw levels down more than increased precipitation, which is also predicted, will raise them. The GLAM Committee will consider using scenario analysis with plausible future supplies, acknowledging that estimates of statistical probabilities are difficult to defend.

This has been done in the past as well. As an example, during the LOSLRS, the Study Board also asked whether high ranking plans also performed well in extreme conditions. To test this, four extreme centuries were extracted from the stochastic sequence that represented:

S1 Driest – the century with the most severe Lake Ontario supply drought

S2 Wettest – the century with the most severe wet Lake Ontario supply period, which also had the largest range from wet to dry supplies

S3 Like Historical – a century with a similar range and average of supplies as the historical

S4 Longest Drought – a century with the longest sustained Lake Ontario drought

Figure 2-27 below shows a five-year moving average of NTS for the historical and four stochastic centuries. As shown in Figure 2-27 below, S2 (green line) has an extreme wet period towards the beginning of the 101-year sequence.

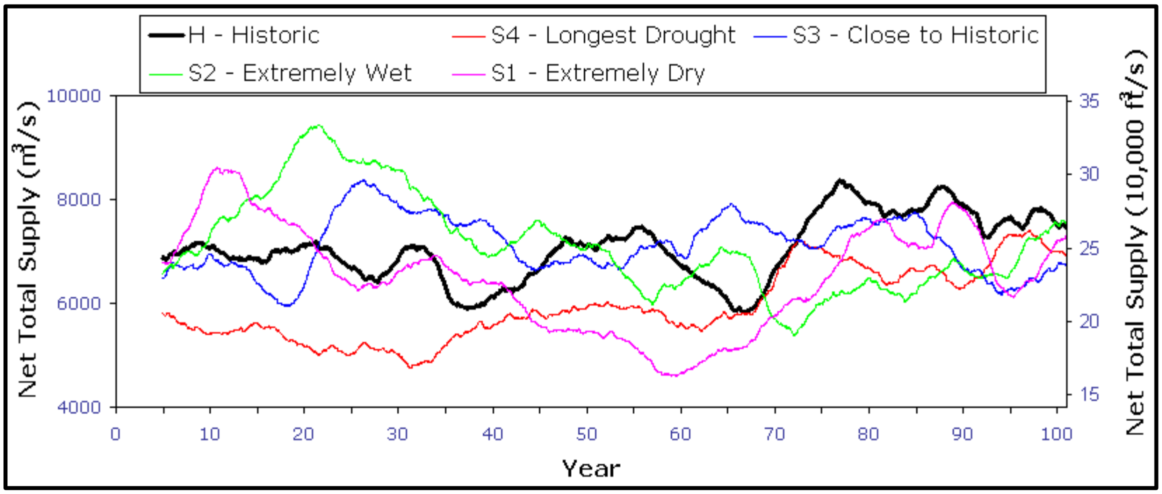

Figure 2-27 Five-year moving average of NTS) (The net amount of water entering the lake) for the four stochastic centuries

Figure 2-28 compares 2017 to the S2 extremely wet sequence extracted from the 50,000 year stochastic. This further shows that 2017, based on historical climate statistics, is a relatively rare occurrence falling in less than the 1% exceedances in the 50,000 year sequence and still exceeds the quarter monthly maximums used to test the regulation plans in the first week of May and again in the first week of November.

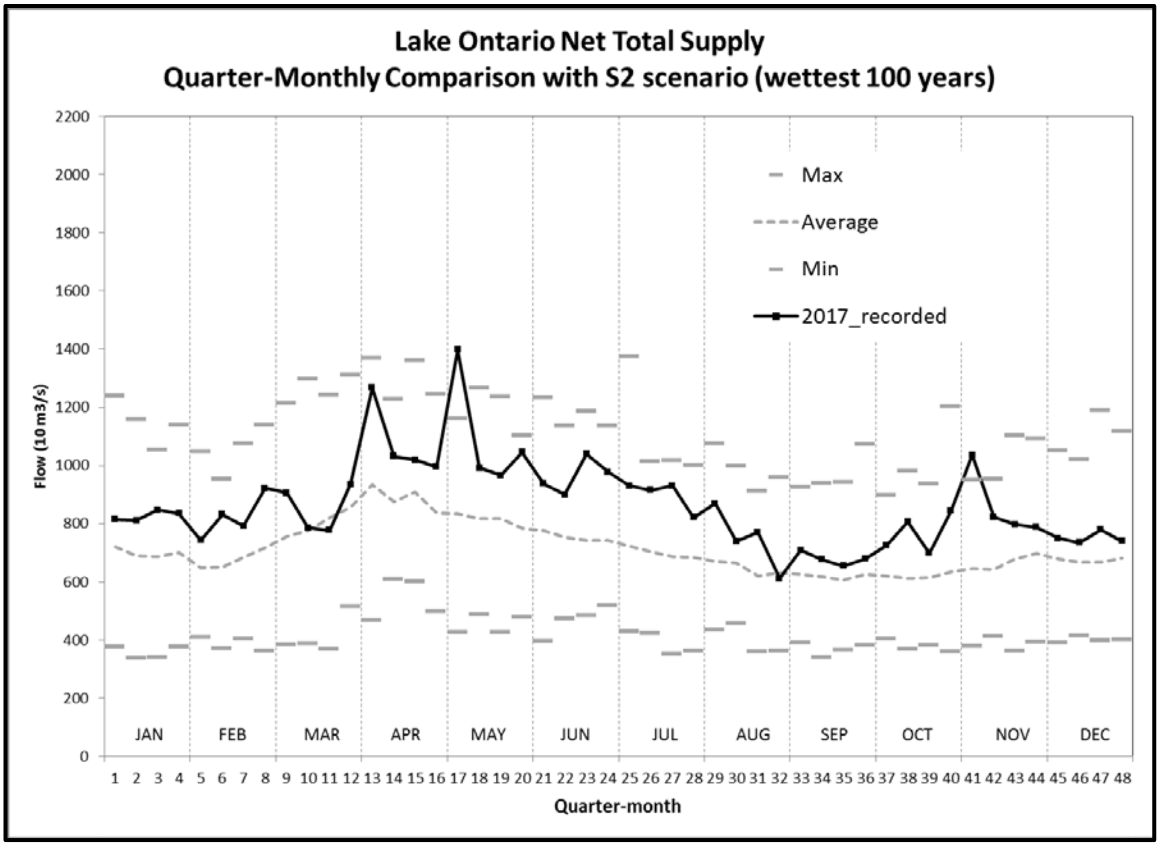

Figure 2-28: Quarter monthly comparison of Net Total Supplies in 2017 versus the S2 extremely wet century extracted from the 50,000-year stochastic supply sequence. The GLAM Committee will need to further consider this type of scenario testing of the regulation plans in their plan reviews moving forward.

2.4.2.5 Ottawa River flows

Ottawa River flows set new record highs in 2017 for April and May. Although the Ottawa River flows in 2017 did not exceed the highest flows in the full stochastic series, the flow at QM 15, 17 and 18 were above those of the 1% exceedance level in the stochastic series (Figure 2-29 and 2-30).

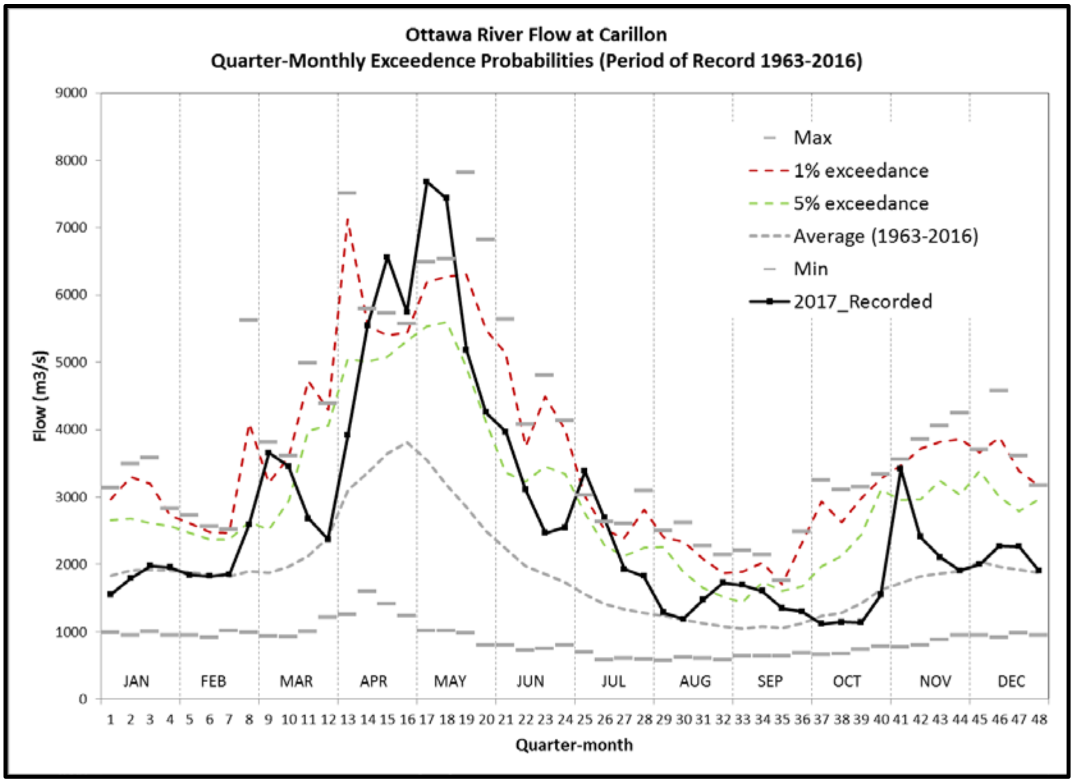

Figure 2-29: Ottawa River flow in 2017 compared with the historical period of record (1963-2016)

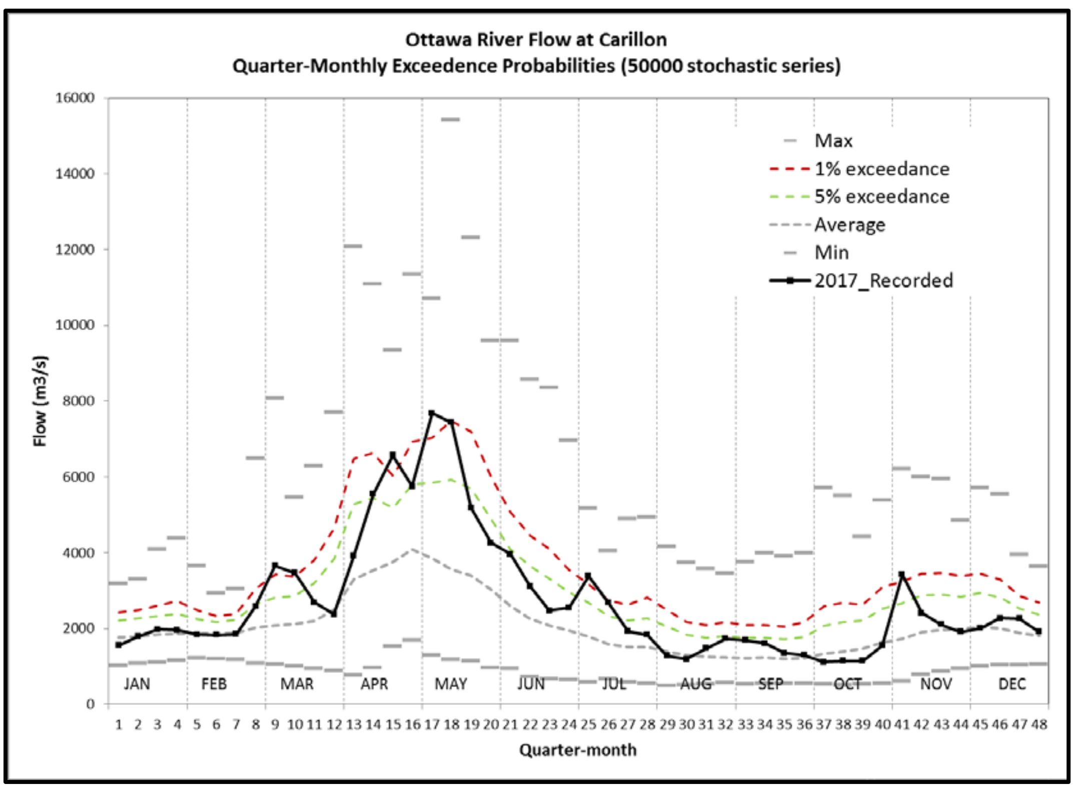

Figure 2-30: Ottawa River flow in 2017 compared with the full stochastic series

Finally, the combination of high water supplies to Lake Ontario and high Ottawa River flows well exceeded those of the historical record (Figure 2-31) during a number of QMs in 2017, including in April and May, as well as a number of QMs throughout the summer and into the fall. However, the combined quarter-monthly supplies did not exceed maximum values in the 50,000 year stochastic time series (Figure 2-32), though the combined supply at QM 17 almost reached those of the maximum at that QM. Unlike lake levels, higher temperatures and evaporation may not be as important as increased precipitation in determining tributary flows into the St. Lawrence, so the 2017 flows may indicate that the GLAM Committee should reconsider the stochastic tributary dataset, its use, or both.

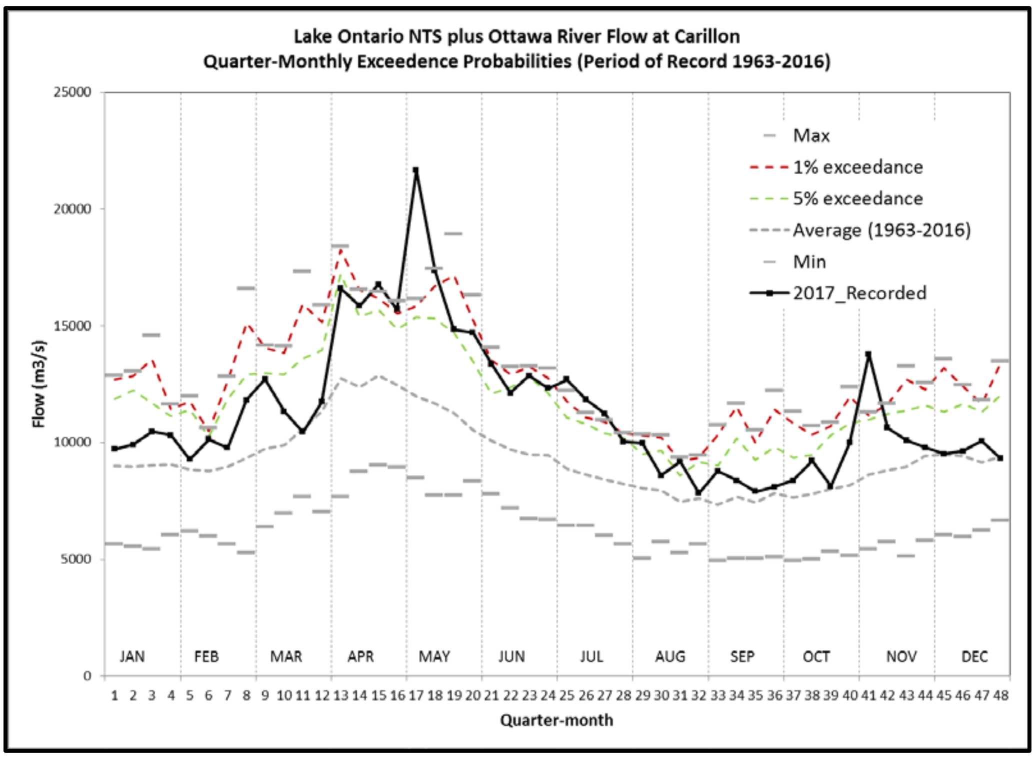

Figure 2-31: Lake Ontario NTS plus Ottawa River Flow at Carillon quarter-monthly exceedance probabilities for 2017 based on the historical period of record 1963-2016

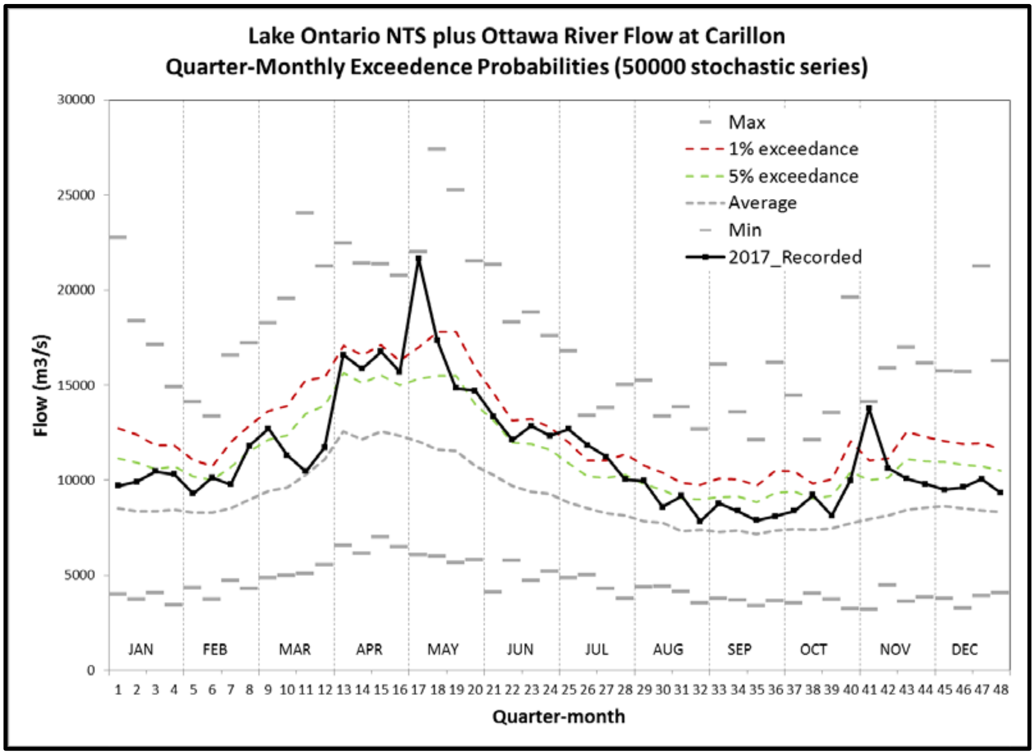

Figure 2-32: Lake Ontario NTS plus Ottawa River Flow at Carillon quarter-monthly exceedance probabilities for 2017 based on full 50,000 year stochastic time series

References

International Lake Ontario – St. Lawrence River Study Board (ILOSLRSB), 2006, *Options for Managing Lake Ontario and St. Lawrence River Water Levels and Flows – Annexes*.