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

Summary of 2017 Great Lakes Basin Conditions and Water Level Impacts to Support Ongoing Regulation Plan Evaluation

November 13, 2018

A report to the Great Lakes Boards and the International Joint Commission
Covering the period Jan. 1, 2017 to Dec. 31, 2017

Cover photo: *Top left: Erosion of dunes along Lake Superior on Duluth's Park Point (photo credit: Bob King / rking@duluthnews.com; Top right: High water conditions near Fair Haven, New York (photo credit: U.S. Army Corps of Engineers, June 2017); Bottom left: Coastal flooding and beach washout near Ontonagon, MI (Lake Superior) after 24-October-2017 storm (photo credit T. Lancioni,2017); Bottom right: Lake Saint-Pierre (Pierreville) in Nicolet-Yamaska Regional County Municipality (photo credit: Transport Canada National Aerial Surveillance Program, May 2017)*

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NOTE: *The Great Lakes-St. Lawrence River Adaptive Management (GLAM) Committee was established by the International Joint Commission and is comprised of an equal number of members from the United States and Canada. Members of the Committee serve at the pleasure of the IJC and are expected to be full participants in all activities of the Committee. As with all IJC Boards and Committees, the GLAM Committee members serve in their personal and professional capacity, not as a representative of their agencies or employers.*

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Executive Summary

This is a special report of the International Joint Commission's (IJC) Great Lakes – St. Lawrence River Adaptive Management (GLAM) Committee covering the hydroclimate, flows and water level conditions, as well as their impacts on multiple interests, experienced in 2017 throughout the Great Lakes-St Lawrence River system. The focus is on the extraordinary conditions caused by record rainfall, runoff and the resulting high water levels on Lake Ontario and the St. Lawrence River in 2017. The information gathered for the 2017 event will be used to support the primary objective of the GLAM Committee: to evaluate the regulation of outflows from Lake Superior and Lake Ontario, and the effects of this regulation on interests throughout the system. This on-going evaluation will help the IJC to better regulate water releases from Lake Ontario and Lake Superior and the information compiled for this report will be used over time to adaptively manage and improve the rules governing those releases.

The information gathered came from a variety of sources in both countries; however, much of the quantitative economic and environmental data on impacts from high water levels in 2017 required to support the validation of models used to evaluate the performance of the regulation plans is not available. The GLAM Committee will continue to refine the impact models as more data become available and the ongoing evaluation of the regulation plans will focus on the priority areas identified in this report.

Lake Ontario and St. Lawrence River – the story in 2017

During 2017, the Lake Ontario – St. Lawrence River experienced one of the most extreme hydrologic events recorded in the basin in over 100 years. The simultaneous occurrence of record-breaking rainfall over both the Lake Ontario and St. Lawrence River basins, combined with high inflows from Lake Erie and record flows out of the Ottawa River, culminated in new record high water levels on Lake Ontario and the St. Lawrence River and extensive impacts across various interests and regions. Lake Ontario's daily level peaked at 75.88 m (248.95 ft) in late May, the highest recorded on the lake since records began in 1918. Water levels downstream on the St. Lawrence River also approached (and in some cases exceeded) record highs. At Lake Saint-Louis near Montreal, levels were close to record highs throughout much of the spring and new record highs were set for the months of June, July and August.

Impacts from high water conditions

Coastal properties across Lake Ontario and the St. Lawrence River in New York, Ontario and Quebec experienced significant impacts from flooding, erosion and damage to shore protection structures. Impacts were widespread across the basin, with some areas experiencing greater impacts than others. Reports of flooded homes, roads, driveways, trails, lawns, emergency response and extensive sandbagging efforts to protect houses and properties made the news for months. Reports of shoreline erosion and loss of beaches, vegetation and land, decks and docks were common on the south and north shores of Lake Ontario. There were reports of shore protection structures failing or being damaged by wave action with the high water conditions, leaving properties even more vulnerable. States of emergency were issued across all US counties bordering Lake Ontario and the upper St. Lawrence River and for a number of Canadian municipalities, particularly on the lower St. Lawrence River during the peak flooding in May 2017.

Municipal and industrial water and wastewater uses experienced some direct impacts such as increased storm water infiltration in wastewater collection systems and treatment plants leading to sewer overflows, though these may have been due to the excessive rainfall rather than the high lake and river levels in some cases. Nonetheless, by all accounts, the millions of users of larger municipal water and wastewater systems were able to rely on necessary services in 2017.

Commercial navigation experienced impacts due to very high velocities on the St. Lawrence River. To ensure safe navigation and prevent losses that would have arisen with a closure of the Seaway, this sector applied a number of mitigation measures to adapt to the extreme conditions. Despite the associated costs and delays due to the necessary mitigation measures, it was still a very productive year for the commercial navigation sector due to robust economic demand.

The **hydropower** sector reported some adverse impacts related to the high water despite overall increases in energy production realized in 2017 through the Moses-Saunders and Beauharnois dams. These impacts included losses to future production opportunity due to increased spillage of water, increased operating costs to mobilize crews more frequently for additional gate operations and to clean additional debris and the need to defer maintenance on various pieces of equipment.

Environmental impacts from water levels are often most influenced by seasonal and multi-year cycles, and the effects of high water in 2017 are expected to be more apparent in future years. Field data from the surveillance in 2017 did show a reduction of percent cover of meadow marsh from 2015, as predicted by the wetland vegetation response model used to evaluate Lake Ontario regulation plans. The GLAM Committee is working with environmental agencies in 2018 to measure shifts in vegetative guild areas caused by 2017 water level conditions, but evident only in subsequent years, because of the lag in response from plant communities.

Recreational boating and tourism activities were negatively impacted throughout the Lake Ontario – St. Lawrence River in 2017 due to problems with flooded docks and marina facilities, shoreline access and floating and submerged debris, with some locations appearing to be more vulnerable than others. The GLAM Committee is conducting a marina and yacht club survey to better document 2017 impacts.

Reviewing Lake Ontario regulation plans evaluations: perspectives from 2017

The GLAM Committee reappraised several aspects of Lake Ontario regulation plans evaluations in light of the record high levels in 2017. The key findings are presented in Section 7, while Section 6.3 of this report provides the analysis and rationale for these major findings.

Key Findings

- The year 2017 was unusually wet across the entire Great Lakes with record-breaking precipitation and water levels on the Lake Ontario-St. Lawrence River system, but Lake Ontario and St. Lawrence River levels under Plan 2014 were not higher than they would have been had the International Lake Ontario-St. Lawrence River Board been operating under Plan 1958D and previous operating and deviation authorities **(see Finding 7.1**).
- Environmental outcomes from 2017 conditions are important in validating environmental models used in plan evaluations, but impacts are not expected to be realized immediately. Additional years of monitoring wetlands' response to 2017 high water levels is needed to complete the wetlands model validation **(see Finding 7.9)**.
- Plan 2014 generally performed as it was expected to under extreme weather and water supply conditions, in that it helped to reduce, but could not eliminate the coastal damages and flooding that occur during such extreme events, while also attempting to balance and minimize impacts on other interests. A fresh review of particular items related to how the plan performed in 2017 might provide insights that could be used to improve the way regulation plans are tested and evaluated in the future. This includes:
  - The impacts of modifying certain rules of Plan 2014, including the maximum outflow limits that balance upstream and downstream high water levels (F-limit) and that balance high water conditions with protections for navigation (L-limit) should continue to be reviewed **(see Finding 7.5)**. Plan 2014's maximum limits are defined based on decades of board experience in balancing coastal impacts above and below the dam and balancing those impacts with maintaining safe water velocities and river levels for ships in the St. Lawrence Seaway. An updated analysis of impacts supported by socio-economic and environmental performance indicators, informed by what was learned in 2017, would allow the GLAM Committee to better understand and explain the tradeoffs and balances inherent in the current limits and other Plan 2014 rules; and
  - Changes to the trigger levels that authorize the board to deviate from Plan 2014 should continue to be investigated. Even though the GLAM Committee found that no significant water level reduction could have been achieved in 2017 as a result of any realistic adjustment to the existing high trigger levels (see Section 6.3.2.2), adjustment of trigger levels was the most common suggestion offered by the public to reduce coastal damages. Ongoing analysis, building on previous studies

    by the IJC, supported by lessons learned in 2017 and future years, and covering a wide array of inflow conditions should be investigated **(see Finding 7.6)**.

- The hydroclimate conditions of 2017 raised some questions about future plan evaluations. Specifically:
    - The unprecedented ice and precipitation conditions, and the effects this had on regulated outflows and the water levels that occurred in 2017, highlighted the importance of further and more detailed analysis of such unique scenarios to complement the historical and stochastic hydrologic analyses that have been performed previously **(see Finding 7.7)**; and
    - Improvements in seasonal forecasts are still a work in progress and it may be years, even decades, before they have the skill to inform regulation plan decisions, so a first step is to test the hypothesis that forecasts could reduce flooding while protecting uses. A next step would be to assess the risk of incorrect forecasts **(see Finding 7.8)**.

The upper Great Lakes

All of the upper Great Lakes began 2017 with water levels above average and they remained above average throughout the year. Water levels from June to December 2017 on Lake Superior approached the recorded monthly maximums set in 1985. Lake Michigan-Huron had a higher than average rise from April through July, and Lake Erie came within 15 cm (5.9 in) of its 1986 monthly record high level for May.

Impacts from high water conditions

Data collected by the GLAM Committee indicates that the above average water levels in the upper Great Lakes were tolerated well by the municipal and industrial sector, hydropower and commercial navigation. Recreational boating and tourism, for the most part, also seemed to benefit from the higher water levels, with the exception of some minor, temporary impacts to marinas on Lake Erie. However, there were adverse coastal impacts on all of the upper Great Lakes in 2017, primarily occurring during periods of strong winds and waves, which accelerated coastal erosion. These impacts were a concern frequently cited by coastal interests during 2017; nevertheless, they were generally able to cope with the levels experienced. Ecosystem responses were not detected from just one year of data; however, there is currently research underway in Georgian Bay that might help validate existing ecosystem modelling assumptions.

Reviewing Lake Superior regulation plan evaluations: perspectives from 2017

Regulation of Lake Superior outflows has much less influence on the levels of the upper Great Lakes than regulation of flows through the Moses-Saunders Dam has on Lake Ontario and the St. Lawrence River, and the incremental impacts of different regulation plans tend to be smaller and harder to discern on any of the upper Great Lakes, particularly during a single year and when water levels are within historical ranges. One exception, though, is the St. Marys River, where water levels are more sensitive to changes in the outflow from Lake Superior and, as a result, regulation decisions can significantly change impacts. In recent years, including 2017, the board has deviated from Plan 2012 in order to accommodate expected temporary reductions in hydropower plant capacity on the St. Marys River and reduce the potential that these reductions may have in causing adverse impacts related to high and fluctuating flows in the St. Marys Rapids. Reduced hydropower plant capacity can occur as a result of both expected (e.g., maintenance) and unexpected (e.g., mechanical failure) turbine outages. The timing and magnitude of such occurrences varies and is not easy to predict, but when they do vary during periods of higher levels and flows, more water is typically released through the St. Marys Rapids to offset the lost hydropower capacity and maintain Lake Superior outflows. Such conditions were not considered during the development of Plan 2012.

The 2017 deviation strategy by the board allowed for reduced and more gradual flow changes in the St. Marys Rapids, which resulted in slightly less flooding on Whitefish Island and may have reduced environmental impacts, without causing problems for the commercial navigation industry. The 2017 operations suggest that the GLAM Committee should investigate modifications to Plan 2012 to produce these sorts of benefits routinely, perhaps using predictions of available turbine capacity as an input. Because the expected benefits of the board's deviations for the St. Marys River fish habitat and the reduction in high water damages to Whitefish Island are now qualitative, research to quantify the relationship between flows over the rapids and the environmental and coastal benefits could help produce more beneficial rules.

Key Finding

High outflows from Lake Superior in 2017, as in other recent years, have highlighted two potential impacts on the St. Marys River requiring further analysis. Additional regulation plan performance indicators should be developed in order to i) assess potential impacts of various release scenarios on the spawning habitats of native fish species in the river and ii) to capture flooding impacts on the river and Whitefish Island adjacent to the St. Marys Rapids (**see Finding 7.4**).

Great Lakes basin as a whole

The GLAM Committee reported two key findings on data availability and model improvements that relate to the entire Great Lakes Basin (7.2 and 7.3).

First, while performance indicators generally captured critical sectors in 2017, conditions raised questions about model details and on-going monitoring required for validation. Little quantitative economic and environmental data on impacts from the high water levels in 2017 are available, but such data are essential for the improvement of regulation plan evaluation estimates. Some impacts could not be compared with existing performance indicators, either because the data were not available to support the comparison, or because the impacts observed weren’t directly captured by the existing performance indicators. The GLAM Committee is in the process of estimating some impacts, has supported efforts by others to do so, and will report on these efforts in the future as the data become available **(see Finding 7.2**). The Committee realizes the importance of pursuing on-going monitoring needs into the future to validate models and update performance indicators as needed to support the ongoing review of the regulation plans.

Second, simulations of water levels and flows under Plan 2012 and Plan 2014, as well as alternative regulation strategies, should be continually tested and improved as appropriate to minimize inherent uncertainties **(see Finding 7.3).**

Contents

1.0 Introduction

The International Joint Commission (IJC) and their **International Lake Superior Board of Control (ILSBC)** and **International Lake Ontario-St. Lawrence River Board (ILOSLRB)** serve to manage the outflows of Lake Superior and Lake Ontario in accordance with Orders of Approval issued by the IJC under the 1909 Boundary Waters Treaty. Outflows are managed under widely varying hydrological and climatic (hydroclimate) conditions, including changes in precipitation and temperature, which are two primary drivers of water levels in the system. The intent of outflow management is to achieve expected outcomes over the long-term. Outflows are managed using regulation plans - rules that guide how much water is released through the regulatory structures under a range of possible conditions to meet the needs of various water-using interests throughout the basin. The Great Lakes-St. Lawrence River system is large, dynamic and diverse - always changing and often in ways that cannot be predicted. As a result, it is critical that outflow management and its associated benefits are tracked over time to ensure outcomes and trade-offs across a wide range of socio-economic and environmental interest categories are as expected and continue to be achieved as the system changes. This is the mandate of the Great Lakes-St. Lawrence River Adaptive Management (GLAM) Committee, a 16-member binational committee established by the IJC in January 2015. This report is the GLAM Committee's summary of basin conditions and regulation outcomes and covers the period of January 1, 2017 to December 31, 2017. The intent is to provide an overview of climate and hydrological (water supplies, water levels and flow) conditions within the Great Lakes – St. Lawrence system through the year and to highlight their importance in the plan review process. It is also to identify and document any observed, reported and anecdotal evidence of impacts, both positive and negative, of water levels and flows and compare these actual results against simulated results to test alternative scenarios and conditions.

While all the Great Lakes were well above average in 2017, Lake Ontario and the St. Lawrence River started out fairly typical for water levels. However, the cumulative effect of highly variable winter weather, unprecedented ice conditions, massive spring storms and exceptional rainfall within the Lake Ontario and St. Lawrence River basin resulted in record high water levels, flooding and, in places, intense coastal damages. Many residents and communities suffered significant financial and emotional stress along with the physical damages.

This report serves to document observed impacts and the information will be used to support an adaptive management approach towards the on-going assessment of regulation plan performance to inform future improvements.

1.1 Purpose and objectives

The GLAM Committee reports directly to the ILSBC and the ILOSLRB, as well as to the International Niagara Board of Control (INBC). The primary objectives of this GLAM Committee report to the boards are to:

- review and evaluate the performance of the Lake Superior and Lake Ontario regulation plans based on 2017 conditions and new information gathered;
- determine how long-term regulation plan evaluations may be influenced by what was learned in 2017;
- identify pieces missing to adequately evaluate plan operations and rules; and
- use information gathered and learned to prioritize next steps in the ongoing review of the regulation plan.

This report and its Annexes support the Committee's essential mission to coordinate the required monitoring, modelling and assessment related to the ongoing evaluation of regulation plans on the Great Lakes – St. Lawrence River, and report that information back to the ILSBC, ILOSLRB and the IJC. By documenting critical information regarding hydroclimate conditions, effects associated with observed water levels and flows and simulations of alternative regulation strategies, this report provides critical information to help support the adaptive management process. The overarching adaptive management strategy provides a roadmap of where the GLAM Committee is going and what is needed to conduct a full evaluation of the regulation plans within the requirements of the IJC Directive. The annual work plans are driven by this long-term strategy, but also by what is learned each year.

Ultimately, the GLAM Committee is to track performance of the regulation plans over time with the intent of providing the necessary information to the boards and the IJC for improving water management outcomes. Plan performance must be considered under a range of water level conditions. Based on the conditions of 2017, performance indicators may need to be revisited to account for the impacts of extreme conditions not currently captured by models. It may take several years of monitoring and evaluation to fully understand how well the performance indicators represent what actually happened in 2017 and subsequent years. This report, covering conditions in 2017, provides a starting point for reviewing plan performance and identifying priority areas for further investigation in support of adaptive management.

1.2 Overall GLAM Committee approach to ongoing regulation plan review

As part of the GLAM Committee's on-going process to review the regulation plans, a strategy has been established that includes efforts to perform a regular check-up of what has been happening over recent years in terms of water levels and supplies, the management of outflows and the effects these have on various interests. The idea is to generate a stream of information that will identify and assess priorities for future work. It should be noted that it is not possible for the GLAM Committee to track each and every interest on an annual, ongoing basis, nor update every tool utilized in the evaluation process at this level of frequency. It was nevertheless determined to be important for the GLAM Committee to continually stay abreast of the critical aspects required to evaluate regulation plans so that proper maintenance and updating of the data and tools can occur when necessary and can be done efficiently.

In accordance with the IJC directive (http://ijc.org/en_/GLAM/Directive), this review of the existing regulation plans will consider not only whether the plans are meeting intended objectives over time, but also how the Great Lakes – St. Lawrence River system may be changing, and how that might alter the outcomes of water regulation and the decisions made on how best to regulate outflows. Regulation plan performance is not evaluated in isolation or using absolute outcomes. Instead, performance is typically evaluated on a relative scale against some baseline condition such as an existing regulation plan or the case without regulation. The ability to evaluate a regulation plan begins with the calculation of water levels and flows resulting from hydrologic conditions and a given regulation plan. Water levels and flows are then used as the primary inputs to predictive models which use performance indicators to assess the potential positive and negative impacts to various interests including municipal and industrial water uses, hydropower, navigation, riparian land owners, recreational boating and tourism and the environment. The better the ability to understand and predict future water levels and impacts from changing water supplies, the more robust water management planning will be. In 2017, unprecedented high water levels throughout the Lake Ontario-St. Lawrence River system due to extreme water supply conditions illustrated the impacts of system-wide high water and the importance of understanding other potential future water supply conditions, and improving tools to estimate outcomes under such exceptional conditions. It also provided a unique opportunity to conduct further testing to examine the effects and limitations of outflow management under extreme conditions and to test whether outcomes could have been improved using different regulation choices.

The GLAM Committee activities build, in part, from two previous IJC studies, including the Lake Ontario-St. Lawrence River Study (LOSLRS) from 2000 to 2006 and the International Upper Great Lakes Study (IUGLS) from 2007 to 2012. In the IUGLS, the evaluation of alternative regulation plans was framed by the expected impacts of Lake Superior outflow regulation on both Lake Superior and Lakes Michigan-Huron water levels. However, due to a combination of physical and operational constraints on the system, outflow regulation can do little to reduce long-term water level fluctuations on Lakes Michigan-Huron without resulting in a disproportionate increase in extreme water level fluctuations on Lake Superior (IUGLS, 2012). Performance indicators and more broadly defined coping zones (see Section 5.1.1) were used to identify potential water level and flow impacts on the key interest groups. The IUGLS resulted in a recommended regulation plan being proposed to the IJC which was, after considerable public consultation, adopted as Plan 2012 and implemented at the beginning of 2015. The LOSLRS provided an improved understanding of the effects of Lake Ontario outflow regulation on a variety of interests, including the environment. It also helped lead to an improved understanding of the overall functioning of the Lake Ontario-St. Lawrence River system and the impacts of potential climate scenarios. Through the LOSLRS, three alternative regulation plans were recommended for the IJC's consideration, one of which eventually led to the development and implementation of the current regulation plan known as Plan 2014. This plan was implemented in January 2017 after considerable public consultation and with concurrence of governments.

The plan evaluation developed under the IUGLS and LOSLRS produced options with varying mixes of performance results relative to the baseline conditions used during those efforts. Ideally, a regulation plan would be superior in every aspect relative to the baseline condition, but typically, gains in one area are accompanied by losses in other areas. Ultimately, it is up to the IJC to decide whether those trade-offs are acceptable as they did with both Plan 2012 for Lake Superior outflows and Plan 2014 for Lake Ontario outflows. Moving forward, the GLAM Committee is responsible for acquiring and using information on regulation plan outcomes to support the boards in assessing plan performance using existing established decision criteria, such as those enumerated in the IJC's Orders of Approval. The intent is to support the boards in providing recommendations to the IJC for possible regulation plan changes and improvements.

The GLAM Committee will use information from this annual assessment to support the long-term adaptive management process by:

- Gathering evidence about the water levels and flows throughout the upper Great Lakes system and the Lake Ontario and St. Lawrence River in 2017 and the impacts, both positive and negative, that occurred because of them;
- Adding new information and gaining new insights into what is likely to occur under a range of conditions and extremes such as 2017, that had only previously been simulated;
- Where feasible, compare the actual observed impacts to the expected impacts based on existing models and tools; and
- Analyze the differences between the modeled and actual impacts, both positive and negative, to:
    - Determine where impact models should be improved;
    - Report on how the plan performed under alternative hydroclimate conditions in comparison to what would have been expected under the previous regulation plans 1977A and 1958D with Deviations; and
    - Report on data and information that would help contribute to the ongoing and overarching question "Are the regulation plans performing as expected and are there possible outcomes that can be improved?".

Monitoring and model validation are critical components of the adaptive management process to ensure that the outcomes of the modeled results are realized in real-world operations. The GLAM Committee must coordinate the monitoring and assessment efforts to validate and update models and assess changing conditions over time. This is no small task and will take considerable ongoing monitoring efforts and assessment to evaluate the regulation plans under a variety of conditions over a number of years, potentially even decades. It is important to note that monitoring and analysis based on only a single year is not enough to draw conclusions on the long-term performance of a regulation plan. However, the information gathered in 2017 is vital to support prioritization of ongoing GLAM Committee activities including improvements to existing plan evaluation tools and possible areas where the performance of the existing regulation plans for Lake Superior and Lake Ontario outflows can be improved.

1.3 Report structure and content

While the report covers the entire Great Lakes-St. Lawrence River basin, it separates results into two sections. The first covers the upper Great Lakes area associated with ILSBC and affected by Lake Superior outflows, including Lakes Superior, Michigan-Huron, Erie and the connecting channels for the St. Marys and Niagara rivers (Note, however, that there is negligible effect of regulation of Lake Superior outflows on Lake Erie and the Niagara River). The second covers the Lake Ontario-St. Lawrence River system associated with the ILOSLRB and Lake Ontario outflow management.

The report was compiled with the input from various GLAM subject matter experts working in groups. The three main groups were the hydroclimate working group, the impact assessment working group and the plan review and evaluation group. The impact assessment group consisted of six sub-groups tasked with compiling the impacts to the main six interest areas of the Great Lakes: municipal and industrial water use, hydropower, commercial navigation, coastal, ecosystem and recreational boating. These experts conducted outreach where necessary to collect information from industry and local interests to ensure that the reported information was as fulsome as possible.

The conditions in 2017 were extraordinary across the Lake Ontario-St. Lawrence River system and, as a result, the ILOSLRB produced a report in June 2018 titled "Observed Conditions and Regulated Outflows in 2017" (ILOSLRB, 2018) that outlines in detail the causes of the record high water levels in 2017 on Lake Ontario and the St. Lawrence River, as well as the regulation of outflows by the board during the event. This GLAM report provides a summary of information on the effects of 2017 water level conditions on various interest categories and how this information will be used going forward. It also initiates preliminary water level simulations of alternative outflow management strategies. Key findings are provided to support both the ILSBC and ILOSLRB as well as guide long-term GLAM Committee efforts. Given the extreme conditions within the Lake Ontario-St. Lawrence River system, an additional set of Annexes (referred to as the Annex 1-Impact Assessment and Annex 2-Plan Review) has been prepared to provide further detail on the impacts of what occurred in 2017 across various sectors and regions in the Lake Ontario-St. Lawrence River system and implications for model improvements to support ongoing evaluation of the regulation plan.

2.0 The Great Lakes – St. Lawrence River System

The Great Lakes are a series of interconnected lakes shared between Canada and the United States. From west to east they are Superior, Michigan, Huron, Erie and Ontario. They span more than 1,200 kilometers (750 miles) and collectively cover an area of more than 244,000 km^2 (94,000 m^2). The lakes cover about 1/3 of the area in the Great Lakes basin (Figure 2-1) which has a total drainage area of 766,000 km^2 (296,000 m^2) and provides drinking water and water use to more than 30 million people. These vast inland freshwater seas are the largest surface freshwater system on Earth. Only the polar ice caps contain more fresh water. They contain 84% of North America's surface fresh water and about one fifth of the world's supply of surface fresh water (USEPA, n.d.)

Water flows from Lake Superior to Lakes Huron and Michigan, southward to Lake Erie, and finally northward to Lake Ontario and down the St. Lawrence River to the Atlantic Ocean. On average, a drop of water which finds its way into Lake Superior from runoff or rainfall takes more than two centuries to travel through the Great Lakes system and along the St. Lawrence River to the ocean. The travelling time is based on retention times or how long, on average, it takes for each of the lakes to replace its water with new water (Statistics Canada, 2010). The surfaces of Lakes Superior, Huron, Michigan and Erie are all close in elevation above sea level (Figure 2-2). Lakes Michigan and Huron are hydrologically considered one lake, as their surfaces are at the same elevation above sea level and are joined through the Straits of Mackinac. Lake Ontario is significantly lower, so the four upper lakes are commonly called the "upper Great Lakes" and will be referred to as such within this report. The upper Great Lakes include the four Great Lakes mentioned (Superior, Michigan, Huron and Erie), their drainage basins, and the connecting channels of the St. Marys River, the Straits of Mackinac, the St. Clair River system (including Lake St. Clair and the Detroit River) and the upper Niagara River above the Falls (Figure 2-1).

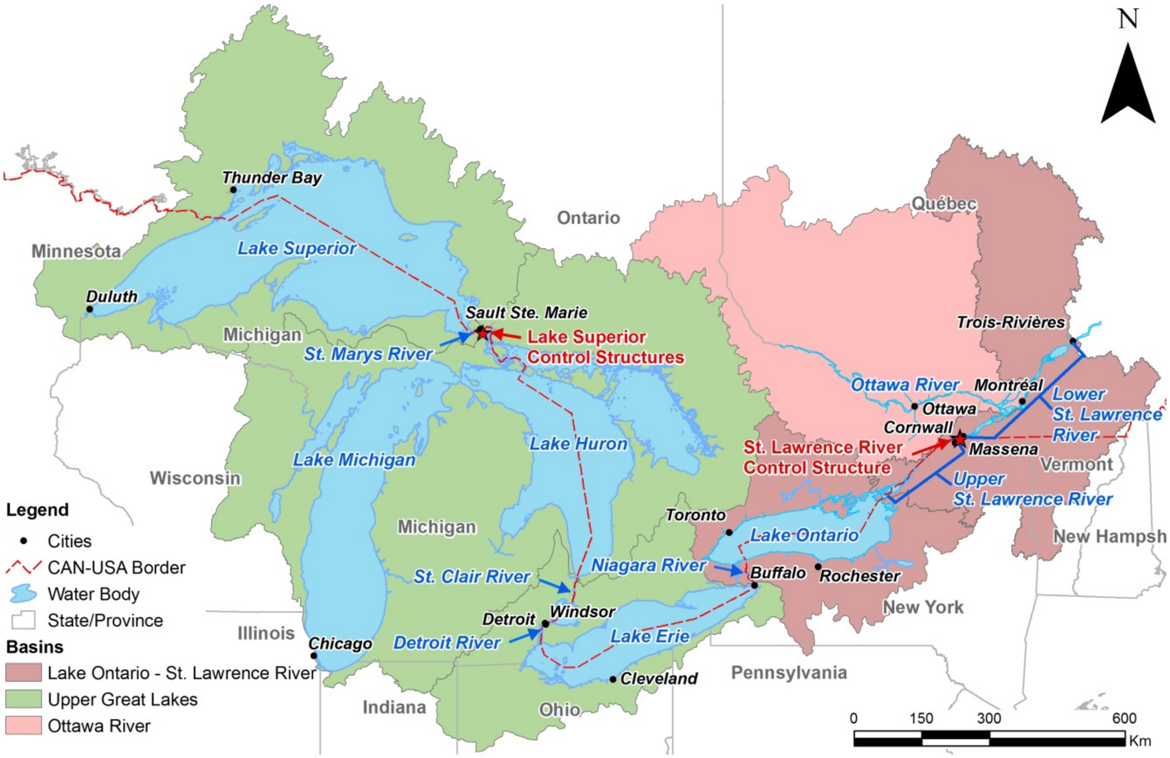


Figure 2-1: Great Lakes-St. Lawrence River system (Source: ECCC)

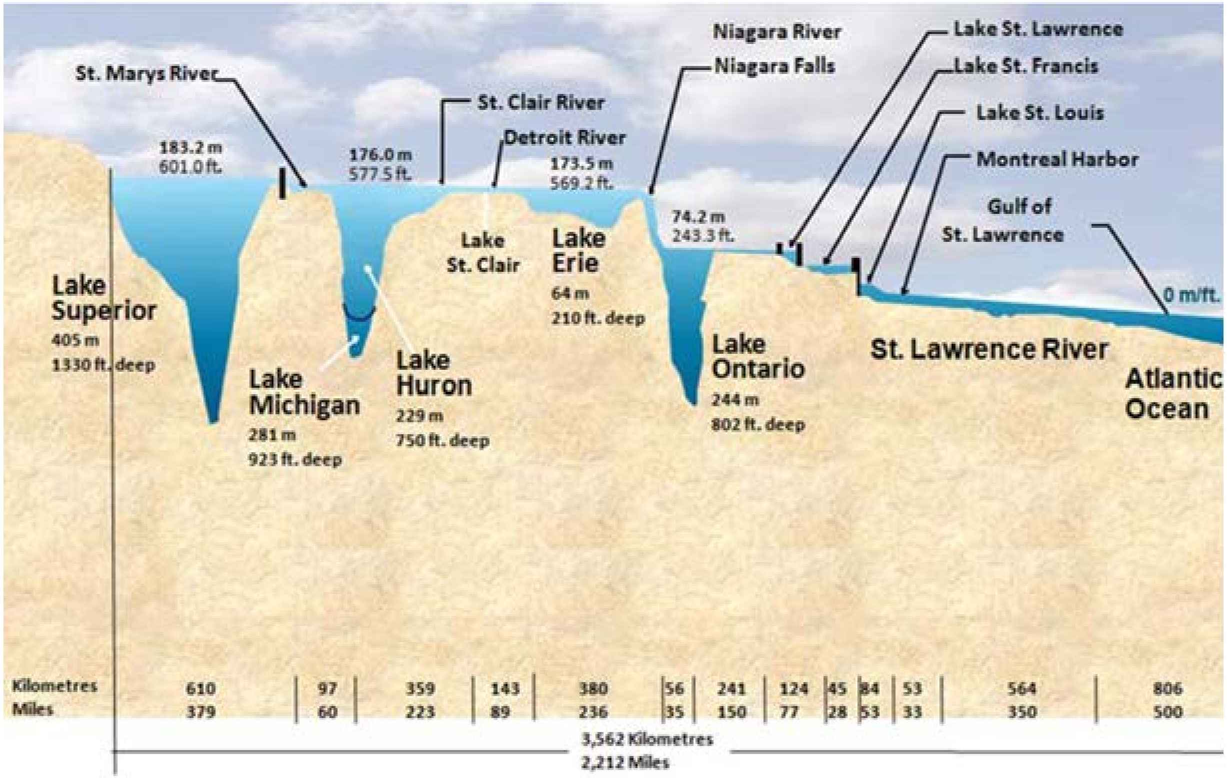


Figure 2-2: Water surface profile of the Great Lakes System (IGLD 1985) (Source: IUGLS, 2012)

The Lake Ontario – St. Lawrence River system covers the Niagara River below the Falls, the Welland Canal, Lake Ontario, the upper St. Lawrence River above the dam and the lower St. Lawrence River below the dam through to Trois-Rivières where the effects of the ocean tides become the dominant factor affecting water levels. The system also includes the vast amounts of water that enter into the St. Lawrence River from the Ottawa River basin below the dam in the Montreal area.

There are two locations on the Great Lakes-St. Lawrence River system where dams are used to manage outflows from one lake to another. The first is on the St. Marys River between the cities of Sault Ste. Marie, MI and Sault Ste. Marie, ON and controls the water flows from Lake Superior into Lake Huron. In the area known as the St. Marys Rapids, the St. Marys River falls approximately 6 meters (20 feet) in a distance of 1.2 kilometers (0.75 mile) (Figure 2-2). Since 1797, when the first lock was built to allow boats to bypass these rapids, various navigation and power structures have been erected along the river. Today, water is routed through a series of structures that stretch across the St. Marys River, including three hydropower plants, a series of navigation canals and locks, and a gated dam at the head of the rapids known as the Compensating Works. The release of water from Lake Superior has been regulated since the completion of the Compensating Works in 1921.

The second location where flow regulation occurs is on the St. Lawrence River at Cornwall, ON and Massena, NY. The St. Lawrence River hydropower project was approved by the IJC in 1952. This authorized the construction of the Moses-Saunders hydropower dam and Long Sault spillway dams at Cornwall, ON and Massena, NY, which together are used to control the outflow from Lake Ontario. The hydropower project included channel excavation to enlarge the river's flow capacity and also facilitated building the series of navigation locks and deepening of sections of the river channel for navigation as part of the St. Lawrence Seaway construction during the 1950s (Figure 2-1). The area immediately upstream of Moses-Saunders Dam is known as Lake St. Lawrence. Lake St. Lawrence was created when the Moses-Saunders Dam went into operation in 1958 and serves as a forebay for the dam. Large increases in outflows cause large and rapid drops in water levels on Lake St. Lawrence. Conversely, large reductions in outflows result in large and rapid water level rises on Lake St. Lawrence (ILOSLRB, 2018).

The IJC oversees the management of outflows from Lake Superior and Lake Ontario by the power companies that operate the dams on the St. Marys River and on the St. Lawrence River at Cornwall/Massena. The structures were built and are operated in accordance with the IJC Orders of Approval. Outflows are set according to IJC-approved regulation plans which are designed to meet the operating criteria contained in the Orders of Approval. A regulation plan is a set of rules and limits that specify how much water to release under differing water level and water supply conditions. It is important to note that ability to alter lake levels through the regulation plans is limited and is dominated by changes in water supplies, which are driven by weather.

As previously noted, the IJC established boards to regulate the outflows in accordance with the regulation plans. The ILSBC was established to regulate monthly outflows in accordance with the IJC's 1914 Order of Approval. Since 1978, the IJC has issued several supplements to the

1914 Order, with the most recent occurring in July of 2014. The current regulation plan, known as Plan 2012, was established by the 2014 Orders and was implemented in January 2015. Plan 2012 replaces the previous Plan 1977A that was in operation between 1990 and 2014. Plan 2012 does not result in significantly different levels from Plan 1977A in most cases, but provides a more robust plan, taking into account a broader possible range of water supplies, and is expected to provide fewer month-to-month changes in flow on the St. Marys River compared to the previous plan, along with a more natural flow relationship to Lake Superior levels (IUGLS, 2012).

The International St. Lawrence River Board of Control was originally established in 1952 and was renamed the ILOSLRB as part of the 2016 revision to the Orders of Approval. The board regulates weekly outflows to meet the conditions and criteria of the Order of Approval. It monitors water supplies, river ice conditions and levels of Lake Ontario and the St. Lawrence River through Trois-Rivières, which is the downstream limit of the influence of regulation on water levels. The previous regulation plan, which had been in place since 1963, was known as Plan 1958-D. Plan 2014, which became effective on January 7, 2017, prescribes a new set of rules that the board must ordinarily follow in setting the outflows from Lake Ontario through the St. Lawrence River. Plan 2014 was designed to provide more natural variation of water levels of Lake Ontario and the St. Lawrence River than would occur using the previous regulation plan, Plan 1958-D with deviation (Plan 1958-DD), which was found to have negatively impacted the environment (IJC, 2014). This effort to have more natural variability is considered critical for the restoration of ecosystem health in the system. Over the long-term, the plan is expected to continue to moderate extreme high and low levels, better maintain system-wide levels for navigation, frequently extend the recreational boating season in the upper St. Lawrence River and slightly increase hydropower production relative to Plan 1958-DD (IJC, 2014). For more information on the Lake Ontario-St. Lawrence River system and the regulation of outflows, please refer to the board report "Observed Conditions and Regulated Outflows in 2017" (ILOSLRB, 2018).

A partial structure also exists above Niagara Falls on the Niagara River, known as the Chippawa-Grass Island Pool (CGIP) Control Structure. This structure does not regulate the outflows of Lake Erie; rather, is it used for apportionment purposes for directing water to the power plants or over Niagara Falls in order to meet the objectives of an institutional agreement between Canada and the United States known as the Niagara River Treaty of 1950. The purpose of the Treaty is to ensure water required for domestic, sanitary and navigation purposes is available, while preserving the scenic beauty of Niagara Falls and allowing for the diversion of water for hydropower purposes. Operation of this structure is the responsibility of the power entities, Ontario Power Generation (OPG) and New York Power Authority (NYPA), supervised by the IJC's INBC (http://www.ijc.org/en_/inbc).

3.0 The Regulation Plans

This section provides additional detail regarding the regulation plans for Lake Superior and Lake Ontario outflows. For a more detailed description of Plan 2014 and how it functions, please refer to the ILOSLRB report "Observed Conditions and Regulated Outflows in 2017" (ILOSLRB, 2018). It should be noted that, for both plans, their ability to alter lake levels in response to short-term variances of regulated outflows is very limited as actual water levels in Lakes Superior and Ontario are dominated by water supplies. The challenge is to balance the objectives of the regulation plans given the limitations of existing control structures, the natural hydrologic systems and the unpredictability of weather events.

3.1 Plan 2012 for Lake Superior outflows

Plan 2012 was the recommended plan identified during the IUGLS. Plan 2012 is a set of rules for how much flow to let out of Lake Superior into Lake Michigan-Huron through the St. Marys River under varying conditions. The basic objectives and limits for the regulation plan are set out in the IJC's 1914 Order of Approval which acknowledges the needs of various interest groups on Lake Superior and the St. Marys River including navigation, hydropower and riparian owners. Since 1978, the IJC has issued several additions to the original Order and in July 2014, the IJC issued a new Supplementary Order of Approval that enabled the ILSBC to adopt Regulation Plan 2012 as the means for regulating Lake Superior outflows henceforth.

Plan 2012 was developed to try to maintain much of the natural variability in lake levels that existed using Plan 1977A, while recognizing the capacities of the current structures at Sault Ste. Marie, winter flow restrictions to reduce ice jams, and a broader range of possible water supplies in the lakes. It also retains the balancing principle of water levels on Lake Superior and Lake Michigan-Huron of the previous plan (1977A). Plan 2012 begins with more natural flows, meaning that when Lake Superior water supplies trend above normal, lake releases are increased and as supplies trend below normal, lake releases are decreased. The Plan then applies a balancing principle which adjusts the outflows depending on the difference of each lake's level from seasonal target levels based on average conditions. The Plan sets limits to respect physical and operational limits. For example, the November maximum is 3260 m^3/s (115,120 ft^3/s), except if Lake Superior is greater than 183.9 m (603.3 ft). Plan 2012 also determines the flow to be released through the rapids and multi-use allocation.

The overall objectives of Plan 2012 are to improve existing benefits to stakeholders throughout the upper Great Lakes system relative to Plan 1977A, balance Lake Superior and Lake Michigan-Huron water levels relative to their long-term average conditions and follow more natural month-to-month outflow patterns in the St. Marys River. Additionally, Plan 2012 is designed to avoid infrequent but serious adverse effects on spawning habitat of lake sturgeon and provide smaller month-to-month flow changes in the St. Marys River.

In most cases, it is anticipated that outflows will be set as is prescribed by Plan 2012. However, as authorized by 2014 Order of Approval, the board may deviate from the plan in certain circumstances or may ask the IJC to approve other deviations from the plan that the board believes are beneficial.

3.2 Plan 2014 for Lake Ontario outflows

The objective of Plan 2014 release rules, as described in the IJC's report to governments on Plan 2014 (IJC, 2014) is to return the Lake Ontario-St. Lawrence River system to a more natural hydrological regime, while limiting impacts to other interests. The 1956 Orders' criteria under Plan 1958-D did not address contemporary considerations such as environmental and recreational boating needs and were designed using historically observed water supplies up to 1954, which consisted of a shorter period of record and did not include several more extreme supply sequences occurring since its development (ILOSLRB, 2018). Regulation of outflows with Plan 1958-D with deviations, as practiced beginning in the 1960s, was found by the Lake Ontario-St. Lawrence River Study Board to have harmed the environment (LOSLRS, 2006). After 14 years of scientific study, extensive public engagement and consideration of many alternative plans, the Commission concluded that Plan 2014 offered the best opportunity to reverse some of the harm to the environment while balancing upstream and downstream uses and minimizing possible increased damage to shoreline protection structures (IJC, 2014). The IJC issued an updated Supplementary Order of Approval on December 8, 2016 after obtaining the concurrence of the governments of Canada and the United States. This Supplementary Order replaces the 1952 and 1956 Orders and includes revised and additional regulation criteria based on the Commission's findings and the performance of Plan 2014 release rules with 1900 to 2008 hydrologic conditions.

Lake releases for Plan 2014 begin with a sliding rule curve based on the pre-project stage-discharge relationship such that as Lake Ontario levels or water supplies increase, outflows increase and as water levels or supplies decrease, outflows decrease. The Plan then uses a series of flow "limits" to address specific conditions. Table 3-1 provides a very brief summary of the various limits that apply. For more detail, please refer to the "Observed Conditions and Regulated Outflows in 2017" report (ILOSLRB, 2018).

Table 3-1: Plan 2014 flow limits (Source: IJC, 2014)

Limit	Description
"F" Limit	multi-tier rule that defines the maximum flow to limit flooding on Lake Saint-Louis and near Montreal in consideration of the level of Lake Ontario
"I" Limit	also referred to as the Ice limit; limits the maximum flows for ice formation and stability during ice cover formation
"J" Limit	defines the maximum change in flow from one week to the next unless another limit takes precedence
"L" Limit	defines the maximum outflow that can be released from Lake Ontario while still maintaining adequate levels and safe velocities for navigation in the international section of the St. Lawrence River
"M" Limit	defines the minimum limit flows to balance low levels of Lake Ontario and Lake Saint-Louis primarily for Seaway navigation interests

In addition to the plan limits, criterion H14 of the 2016 Orders of Approval authorizes the board to deviate from the rules of Plan 2014 when Lake Ontario water levels are extremely high or low. The IJC's December 2016 Directive on Operational Adjustments, Deviations and Extreme Conditions, defines extreme high and low levels of Lake Ontario to be used as thresholds to authorize major deviations from the Plan. The ILOSLRB is required to follow the regulation plan when levels are within these triggers. However, Plan 2014 allows for minor deviations to respond to short-term needs on the river (e.g. short-term hydropower maintenance, assistance to commercial vessels due to unanticipated low levels, assistance for boat haul-out) that are limited to +/- 2 cm (0.79 in) impact on Lake Ontario. The directive also allows for operational adjustments when actual within-week conditions differ significantly from the forecasted conditions used to calculate the regulation plan flow. For more information on deviations and operational adjustments, please refer to the IJC's December 2016 Directive on Operational Adjustments, Deviations and Extreme Conditions.

4.0 Summary of 2017 Hydroclimate Conditions and Observed Water Levels and Flows

Water levels and outflow regulation plans are influenced most predominantly by the hydroclimate conditions of the basin and whether it is wet or dry, cold or warm over any given year and over longer-term patterns. The conditions observed across the Great Lakes – St.

Lawrence River basin in 2017 included higher than average seasonal temperature and precipitation. The majority of the region experienced a wet spring with persistent heavy rain and snowfall, causing a pronounced rise in Great Lakes levels across the system. These conditions were most severe in the Lake Ontario-St. Lawrence River basin, which experienced a relatively wet winter followed by record rainfall in the spring, resulting in record water levels and flows.

The ILOSLRB's May 2018 report ("Observed Conditions and Regulated Outflows in 2017") makes clear that the weather and water supply conditions in 2017 dictated the outflows that were released during 2017 and limited the board's ability to regulate water levels upstream and downstream of the Moses-Saunders dam. The board report provides a detailed explanation of why Lake Ontario reached record high levels in 2017, including a comprehensive description of the 2017 hydroclimate conditions and their role in causing the record levels that occurred.

Hydroclimate is defined as the study of the influence of climate upon the waters of the land including the energy and moisture exchanges between the atmosphere and the earth's surface. This report also addresses the 2017 hydroclimate conditions, but not only has a different scope (i.e., it covers all of the Great Lakes) but a somewhat different purpose than the board report. While both reports consider the interaction of regulation rules and weather on water levels, in this report the focus of the GLAM Committee is to consider how 2017 conditions might inform their IJC directive to assess whether future water supplies will be different from those used to test the current management of levels and flows. By examining what occurred and searching for clues about how to improve future outcomes under similarly severe conditions, the GLAM Committee asks: "What can be learned from the 2017 hydroclimate conditions that could influence future plan evaluations and help improve the Lake Superior and Lake Ontario regulation plans?"

4.1 Overview of the 2017 Great Lakes hydroclimate

This section provides a general overview of weather, water supply, water levels and flow conditions in 2017 across the entire Great Lakes-St. Lawrence River system, in order to provide the context for all subsequent sections of this report. It includes a general overview for the entire basin and then an assessment of the hydroclimate for the upper Great Lakes and for the Lake Ontario-St. Lawrence River portion of the system.

4.1.1 Overview for the Great Lakes

It was a wet year overall for the Great Lakes (Figure 4-1) with generally near to above average precipitation across the basin, and most of the areas north of the lakes seeing the 2017 precipitation totals 10 to 50% greater than average. Most of the Great Lakes region experienced a wet spring with persistent heavy rain and snowfall; in particular, portions of the province of Ontario experienced more than twice the average amount of precipitation in April and May. Fall was wet in the central Great Lakes, with the state of Michigan experiencing record October rainfall.

The temperature was at least 0.5ºC above the annual average for most of the Great Lakes region, with some areas over 1.0ºC above average (Figure 4-2). There were also a few areas around the west end of Lake Superior and the south end of Lake Michigan that were closer to average overall for 2017. As a result of these higher than average temperatures, especially during the cold season months (almost all of the basin experienced near-record to record-breaking high temperatures in January and February), snow accumulations and snow cover duration were less than normal. Fall warm spells in September and October set temperature records in some eastern areas of the region.

Winter and fall warm spells led to record warm temperatures in parts of the basin and the Great Lakes maximum ice cover for the year was 35% below the long-term average, at just 19.4% areal coverage (National Oceanic and Atmospheric Administration (NOAA) and Environment and Climate Change Canada (ECCC), 2018) (NOAA: GLERL, n.d.). More information on climate trends and impacts for the entire Great Lakes Basin can be found in the Annual Climate Trends and Impacts Summary for the Great Lakes Basin produced by NOAA and ECCC.

The primary driver of water levels across the Great Lakes-St. Lawrence River basin is the amount of water coming into the system, referred to as *water supplies*. Total water supplies to the lakes, termed Net Total Supplies (NTS), is the combination of the water that is entering from the upstream lake (inflow) as well as water entering from the lake's basin itself, known as Net Basin Supplies (NBS). NBS is the total of the precipitation that falls directly on the lake surface and the runoff that enters the lake through tributaries and the surrounding drainage basin, minus the evaporation that comes off the lake. The NBS is computed in two different ways: the "component" method uses measurements and modelled estimates of the three main components of NBS, i.e., precipitation, runoff and evaporation; whereas the "residual" method calculates the NBS as the residual water necessary to account for the change in storage (i.e., monthly lake level change) and the measured amount of inflow and outflow from the lake via their connecting channels.

Figure 4-3 compares 2017 to average component NBS while Figure 4-4 shows 2016, 2017 and average monthly residual NBS. Runoff into the Great Lakes was significantly higher than

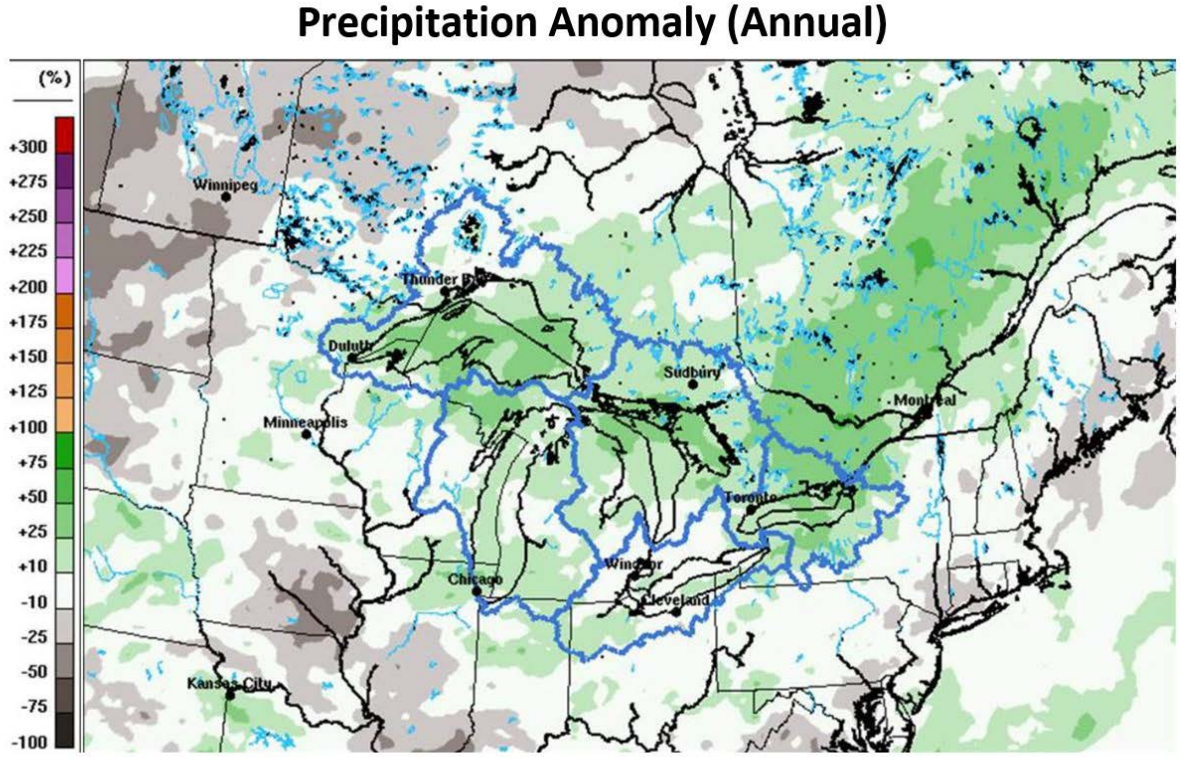


Figure 4-1: Map displaying annual anomalies for total precipitation accumulation in the Great Lakes region. Anomalies for precipitation are % departure from the 2002-2016 mean. Data for precipitation data is a merged dataset containing ECCC model and Numerical Weather Prediction (NWP) model data. Figure created by ECCC.

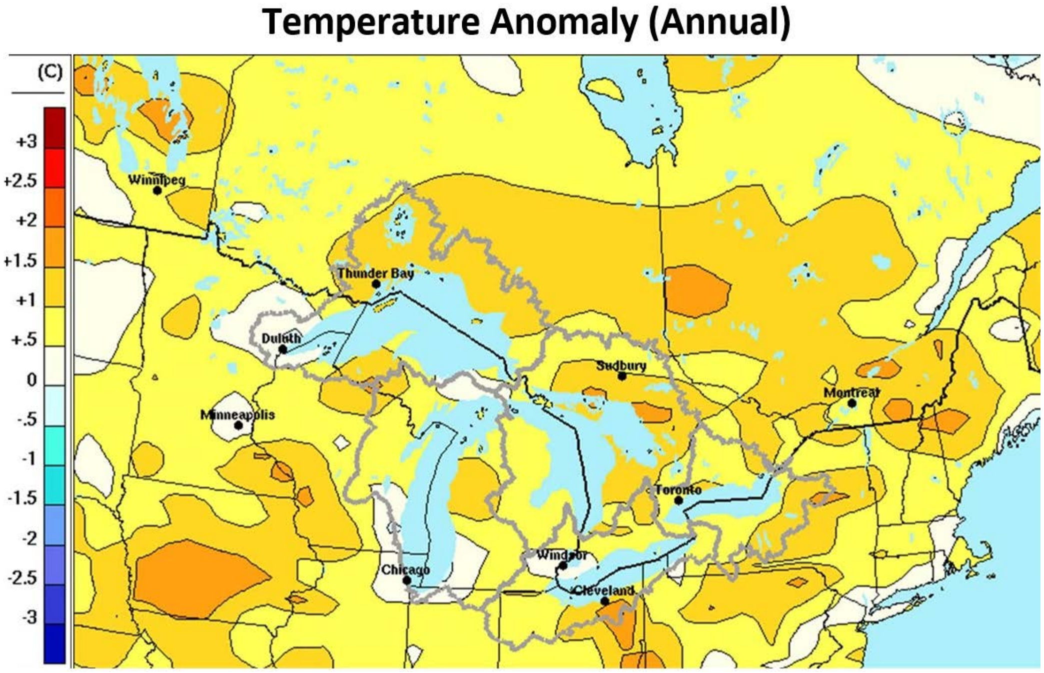


Figure 4-2: Map displaying annual anomalies for temperature in the Great Lakes region. Anomalies for temperature are departures from the 1981-2010 mean. Data for temperature are from ECCC model output. Figure created by ECCC.

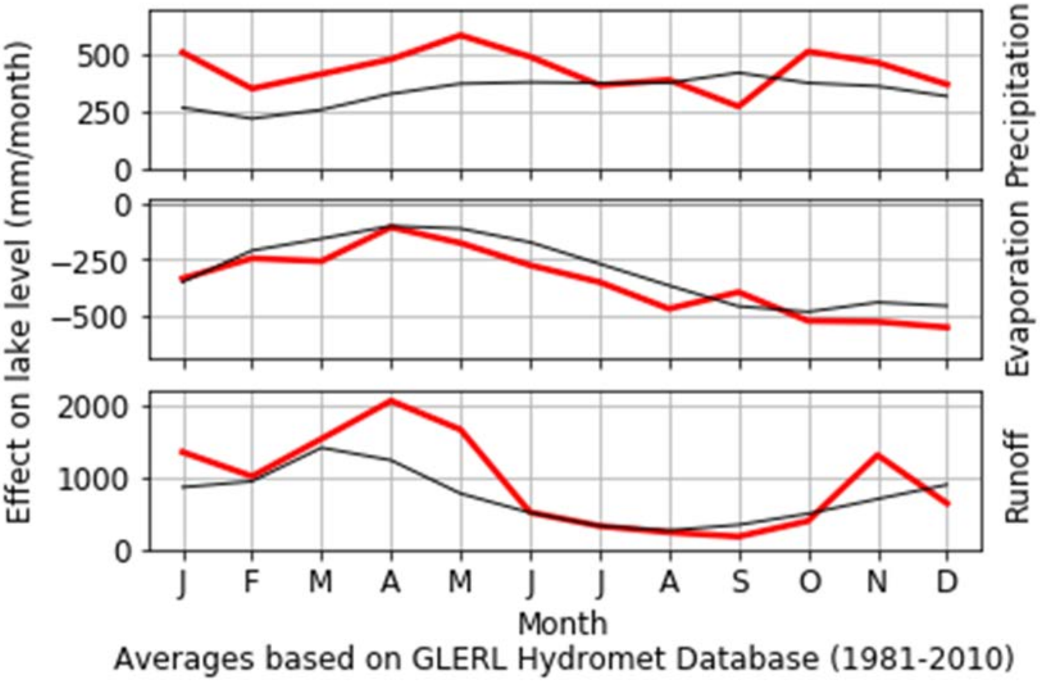


Figure 4-3: Great Lakes Basin NBS components from the GLERL Hydromet Database, red - 2017, black - 1981-2010 average. (Source: Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 2017)

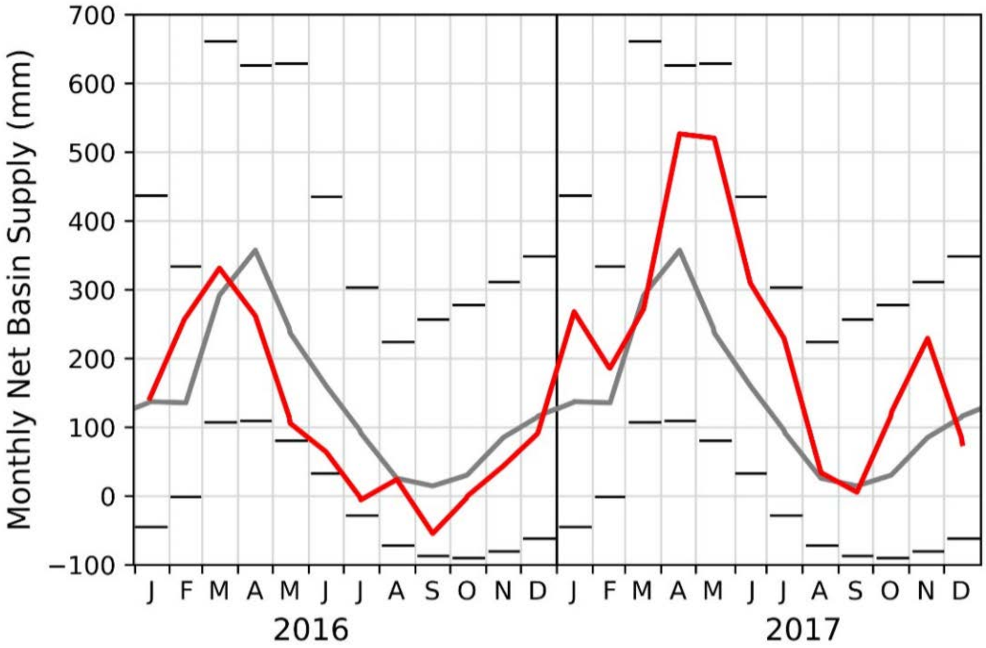


Figure 4-4: Great Lakes Basin residual NBS– (red) compared to the 1981-2010 average (black) for 2016 and 2017. (Source: Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 2017)

average in the first half of 2017, and monthly precipitation was average or higher over the Great Lakes in 2017, except for the month of September. Evaporation over the lakes was fairly close to average throughout the year, and runoff into the lakes was much higher than average in March through June and again in November. The overall NBS for the entire Great Lakes basin was wet for the entire year of 2017 and was dominated by what occurred over the Lake Ontario basin in 2017.

Water levels on the upper Great Lakes, including Lake Superior, Lakes Michigan-Huron and Lake Erie all began 2017 well above long-term average levels, while Lake Ontario started the year very near its long-term monthly average. With the above average precipitation in the basin, water levels in the five Great Lakes remained above average throughout the year, continuing a similar trend during the past several years for the upper Great Lakes. Water levels are based on lakewide averages and are discussed in 4.1.2 and 4.1.3 below. Note that lake-wide average water levels are computed from a network of stations located around the lakes. Water levels at individual locations can vary depending on weather conditions, including winds, barometric pressure, storm surge and wave heights

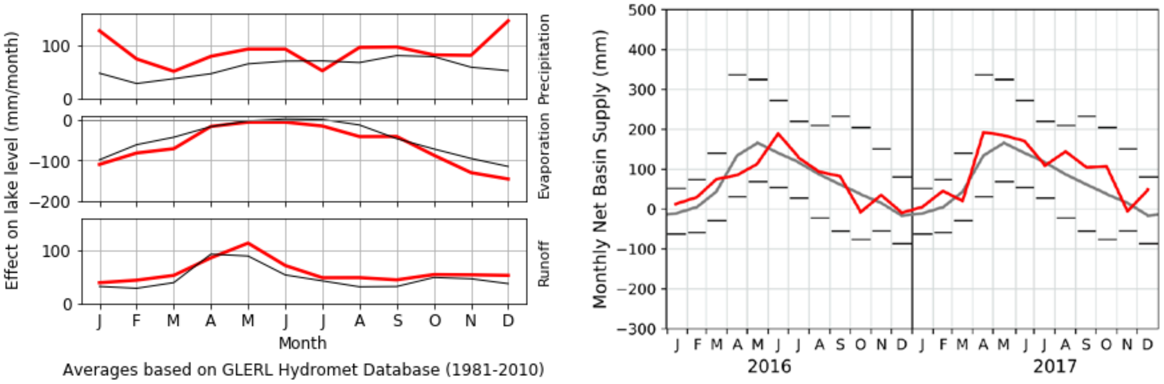
4.1.2 Hydroclimate highlights for the Upper Great Lakes

As discussed in the previous section, it was generally wet over the Great Lakes basin in 2017, including the upper Great Lakes (Superior, Michigan-Huron and Erie).

It was generally wet on Lake Superior throughout the year, with all months except for July recording above average precipitation. Of particular note was that the precipitation on Lake Superior was almost twice the average during both January and December of 2017. The evaporation over the lake was generally higher than average both at the beginning and end of the year, while runoff was either close to the average or slightly above for the entire year. Not surprisingly, given the generally above-average precipitation and runoff, the residual NBS was above average for most of the year, with only March and November coming in below average (Figure 4-5).

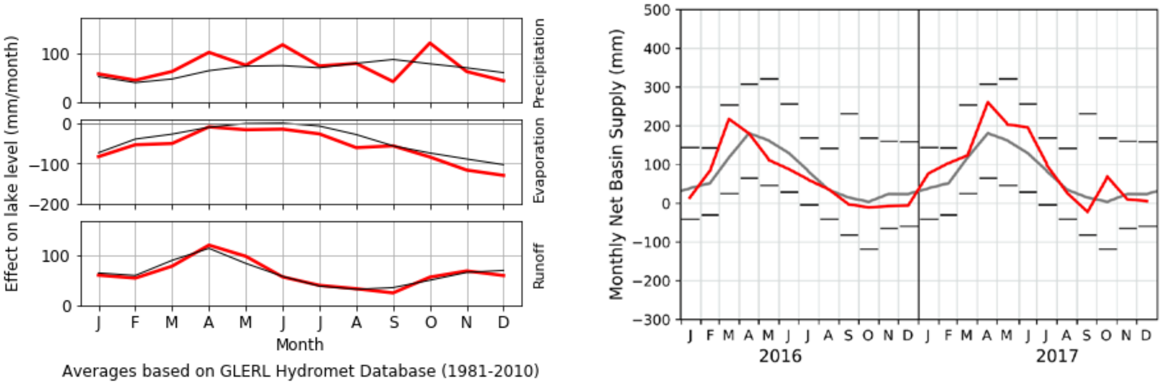
Precipitation over Lake Michigan/Huron was close to its average for most months of the year, with the exceptions of April, June and October, which were well above average, and September, which was the only month that recorded well below average precipitation (Figure 4-6). September was actually the fifth driest on record for that month, but this was followed by its wettest October on record. The lake evaporation was generally a bit higher than average while runoff was very close to average the entire year. The residual NBS followed the precipitation with most of the year being above average and only falling slightly below average during the last few months of the year.

On Lake Erie, the precipitation was generally close to average with only May being well above average and September well below (Figure 4-7). A storm system on November 5 produced 72 mm (2.85 in) of precipitation in Erie, PA, a record for daily November precipitation for the location (NOAA and ECCC (2017). The lake evaporation was close to average most of the year



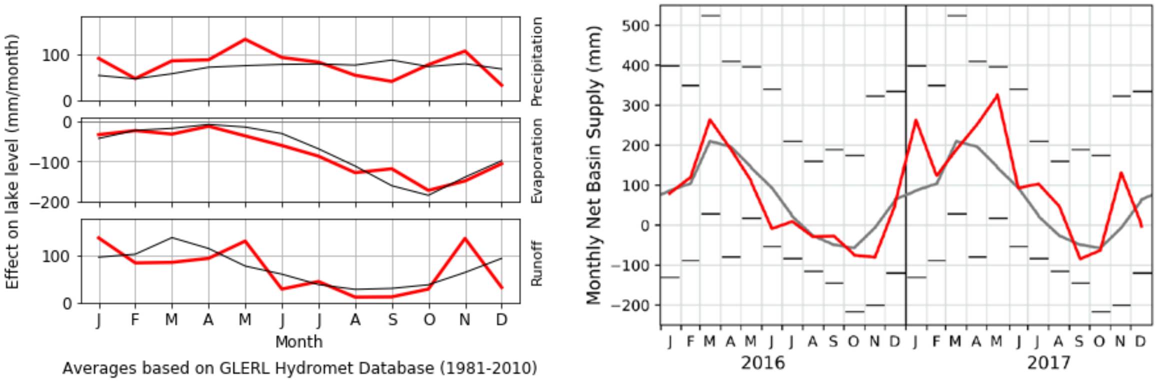
Averages based on GLERL Hydromet Database (1981-2010)

Figure 4-5: Lake Superior 2017 NBS components (left) and residual NBS for 2016-2017 (right)



Averages based on GLERL Hydromet Database (1981-2010)

Figure 4-6: Lake Michigan-Huron 2017 NBS components (left) and residual NBS for 2016-2017 (right)



Averages based on GLERL Hydromet Database (1981-2010)

Figure 4-7: Lake Erie 2017 NBS components (left) and residual NBS for 2016-2017 (right)

NOTE: NBS is the total of the precipitation that falls directly on the lake surface and the runoff that enters the lake through tributaries and the surrounding drainage basin, minus the evaporation that comes off the lake. The NBS is computed in two different ways: the "component" method uses measurements and modelled estimates of the three main components of NBS, i.e., precipitation, runoff and evaporation; whereas the "residual" method calculates the NBS as the residual water necessary to account for the change in storage (i.e., monthly lake level change) and the measured amount of inflow and outflow from the lake via their connecting channels.

except for a below average month in September. The runoff was near or slightly below average in most months, but May and November were well above average, while December was well below. The residual NBS showed significantly above average values during the spring, peaking in May, and from there it decreased, becoming below average in September before recovering in November.

As a result of their levels at the start of the year and overall wet conditions throughout, all the upper Great Lakes experienced well above average water levels in 2017 (Figure 4-8).

After starting 2017 above average, Lake Superior saw a greater than average rise in water levels from April through October, leading to water levels near the recorded monthly maximums set in 1985 from June to December. In October, Lake Superior's monthly level of 183.81 m (603.05 ft) was just 10 cm (3.9 in) below the highest water level recorded in any month on record in October 1985. By the end of December, the water levels had gone down, resulting in an end of year water level that was 18 cm (7.1 in) higher than when it began 2017.

Water levels started and remained well above average on Lake Michigan-Huron throughout the year. Due primarily to high precipitation in April and June, the lake recorded a higher than average rise from April through July. After the summer, the lake level experienced close to the typical seasonal decline and ended the year 26 cm (10.2 in) higher than it began the year.

Overall, above average NBS on Lake Erie, particularly in January and May, lead to an above average rise in water levels in the spring. The lake came within 15 cm (5.9 in) of its 1986 monthly record high level for May and within 21 cm (8.2 in) of the highest recorded level on Lake Erie set in June 1986 of 175.04 m (574.3 ft). The lake had a pretty typical seasonal decline during the summer and fall and the lake was 18 cm (7.1 in) higher at the end of the year compared to where it started in 2017.

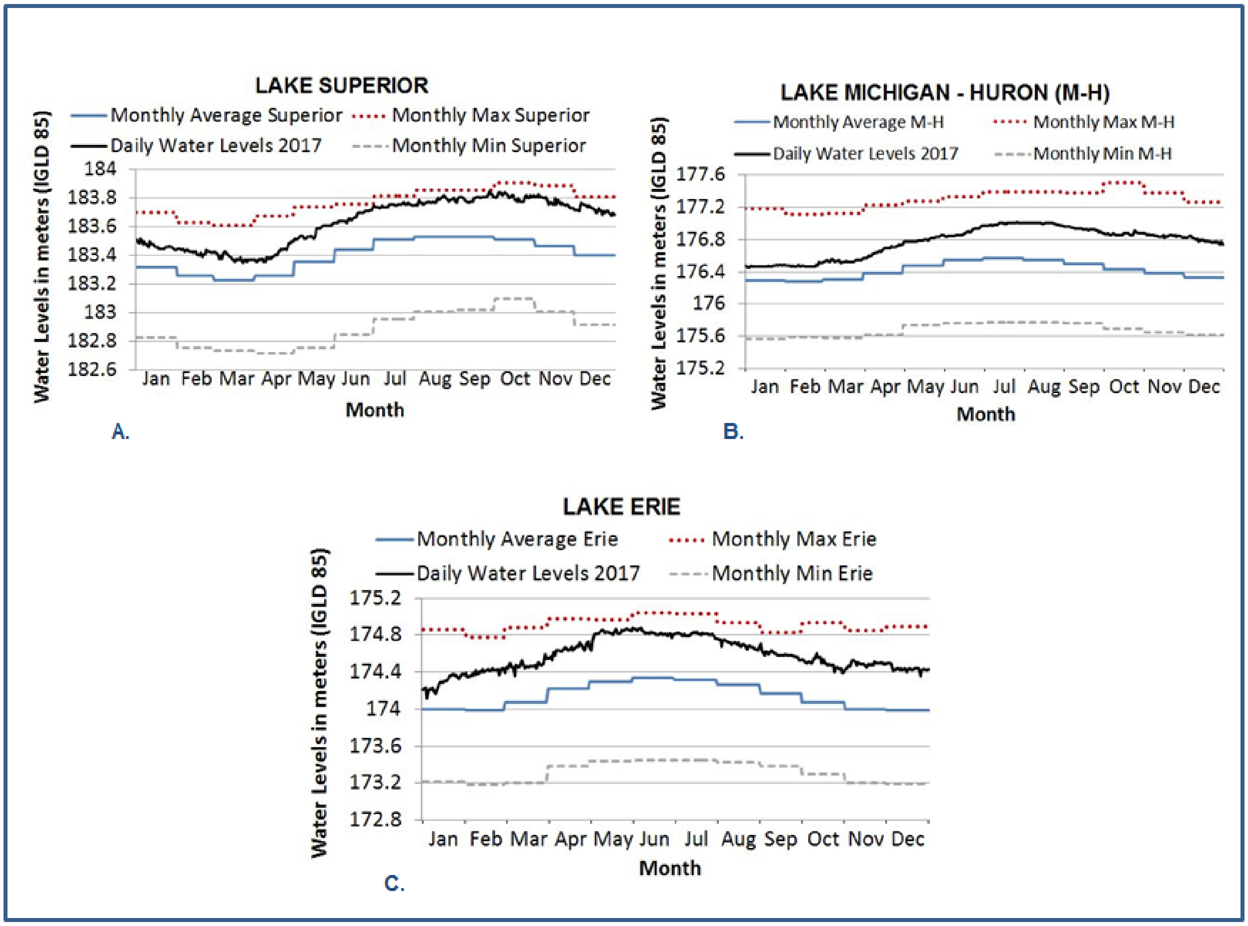


Figure 4-8: Maximum and Average 1918-2017 Monthly Water Levels and Daily Average Water Levels from 2017 for Lake Superior (A), Lake Michigan-Huron (B), and Lake Erie (C). (Source: Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 2017)

In terms of temperatures, January and February were unusually warm across the upper Great Lakes basin. The following spring and summer months were closer to normal, but starting again in autumn, temperatures were generally unseasonably warm across the basin in September and October. For example, Chicago experienced seven consecutive days with record breaking warm temperatures up to 35ºC (95ºF) from September 20-26. Later in November, record cold temperatures were set in many parts of southern Ontario, New York and Pennsylvania.

A strong wind event on October 24 led to straight-line-wind damage and high waves along the southern coastline of Lake Superior. Wind gusts as high as 124 kph (77 mph) resulted in downed trees and power lines leading to road closures and widespread power outages. A wave up to 9.1 m (30 ft) in height was also reported during this event, which is the highest ever recorded on the lake (NOAA: National Weather Service, 2017).

Snow Water Equivalent (SWE) describes the equivalent amount of liquid water stored in the snow pack. It indicates the water column that would theoretically result should the whole snow pack melt instantaneously. Not all basin snowmelt makes it directly to the Great Lakes but the amount that does is captured as part of the runoff component discussed earlier in this section.

Based on data provided by the Snow Data Assimilation System (SNODAS), during the winter of 2016-17, both Lake Superior and Lake Huron had a pretty typical sequence of SWE compared to the 2010-2016 average (Figure 4-9A and B)). Lake Michigan started out the winter season with higher SWE, but showed a steady decline starting around the beginning of 2017 (Figure 4-9C). The early fall of 2016 saw a dramatic accumulation of snow in Lake Erie to well above the average value, but then quickly declined and remained low for the rest of the season (Figure 4-9D).

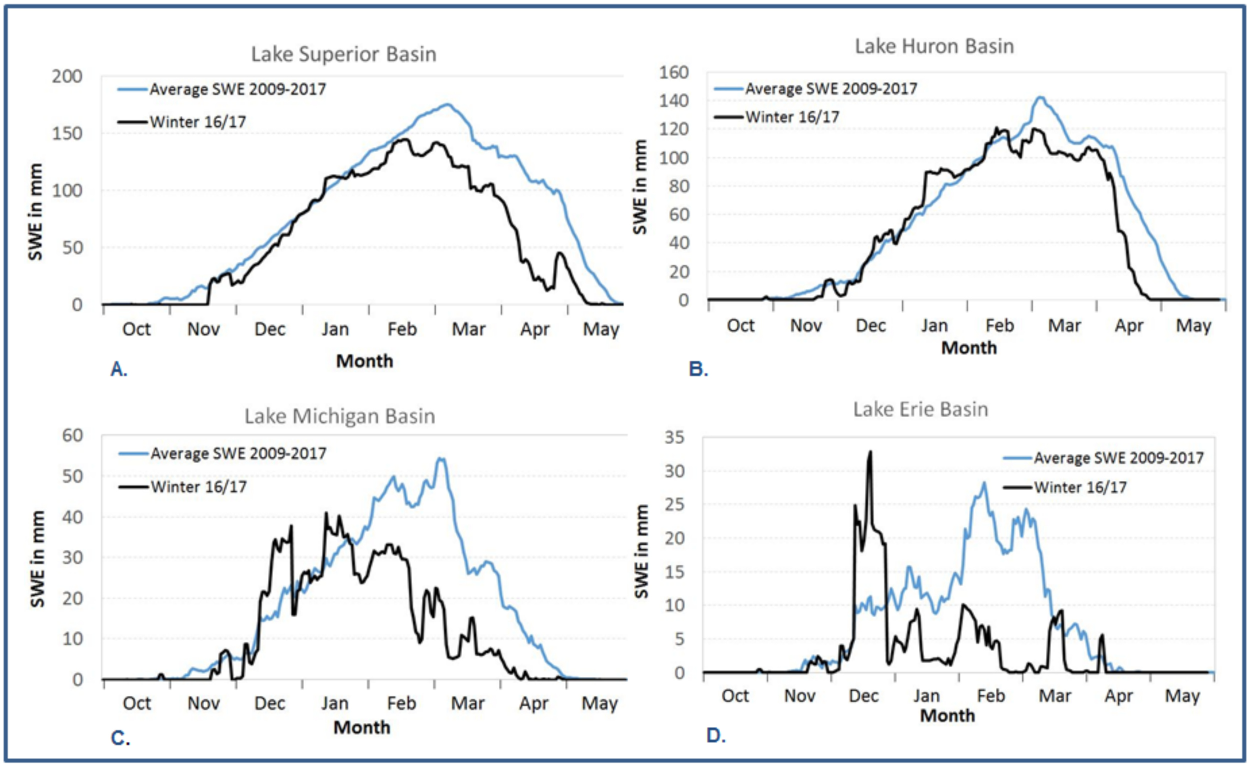


Figure 4-9: SWE from the Snow Data Assimilation System (SNODAS) for each of the upper Great Lakes

4.1.3 Hydroclimate highlights for Lake Ontario – St. Lawrence River

The Lake Ontario – St. Lawrence River experienced perhaps the most extreme hydroclimate conditions recorded in the basin in over 100 years during 2017, as generally wet conditions from January through March were followed by two of the wettest months ever recorded in April and May, raising water levels throughout the system and culminating in new record highs (Figure 4-10).

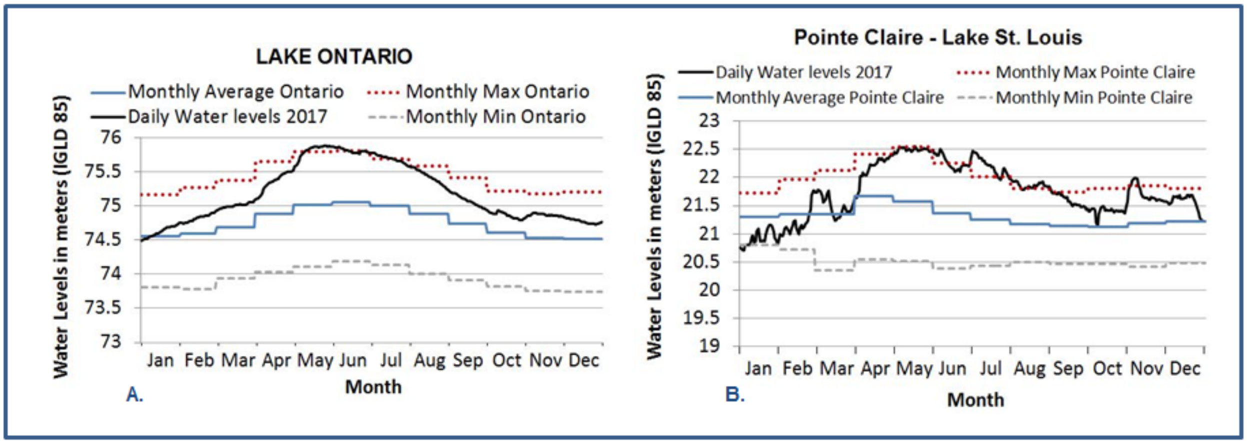


Figure 4-10: Maximum and Average 1918-2017 Monthly Water Levels and Daily Average Water Levels from 2017 for Lake Ontario (A) (Source: Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 2017) and the St. Lawrence River at Point Claire on Lake Saint-Louis near Montreal, QC (B) (Source: Government of Canada).

As fully documented in the board's report, the most significant aspects of this event began in April, as a series of large, heavy storms passed through the region throughout the month, quickly raising water levels of Lake Ontario and the St. Lawrence River. These storms also saturated the land surface and raised water levels of inland rivers and tributaries, the most significant of which is the large Ottawa River basin, which feeds into the St. Lawrence River near Montreal. The wet conditions continued and culminated in two extremely large and slow-moving systems that passed through the region back-to-back, the first from April 29 to May 1 and the second from May 4-8. Ottawa River flows set record highs on May 8, and combined with high inflows from Lake Erie, the result was an exceptional volume of water entering the Lake Ontario - St. Lawrence River system during this period.

The water level on Lake Ontario started the year very close to its average. As the first three months of the year were generally wet, the lake level rose more than average, and began April around 30 cm (11.8 in) above the average. The extreme water supplies in the spring contributed to the record-breaking rise in Lake Ontario during the months of April and May, and the lake peaked at 75.88 m (248.95 ft) in late May, the highest level ever recorded on the lake since records began in 1918. Levels remained high through the summer, but as conditions became relatively drier and high outflows were released, the level of the lake fell dramatically in the subsequent months, breaking record declines in August and September 2017. The level of Lake Ontario was about 25 cm (9.8 in) higher than average at the beginning of October and stayed at about this level relative to average until the end of the year.

Water levels on the St. Lawrence River as measured at Point Claire on Lake Saint-Louis (Figure 4-10 B) began the year below average, continuing a trend that had begun in the summer of 2016. In February, water levels edged upward with a sudden and pronounced rise following a significant thaw event marked by thunderstorms and rainfall. Levels varied through March responding to flows, weather and ice conditions but rose quickly throughout the first three weeks of April following another thaw event again marked by thunderstorms and rainfall. Water levels rose throughout the first third of May as Ottawa River outflows rose rapidly due to heavy rainfall. Levels generally fell in June as the Ottawa River outflows declined but rose again following heavy rainfalls in the latter half of the month. Lake Saint-Louis levels in June, July and August set new record high monthly means. Water levels began to decline through the fall but remained above average. As they neared average in October, another storm hit and levels on the St. Lawrence River rose rapidly towards the end of the month. By the end of the year, Lake Saint-Louis declined to near-average levels.

The main trend of the extraordinary weather patterns experienced in late April and early May 2017 were what is referred to as a high-amplitude or meridional flow pattern (Figure 4-11), which are characterized by deep pressure ridges and troughs that tend to direct the general air flow pattern from north-to-south or from south-to-north. This type of pattern can result in storms following a path directly over the Great Lakes after obtaining moisture from the Gulf of Mexico, and this occurred in late April and early May 2017. These storm systems are often slow moving and thus have lots of time to release their moisture over an area, which adds to the amount of precipitation they deliver. In late April and early May 2017, this effect was augmented by an area of high pressure over the east coast of North America, which caused the moisture-laden systems to slow down even more and resulted in well above-normal precipitation totals across Lake Ontario, the St. Lawrence and Ottawa Rivers (Figure 4-12).

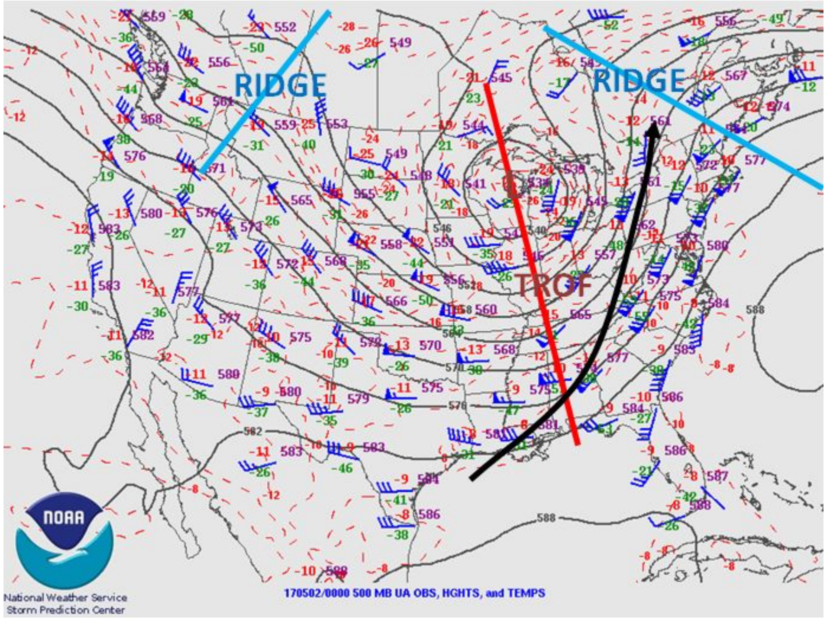


Figure 4-11: Analysis of 00z (8 p.m. EDT) May 2nd, 2017 500mb chart courtesy of the National Weather Service Storm Prediction Centre. Ridge lines have been drawn in blue, and troughs in red. The general steering flow from the Gulf of Mexico has been depicted by the black arrow. (Source: NOAA, Storm Prediction Centre, 2017)

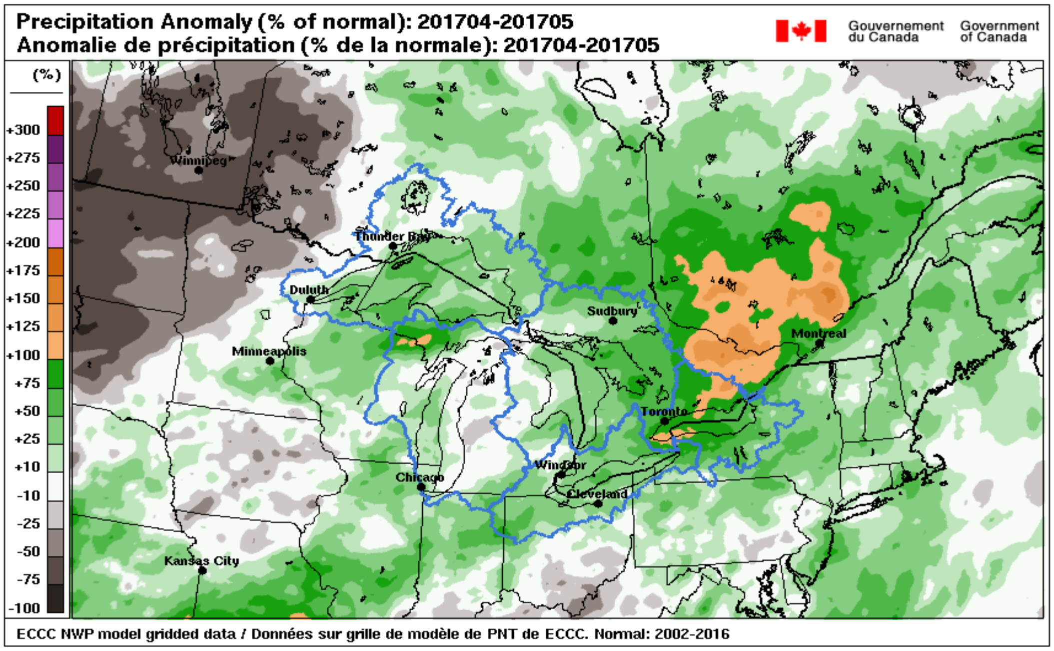


Figure 4-12: Anomaly for total precipitation accumulation in April and May 2017 in the Great Lakes region based on % departure from the 2002-2016 mean. Precipitation data are a merged dataset containing ECCC model and Numerical Weather Prediction (NWP) model data. (Source: ECCC – Meteorological Service of Canada)

After the wet spring, the rest of the summer and early fall saw closer to average precipitation on Lake Ontario. However, another extremely wet month came in October when the lake saw almost as much precipitation as it did during May. A particularly strong storm late that month helped maintain high runoff conditions into November.

In 2017, fluctuating temperatures during the winter months influenced Lake Ontario outflows and water levels primarily due to their role in creating unique ice conditions in the St. Lawrence River. January and February were much warmer than average, with record-breaking warm temperatures in February across much of the Great Lakes basin. This was followed by much colder temperatures in March, all of which contributed to an unprecedented freeze-thaw cycle, with an ice cover forming and then melting five times on the St. Lawrence River. As explained in the board's report (ILOSLRB, 2018), these variable ice conditions required outflows to be nearly continuously adjusted to avoid disturbing the fragile ice cover and potentially causing it to collapse and create ice jams.

The influence of wind and waves can, of course, greatly increase the problems associated with high water levels. Depending on the direction and strength of the wind, waves can build up over a long fetch on large lakes such as Lake Ontario. Both wind speed and wave height, which are tightly correlated, are greatly dependent on local conditions; however, generally speaking, the highest wind speeds tend to occur in the spring and fall.

To get an idea of wind conditions on Lake Ontario during the spring of April and May 2017, when lake levels were approaching their peak and a number of wind-related high water events were also noted, data from a buoy located off the north coast of Lake Ontario near Prince Edward Point (Lat 43.79N Long 76.87W) were examined. Based on these data, the average and maximum wind speeds during April and May were typical when compared to the historical record of this station that goes back to 1992. The measured maximum wave heights recorded at this buoy during April and May were 1.24 m (4.07 ft) and 1.56 m (5.12 ft), respectively. In the historical record, the maximum wave height for April averages 1.9 m (6.23 ft) and for May it averages 2.4 m (7.87 ft). There is nothing in this data record that indicates there was anything unusual about the wind speed or wave height during these two months of the year at this location. Nevertheless, with the record high water levels, even these relatively normal wind and wave conditions and storm surge (e.g. April 30, 2017) were an important contributor to shoreline impacts as discussed in Section 5.

In the Lake Ontario basin, data from the US Army Corps of Engineers (USACE) indicates that the daily SWE value was a little higher at the beginning of February than the 2009 to 2017 average for that time of year (Figure 4-13). However, the warm temperatures during February resulted in a dramatic drop in the SWE. It recovered somewhat during March but was then followed by the typical late season melt.

In the Ottawa River basin, the SWE in the southern half of the basin was slightly below average at the beginning of April, while in the northern half it was above average, although values were well below what had been seen in the previous year.

Looking specifically at the NBS components for Lake Ontario, the story was dominated by the very wet spring (Figure 4-14). The precipitation on the lake was double the average during the months of May and October and only significantly below average during September. The lake evaporation was close to average for the entire year. The runoff into the lake rebounded from a slightly below average start to well over double the average amount during May. It then gradually decreased over the summer before jumping well above average during November.

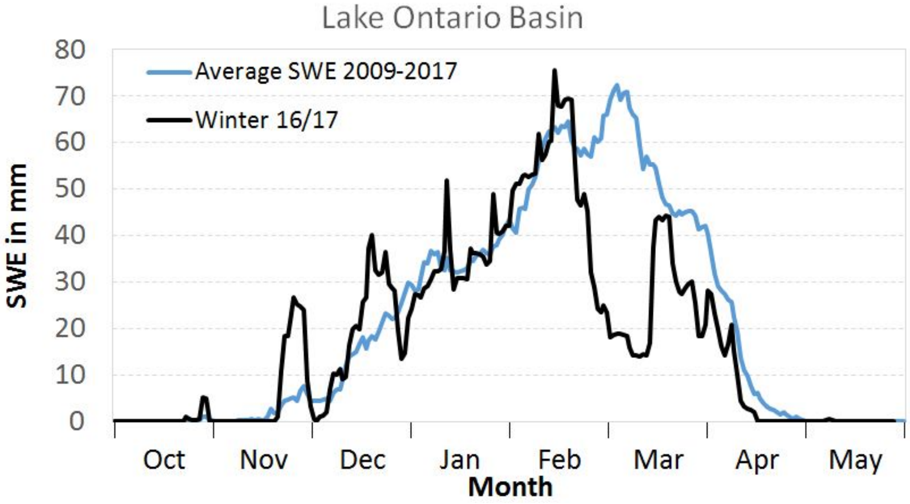


Figure 4-13: Lake Ontario SWE from the Snow Data Assimilation System (SNODAS)

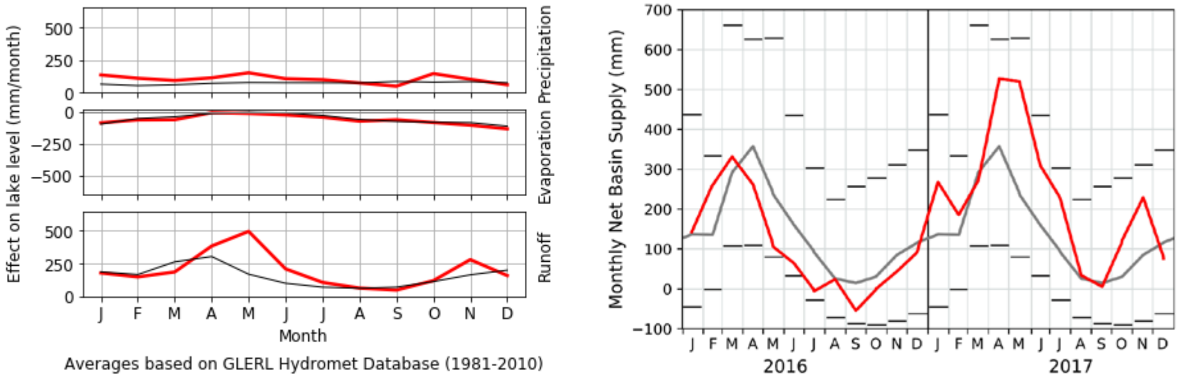


Figure 4-14: Lake Ontario 2017 NBS components (left) and residual NBS for 2016-2017 (right)

NOTE: NBS is the total of the precipitation that falls directly on the lake surface and the runoff that enters the lake through tributaries and the surrounding drainage basin, minus the evaporation that comes off the lake. The NBS is computed in two different ways: the "component" method uses measurements and modelled estimates of the three main components of NBS, i.e., precipitation, runoff and evaporation; whereas the "residual" method calculates the NBS as the residual water necessary to account for the change in storage (i.e., monthly lake level change) and the measured amount of inflow and outflow from the lake via their connecting channels.

4.2 Could the hydroclimate conditions of 2017 have been predicted?

Total water supplies to the Lake Ontario and Ottawa River basins are a primary driver of water level changes in the system and as a result, represent an important aspect of outflow regulation on the St. Lawrence River. Plan 2014 incorporates indicators of future water supply conditions, as did its predecessor Plan 1958-DD, in an attempt to reduce the frequency and severity of extreme water levels from what would occur without regulation.

During the LOSLRS and subsequent efforts, a range of simulations were done to illustrate the potential benefit of improved forecasts of water supply conditions should sufficient improvements become available in the future. The results suggested that in theory at least, foreknowledge of wet or dry weather three to six months in advance could improve regulation plan performance in some situations by providing the opportunity to adjust outflows in time to reduce, though not eliminate, the risk of extreme water levels. So how well did existing long-range seasonal forecasts predict the extreme conditions of 2017 and can anything be learned from the event to improve predictions in the future?

The long-range forecasts did not do well. As an example, the North American Multi-Model Ensemble (NMME) is a multi-model seasonal forecasting system that uses forecast data produced by research centers from both the US and Canada. Each month the NMME uses data from a suite of individual models to create six-month global forecasts of both temperature and precipitation. These are among the most sophisticated seasonal forecasting models currently available.

Figure 4-15 below shows the distribution of NMME model forecasts for Lake Ontario precipitation done in March 2017 for the following six months. The figure indicates a wide range of possible precipitation forecasts were produced by the various models (see the figure caption for a detailed description of the figure), ranging from above-normal (red) “wet” conditions to below-normal (blue) “dry” conditions, but with most model forecasts falling in the near-normal (grey) category. Very few of the forecasts exceeded the historical ranges, indicating that extreme precipitation was not considered likely in the months of April and May. Interestingly, the average of the forecasted May precipitation was slightly below the historical average for the month, suggesting that most models were calling for a drier-than-normal May.

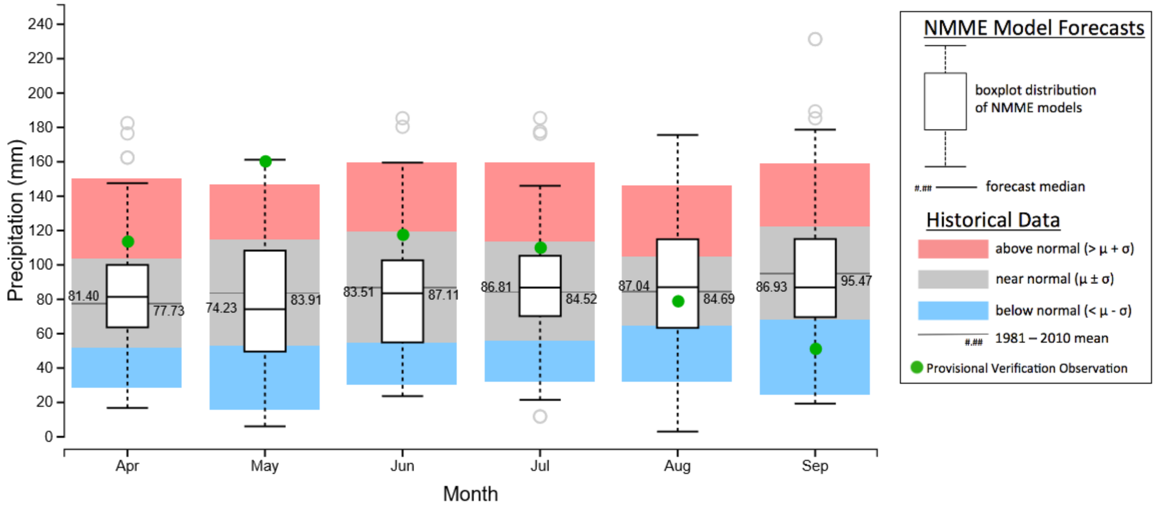


Figure 4-15: Distribution of NMME six month forecasts made in March 2017. The red, grey, and blue bars represent above, near, and below average ranges based on 1981-2010 data, respectively. The box for each month represents the 25th to 75th percentile while the horizontal black bar in the middle of the box is the median of all the forecast models and the green dot is the actual value of precipitation for that month. (Source: NOAA – Great Lakes Environmental Research Laboratory (GLERL), March 2017)

The green dots show actual precipitation that occurred, with above-normal precipitation in April followed by well-above normal precipitation in May. Thus, it can be seen that even one month in advance there were no reliable signals in the available forecasts that the precipitation during the spring of 2017 was going to be extreme. Furthermore, forecasts three to six months in advance tend to be even more uncertain, and while an accurate forecast this far in advance might allow the lowering of lake levels ahead of extreme supplies, it is also possible that other factors may preclude it (this was indeed the case in 2017, as ice conditions would have limited flows from January through March and prevented the high outflows that would have been necessary to lower Lake Ontario in advance of what were unpredicted extreme water supplies later in spring).

The question remains, is there any way of improving these forecasts? What if, for example, the same climatological conditions preceded the 2017 high water as had preceded high water events in previous years, then perhaps a forecast of high water could be made whenever those conditions appeared.

Teleconnection patterns are the name given to large-scale patterns of pressure and circulation anomalies that can encompass large areas of the globe. Depending on the teleconnection pattern, one can persist from weeks to months to years and have significant impact on weather patterns many thousands of kilometers away. These patterns reflect the changes that are seen in the atmospheric wave and jet stream patterns across the planet. The teleconnection patterns that are generally thought to have some influence on North American weather to varying degrees are: The North Atlantic Oscillation (NAO), Pacific/North American pattern (PNA), the El Niño-Southern Oscillation (ENSO), and the Arctic Oscillation (AO).

Typically, correlations between the teleconnections and weather patterns are strongest when the teleconnections are either in the high or low end of their ranges, but this was not the case for any of these teleconnection patterns during the first half of 2017: NAO 0.3 (ranges from -3 to +3), PNA 0.3 (ranges from -3 to +3), ENSO 0.1 (ranges from -2 to +3), and AO 0.4 (ranges from -4 to +4). Thus, there was no indication from the values of the teleconnection patterns that there would be record high precipitation over Lake Ontario during April and May.

A recent paper (Carter and Steinschneider, 2018) catalogues similarities and differences among seven modern Lake Ontario floods (1951, 1952, 1973, 1974, 1976, 1993, and 2017) and using other referenced work, provides a high-level overview of the climatic drivers and teleconnection patterns of interest. Although there were significant high-water years on record before 1951, there was less recorded about climate phenomena that could help explain the cause of the high levels.

In six of the seven flood years (the one exception being 1993), wintertime precipitation over the Great Lakes was above average and most were well above average. Four of the six years were also coincident with low values of ENSO (commonly referred to as La Niña), including 1951, 1974, 1976 and 2017. Historically, La Niña years have shown a tendency towards relatively dry weather conditions in the southern US, and wet conditions in the north and in southern Canada, including the Great Lakes, and this was indeed the case in 2017. Physically, this happens because the jet stream in the eastern Pacific moves north and more water moves through an atmospheric "river" of water vapor over the Pacific northwest. The fact that there are some common ocean and atmospheric conditions present in some of these high-water years suggests the possibility that floods could be forecast with a somewhat greater degree of accuracy in advance.

However, not all La Niña years have resulted in wet winter weather on the Great Lakes or in high water levels later in spring. This is, in part, because ENSO is just one of the influences of weather in the Great Lakes, and there are many effects that are not captured in these teleconnections.

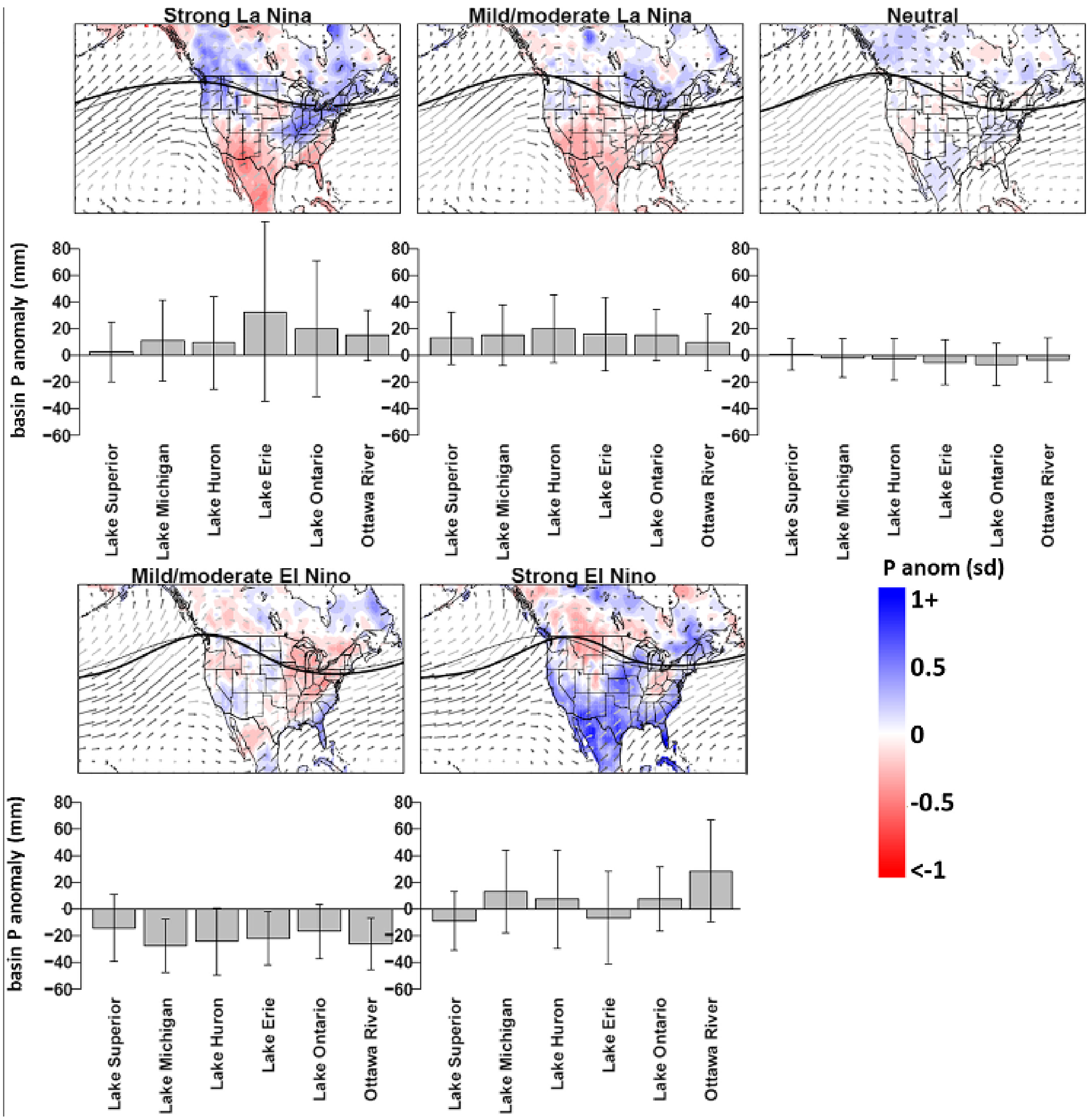


Figure 4-16: Great Lakes and Ottawa River cumulative precipitation anomalies for December through March, categorized based on ENSO conditions (Source: Carter and Steinschneider, 2018).

As can be seen in Figure 4-16, while both strong and mild/moderate La Niña years have shown an overall tendency towards above average winter precipitation (as indicated by the positive grey bars) in the Great Lakes and Ottawa River basins, not all years have shown this (as indicated by the black whiskers both above and below zero). Nor have all wet winters resulted in high water conditions in spring of the subsequent year. This indicates that although ENSO conditions may have some effect on the weather patterns on the Great Lakes, they are by no means a perfect indicator and there are certainly other important factors that influence high water conditions in the basin.

So, are there other global factors that could be used in combination with La Niña to forecast high water levels? Testing of the regulation plans during the LOSLRS showed that Lake Ontario levels over 75.5 meters are caused in great part by high NBS. High inflows from Lake Erie can contribute to these high levels, but high Lake Erie inflows are also somewhat more predictable, and regulation plans take that into account (LOSLRS, 2006). As was evident during the extreme wet conditions in 2017, high springtime NBS resulting from both heavy over-lake and over-land precipitation, may be an even more important driver of Lake Ontario flooding. Carter and Steinschneider (2018) argue that while ENSO conditions in the Pacific Ocean may provide some indication of winter weather conditions in the Great Lakes, teleconnection patterns in the Atlantic Ocean may be more indicative of spring weather, specifically, the position of the North Atlantic subtropical high (NASH). The NASH causes air flow to turn clockwise around a center with high atmospheric pressure located roughly due east of Florida. The position and orientation of the western edge of the NASH is a strong driver of summertime precipitation in the southeastern United States and may have some influence on springtime precipitation on the eastern Great Lakes.

Carter and Steinschneider (2018) have argued that the position of the western edge of the NASH may be connected to high springtime NBS on Lake Ontario. For example, of the seven flood years reviewed, four showed high spring precipitation anomalies, and three of these, including 2017, corresponded to years where the western ridge of the NASH was shifted furthest west than normal (Figure 4-17).

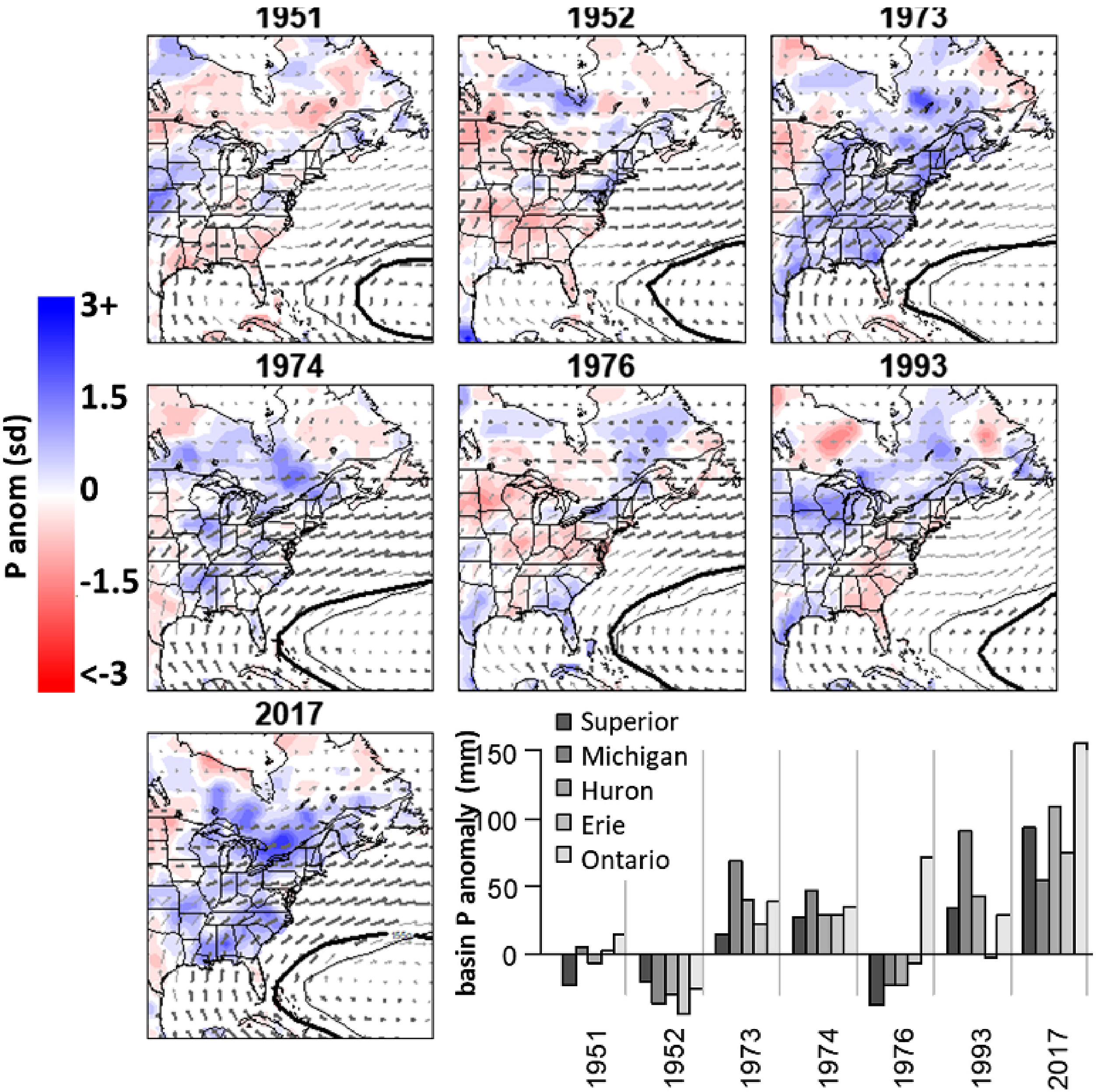


Figure 4-17: Great Lakes cumulative precipitation anomalies for April through June for seven historical high water years categorized based on NASH conditions (Source: Carter and Steinschneider, 2018).

This suggests that efforts to produce a forecast of high lake levels based on ENSO and NASH may hold some promise. The first step would be to further investigate the relationship between these teleconnection patterns, water supplies and Great Lakes water levels. Even if strong relationships are indicated, it would then be necessary to determine how well and how far in advance these factors can be forecasted, given any actions taken through outflow regulation would need to occur weeks, if not months, in advance to have a meaningful impact at reducing risk. Although there exists some skill in the forecasting of ENSO, at the moment, there is no forecast of NASH that has shown any skill in accurate prediction.

As illustrated by the recent work of Carter and Steinschneider (2018) and the results of the predictive capacity of the current operational models (NMME), a considerable gap remains between available long-term water supply forecasts and operational decisions. Improving the skill of long-term water supply forecasts is an area of active research and there is the potential that such work will improve forecast confidence and accuracy in the future. In the long-term, regulation of Lake Ontario outflows may benefit from forecast improvements that provide sufficient lead time (and confidence) to support lowering or raising of levels in anticipation of extreme conditions to reduce their frequency and severity. However, such improvements seem to be a ways off and even if successful, are not likely to eliminate trade-offs between interests.

4.3 How did 2017 fit with historical conditions?

In addressing the GLAM Committee's directive of assessing whether future water supplies will be different from those used to test the current outflow regulation plans, it is important to track historical data to assess whether conditions may be changing over time. It is widely understood that climate is not stationary and that decadal and longer-term trends are to be expected (Livingstone, 2008). It is only through on-going monitoring that the magnitude and direction of those trends can be detected across the Great Lakes. The conditions of 2017 were undoubtedly highly unusual, but the GLAM Committee is interested in knowing just how unusual they were relative to the historical record and whether these conditions are consistent with recent data conditions that might indicate a trend and possibly a greater chance of such conditions occurring again or occurring more frequently in the future. Such trends, if they exist, could inform the robustness of the regulation plan evaluations.

This section examines the various components of the NBS including over-lake precipitation, lake evaporation and basin runoff, and the recent conditions across the five Great Lakes basins and how 2017 compared with recent historical data.

Although there are many different variables that are available, this report will focus on the ones that are relevant when considering the regulation plans that currently exist, namely precipitation, runoff, and evaporation. Currently the longest consistent source of this type of data for the Great Lakes comes from NOAA's Great Lakes Environmental Research Laboratory (GLERL) based on their Advanced Hydrological Prediction System (AHPS). Also note that the data from the most recent years is considered preliminary.

As with any sequence of meteorological data, there is a lot of variability in the annual totals and this can mask longer-term trends. Thus, it can be useful to summarize the data over longer time periods. This can be seen in the total over-lake precipitation for Lake Superior: while there is a lot of variation in the annual data, a general trend is much more easily seen in the data averaged over decadal periods (Figure 4-18). In this case, it appears a trend towards increasing precipitation has occurred during the last century, although it has somewhat leveled out since the 1970s. The total for 2017 (1080.1 mm; 42.5 in) continued the pattern of high over-lake precipitation over the last few years.

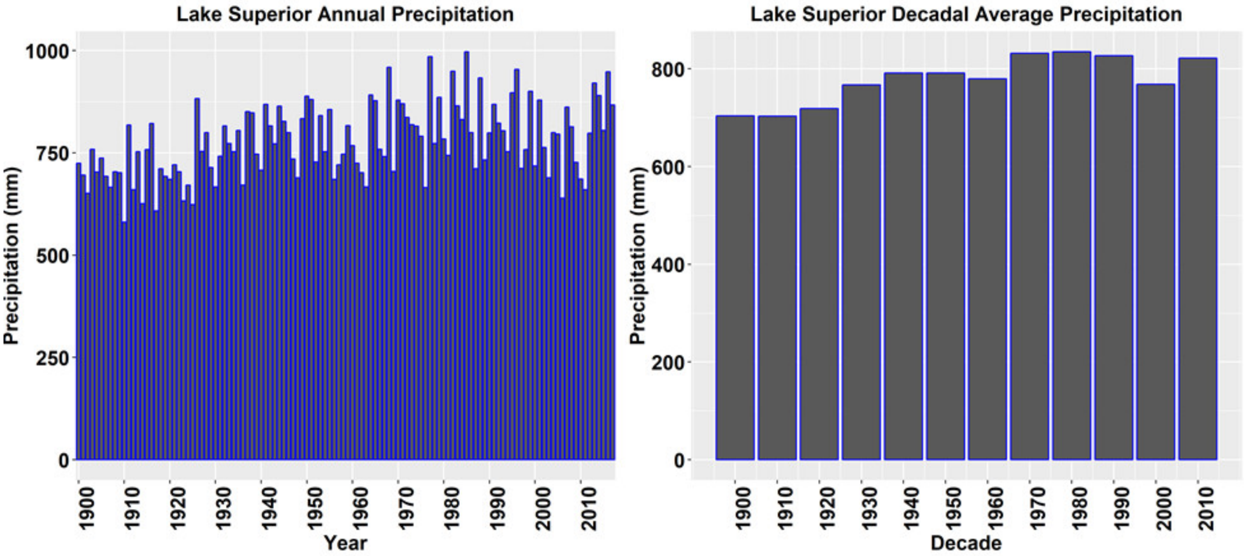


Figure 4-18: Annual and decadal over-lake precipitation for Lake Superior.

The Lake Superior lake evaporation shows a clear trend of increasing values (note that reliable evaporation data only goes back to the 1950s) with a notable jump between the 1990s and the 2000s (Figure 4-19). For 2017, the lake evaporation (713.9 mm; 28.1 in) was one of highest seen in the historical record. While runoff into the lake has seen a general reduction over the past three decades (Figure 4-20), the value for 2017 (713.1 mm; 28.1 in) was the highest seen in the past 20 years.

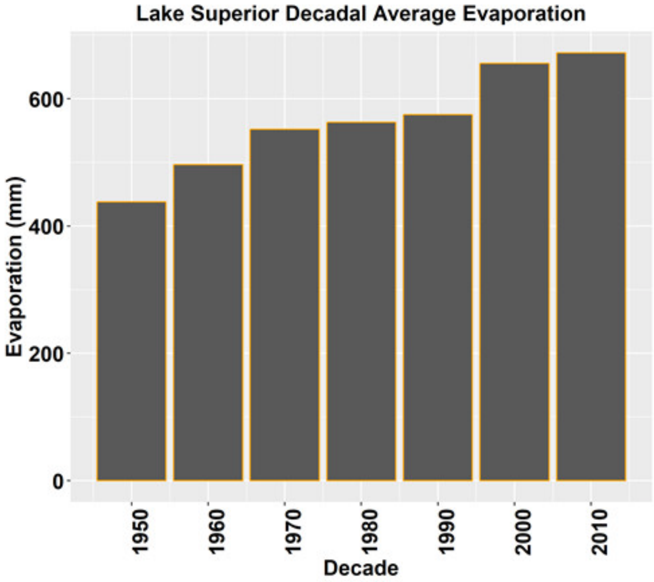


Figure 4-19: Lake Superior decadal average evaporation

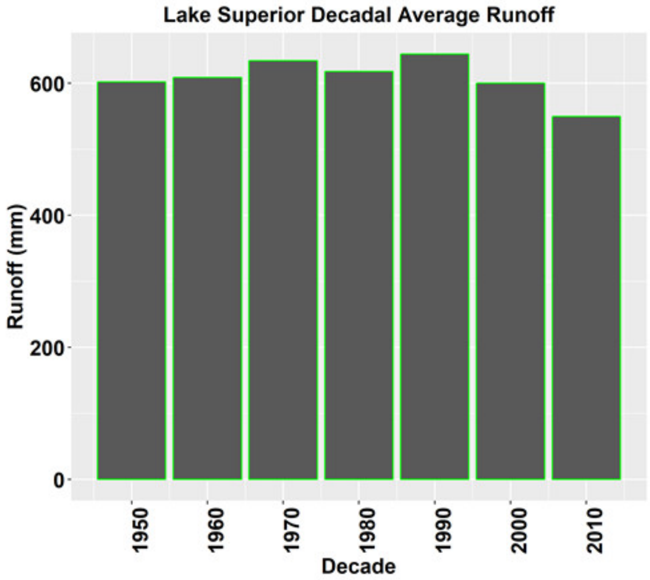


Figure 4-20: Lake Superior decadal average runoff

As in Lake Superior, Lakes Michigan/Huron have also seen a general rise in over-lake precipitation over the past century and a general levelling off in the most recent decades (Figure 4-21). The 2017 over-lake precipitation (877.7 mm; 34.6 in) is a little higher than the average value for the past few decades. Lake evaporation experienced a marked increase between the decade of the 1990s and the 2000s, with 2017 (688.3 mm; 27.1 in) coming in about the same as the average for the 2010s (Figure 4-22).

The amount of runoff coming in to Lakes Michigan/Huron has seen a sharp reduction in value in the most recent decade, with the decade of the 2010s being the lowest in the records going back to 1950 (of course, this decade is incomplete and the addition of a couple more years may change this finding, but likely not significantly) (Figure 4-23). Although the value for 2017 (751.4 mm; 29.6 in) was above the 2010 decadal average, it was still less than the previous four decadal averages.

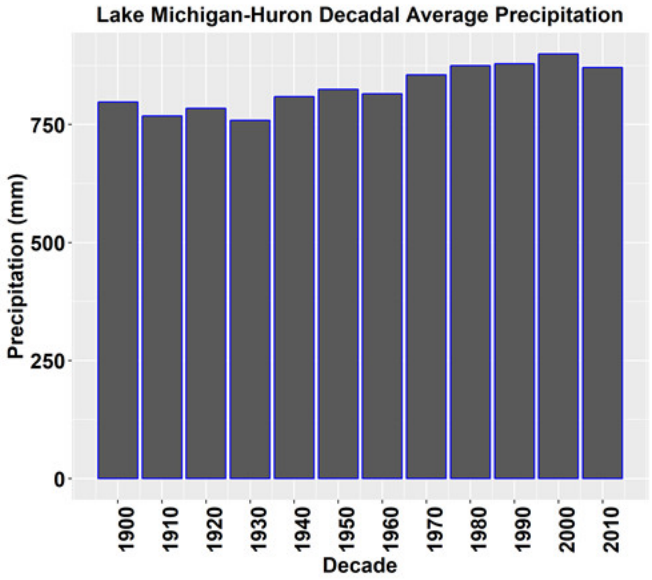


Figure 4-21: Lake Michigan-Huron decadal average precipitation

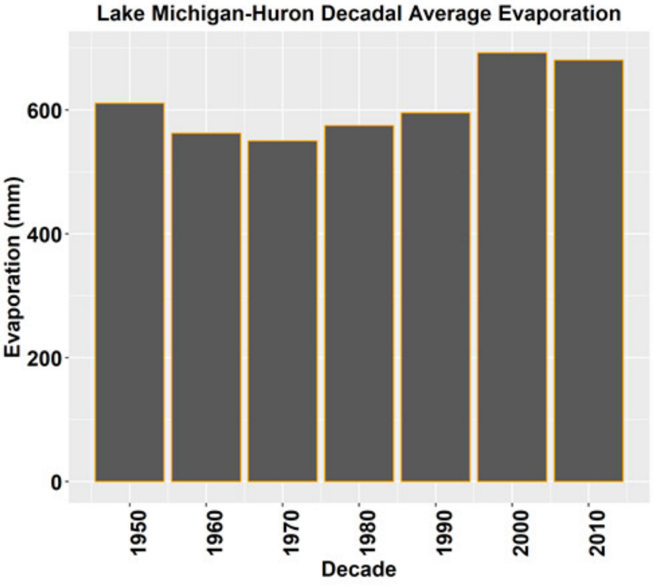


Figure 4-22: Lake Michigan-Huron decadal average evaporation

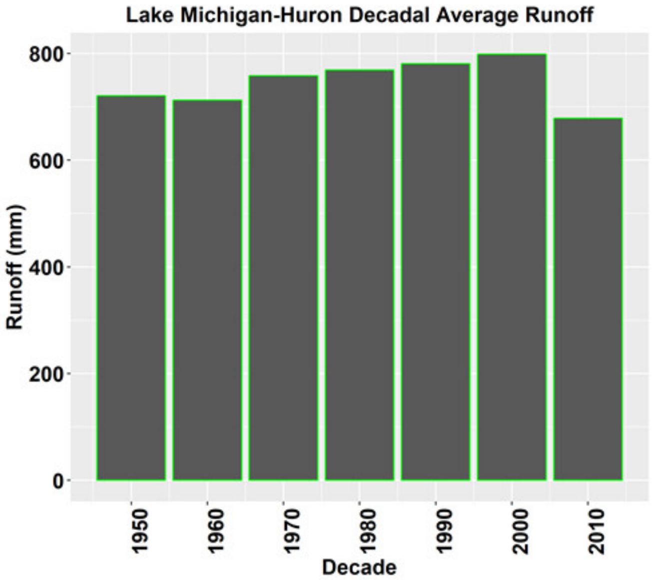


Figure 4-23: Lake Michigan-Huron decadal average runoff

The over-lake precipitation on Lake Erie has seen generally increasing values since the middle of the last century, although so far, the current decade is slightly below the value for the decade of the 2000s (Figure 4-24). The value for 2017 (927.1 mm; 36.5 in) was the highest in the past six years. Although the lake evaporation has been increasing, there was not the same sharp rise seen on Lake Erie as in the previous lakes (Figure 4-25). The amount of evaporation in 2017 (956.0 mm; 37.6 in) was just a little less than the average of the past decade. Once again, runoff saw a marked decrease during the last decade coming into Lake Erie (Figure 4-26). With the increase in precipitation, it can be assumed that overland evaporation also had to increase in the past decade. The 2017 value for runoff (826.6 mm; 32.5 in) was the highest seen since 2011, but less than the decadal average for the 2000s.

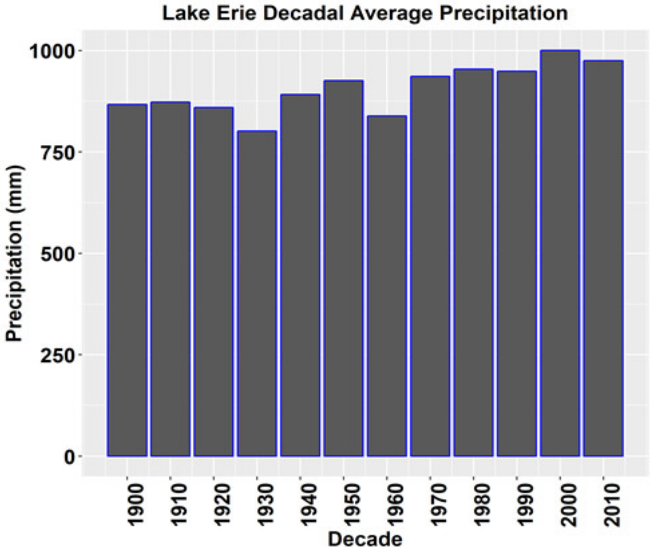


Figure 4-24: Lake Erie decadal average precipitation

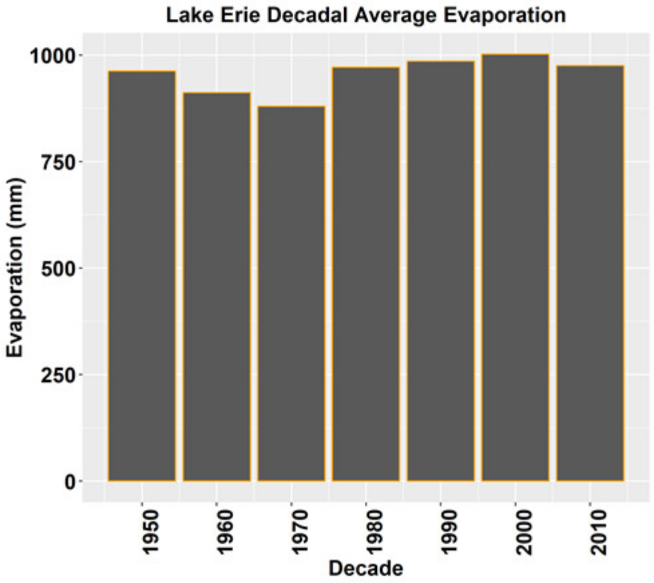


Figure 4-25: Lake Erie decadal average evaporation

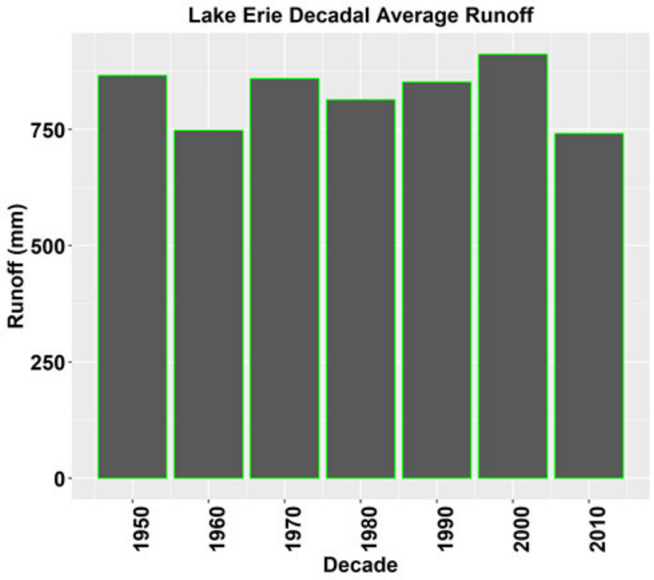


Figure 4-26: Lake Erie decadal average runoff

After rising in the decades of the latter half of the last century, the over-lake precipitation on Lake Ontario has remained relatively steady the last few decades (Figure 4-27). In 2017, the total over-lake precipitation value (1222.2 mm; 48.1 in) was the highest total in the recorded history of the lake which goes back to 1900. Evaporation over the lake has shown a steady decadal increase since the 1990s (Figure 4-28). The value for 2017 (742.4 mm; 29.2 in) was typical of what we have seen in the past decade. The runoff into Lake Ontario has seen a dramatic decrease in the last decade; in fact, since records began in 1950, four of the lowest five values have occurred since 2012 (Figure 4-29). However, the 2017 value (2363.4 mm) did not fit this trend whatsoever and was instead the highest value of runoff into Lake Ontario on record.

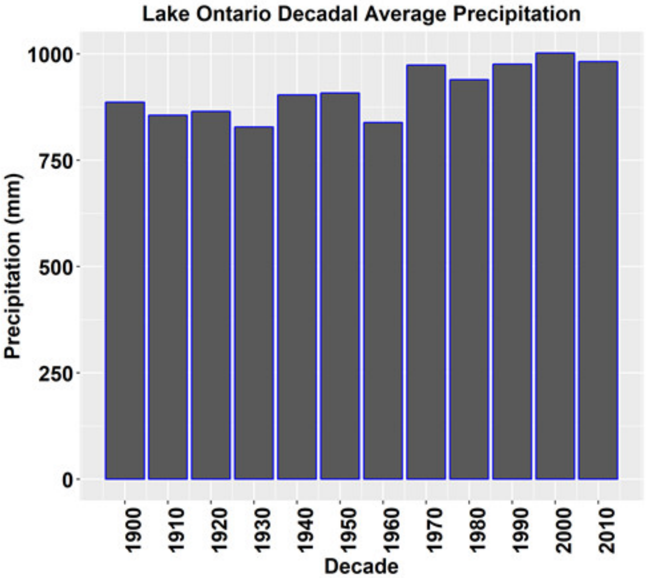


Figure 4-27: Lake Ontario decadal average over-lake precipitation

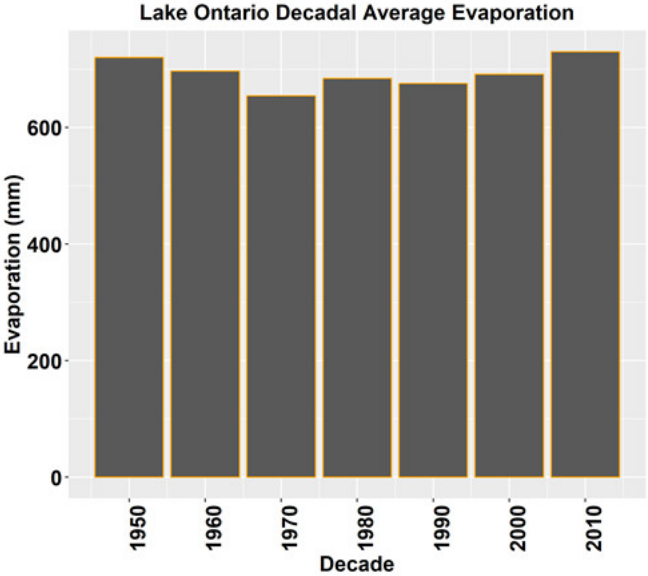


Figure 4-28: Lake Ontario decadal average evaporation

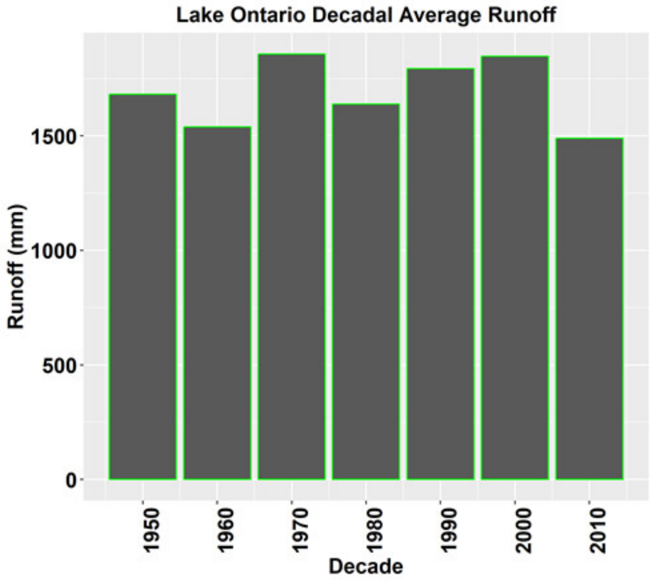


Figure 4-29: Lake Ontario decadal average runoff

It is possible that recent trends in over-lake precipitation and evaporation may continue into the future given a changing climate, but it is beyond the capabilities of the current state of research to confidently state when these types of condition will be repeated. The conditions in 2017, while a rare occurrence, seem to mostly fit within the range of water supply conditions used during the past IJC studies (IUGLS and LOSLRS), which were based largely on historical climate conditions, supplemented with statistical and climate models describing potential future scenarios. However, it is unclear whether such conditions may occur more frequently in the future.

4.4 What was extraordinary about the 2017 Great Lakes hydroclimate?

4.4.1 Record precipitation on both the Lake Ontario and Ottawa River basins

The Ottawa River basin covers an area of 146,300 km^2 (56,480 square miles) and is the largest tributary to the lower St. Lawrence River. The flow of the Ottawa River combines with the outflow from Lake Ontario upstream of Montreal, and as a result, it is critical in the regulation of Lake Ontario and the St. Lawrence River.

Figure 4-30 depicts what an extraordinary precipitation year 2017 was for Lake Ontario and the Ottawa River basin. Total precipitation over Lake Ontario during April-May (source data from GLERL (Hunter et al., 2015)) from 1900-2017 is plotted against the same parameter at the City of Ottawa in the southern part of the Ottawa River basin (source data from ECCC meteorological

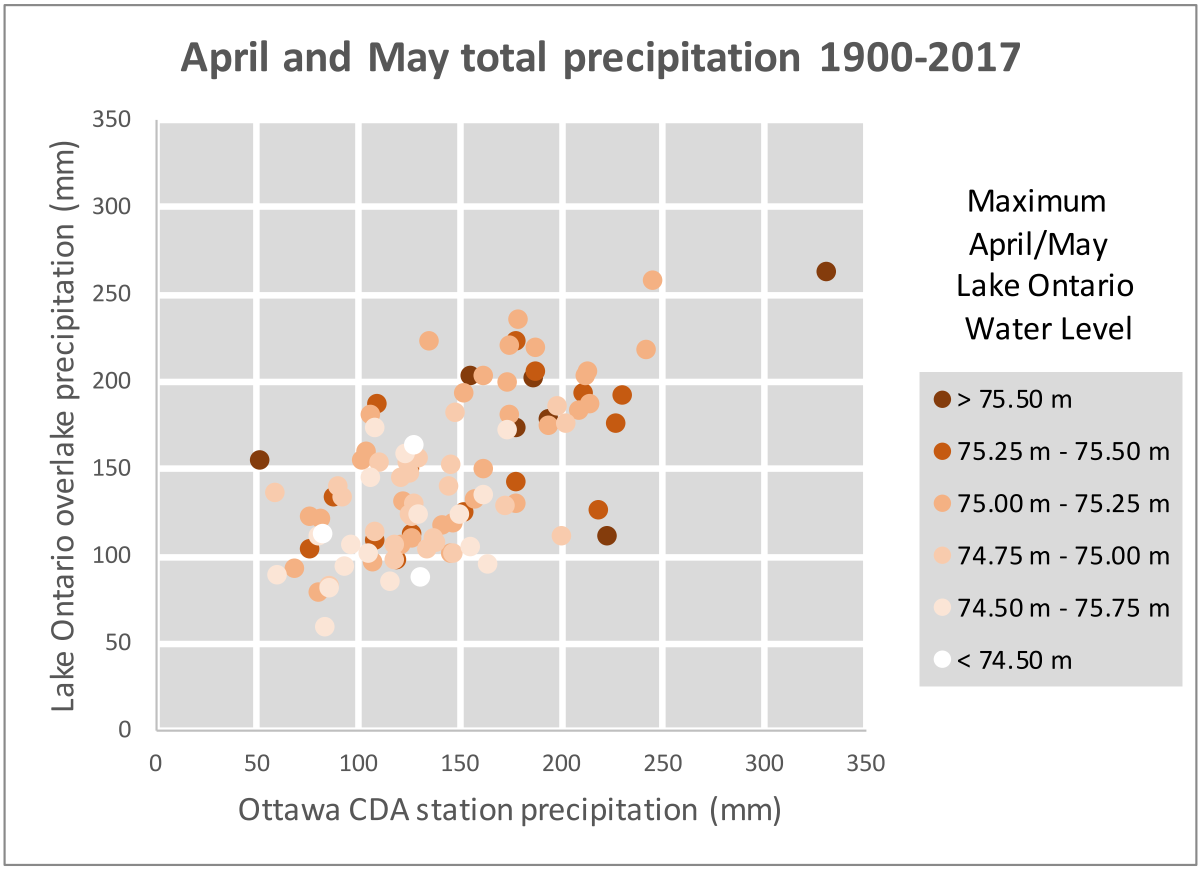


Figure 4-30: Comparison of the total April and May 2017 precipitation between over-lake Lake Ontario precipitation and the meteorological station "Ottawa CDA".

station “Ottawa CDA” at the Central Experimental Farm in the City of Ottawa; this station was used to represent the Ottawa River basin as it had data back to 1900). Each year is a dot and each dot is color coded to show the maximum monthly Lake Ontario elevation during April-May in that year. The year 2017 stands far apart from the past 117 years, setting records for high water levels, Lake Ontario basin precipitation and Ottawa River basin precipitation. Under a stationary climate, there would only be a 0.6% chance of this happening in a given year (or a 1 in 160-year event).

For the Ottawa CDA station, the total precipitation for April 2017 of 159.0 mm (6.26 in.) was the highest seen in the historical record (0.7% chance or a 1 in 148-year event), while the 172.4 mm (6.79 in.) in May was the third highest in the record (0.7% or 1 in 136-year event). The combined April and May total was the highest in the historical record (0.6% or 1 in 166-year event).

The April 2017 total over-lake precipitation for Lake Ontario of 111.8 mm (4.40 in.) was the fifth highest seen in the record (0.8% chance or a 1 in 119-year event). For May, the total of 150.3 mm (5.92 in.) was the second highest only behind 1919 when 152.1 mm (5.99 in.) fell (0.8% chance or a 1 in 127-year event). The total for both April and May of 2017 was 262.1 mm (10.32 in.), which is the highest in the record (0.8% chance or a 1 in 132-year event), but only slightly higher than the 257.6 mm (10.14 in.) in 2011.

The extreme precipitation in the Lake Ontario and the Ottawa River basins was further exacerbated by high inflows to Lake Ontario from Lake Erie. The wet conditions in the Lake Ontario basin in 2017 (Figure 4-31) are further illustrated through the weekly NTS for the year, which includes the effects of both Lake Ontario NBS and Lake Erie inflows. As shown in Figure 4-32, NTS exceeded record highs on multiple occasions in 2017, the most notable being the start of May, where NTS exceeded the highest values ever previously recorded (1900-2016).

Although it is difficult to attribute conditions in one particular year to the effects of climate change, one of the predicted outcomes from climate change is more severe storms and extreme precipitation. One sequence of climate parameters based on the most recent future climate scenarios used during the IUGLS suggests that months with extreme precipitation over Lake Ontario would be anywhere from two to three times more common during 2050 when compared to the current climate (MacKay and Seglenieks, 2013). The U.S. National Climate Assessment for 2018 Great Lakes Synthesis report indicates that the tendency towards more intense precipitation events is projected to continue into the future (GLISA, 2018;D’Orgeville et al., 2014; Notaro, M. et al.), although it also notes that model projections for precipitation changes are less certain than those for temperatures (GLISA, 2018; Pryor et al. 2013; Kunkel et al. 2013). The runoff amounts of 2017 were within the bounds of the water supply data used to evaluate the plans in the LOSLRS, but for the GLAM Committee it raises the question of whether our simulations adequately test the possibility of a significant upward shift in magnitude and/or frequency of high precipitation and runoff. This is further discussed in Section 6.

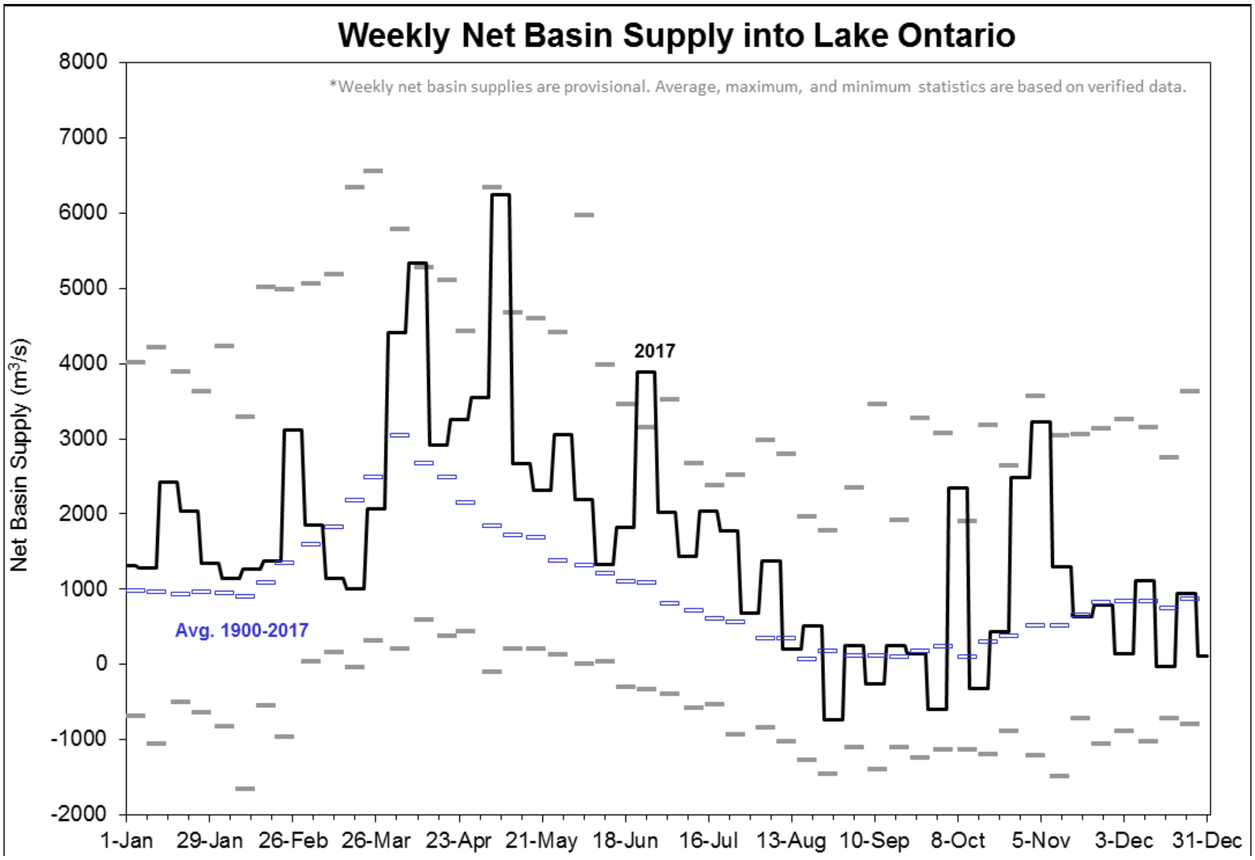


Figure 4-31: Weekly net basin supplies (NBS) for the Lake Ontario basin in 2017. (Source: International Lake Ontario – St. Lawrence River Board)

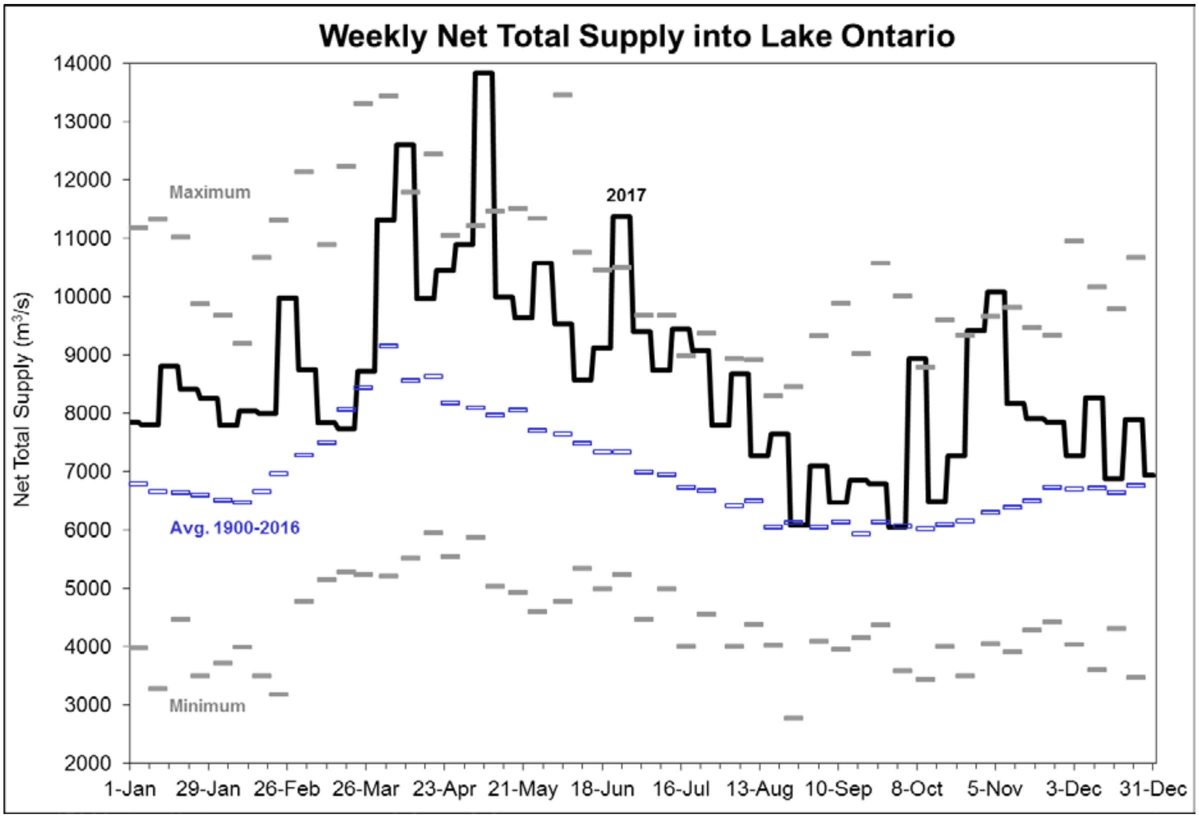


Figure 4-32: Weekly net total supplies (NTS) for the Lake Ontario basin in 2017. (Source: International Lake Ontario – St. Lawrence River Board)

4.4.2 Fluctuating ice conditions

The ice conditions along the St. Lawrence River and downstream of the Moses-Saunders Dam at Beauharnois in early 2017 also influenced the regulated outflows from Lake Ontario that were released during the winter. Formation of a stable ice cover in the critical areas of the St. Lawrence River is important as it reduces the risk of ice jams, which can severely restrict outflows and potentially result in flooding upstream. As ice begins to form, outflows are typically reduced to lower the current velocities in the St. Lawrence River, which helps prevent the fragile ice cover from breaking up or collapsing on itself, and also reduces the potential for frazil ice development (i.e., super-cooled ice crystals), which can accumulate and further increase the risk of ice jams at critical locations. Once an ice cover has formed and is stable, these risks are reduced and outflows can be safely increased. However, if the ice cover becomes unstable or breaks up subsequently, flow must be again reduced in order to reduce the risks upstream and downstream.

During many years since regulation of Lake Ontario and the St. Lawrence River began, the pattern seen in the St. Lawrence River has generally been that cold temperatures at the beginning of winter would create an ice cover in the critical sections (i.e., the Beauharnois Canal and international section of the river), and then this ice would remain stable during the winter and eventually melt out when warmer temperatures returned in the spring. Historically, ice records on the St. Lawrence River date back to 1961; however, early records generally only include dates of first and last ice on the St. Lawrence River, and they do not describe fluctuations in temperatures and/or ice conditions in detail. More detailed records including such information have only been kept since about the year 2000.

In 2017, ice briefly came and went during the mild and near record warm temperatures in January and February, before reforming again as temperatures became unusually cold in March over the Lake Ontario-St. Lawrence River basins. Substantial ice cover formed and disappeared twice on the St. Lawrence River during March 2017, both unprecedented events. Overall, the winter experienced five periods of ice formation in the critical areas of the St. Lawrence River, which is likely the most freeze/thaw cycles ever seen on the river (the board report ("Observed Conditions and Regulated Outflows in 2017") covers ice conditions in greater detail).

Future climate scenarios generally agree that higher temperatures, especially during the winter period, are more likely to be seen in the coming decades (GLISA, 2018). There is some evidence of this in the historical record. For example, using data from the airport at Dorval, QC, which is near Montreal and not far from Beauharnois or Moses-Saunders dams, during the decades of the 1960s and the 1970s there were no years that 25 or more days in January and February recorded temperatures above zero. During the 1980s, there was one of these years; the 1990s saw two; while the 2000s recorded this only once. However, since 2010 this has already happened four times, including 2017.

Thus, it is not unreasonable to expect the pattern of warmer temperatures and, by extension, fluctuating ice conditions to continue, and such potential patterns and trends are an important consideration and area of research for GLAM, given they can influence outflow regulation and the ability of regulation plans to release water during the winter months.

4.5 Key findings: what can be learned from the 2017 hydroclimate conditions?

While the NBS of 2017 was very wet across the Great Lakes basin and even record-breaking in some weeks over the Lake Ontario basin, it was the combined precipitation over the Lake Ontario and Ottawa River basin with high inflows from Lake Erie that made 2017 so extraordinary. The unusual St. Lawrence River ice conditions in 2017 added to the extreme levels. What these unusual events in 2017 highlight is the importance of testing plausible extreme conditions in coordination with GLAM's plan evaluation efforts. The GLAM Committee recognizes the importance of continued analysis in this area, particularly in terms of how extreme hydroclimate conditions may be able to impact outflow regulation.

While extremes have happened in the past, there is no doubt that 2017 was a rare event within the historical record. Whether the conditions of 2017 are more likely to happen in the future is difficult to assess. The high water supplies were unforeseen by most seasonal forecasts at the start of the year, indicating that extreme precipitation was not likely in April and May of 2017. In addition, it should be remembered that long-range seasonal precipitation predictions are still very much a work in progress. Research and development of more sophisticated long-term forecasting tools is an involved process requiring multiple years and substantial resources. This is an area of ongoing research globally, but long-range seasonal precipitation predictions will continue to be a challenge going forward. Though the existing forecasting models show some potential improvements in skill over the past couple years, it is unclear how these models could currently be leveraged to assist the GLAM Committee's long-term goals of plan review and evaluation. Furthermore, the accuracy of such forecasts decreases at longer lag times, whereas outflow release decisions would need to be modified weeks or months in advance to significantly reduce the risk of high water levels and flooding on Lake Ontario and the St. Lawrence River.

A preliminary analysis of the implications of varying hydroclimate conditions is initiated in Section 6 of this report and is further described in the Annex 2-Plan Review. Future work in this area is anticipated.

5.0 Impact Assessment of 2017 Water Levels and Flows

5.1 Introduction

This section provides a general overview of impacts experienced across a range of sectors in 2017 throughout the Great Lakes-St. Lawrence system based on observed water levels and conditions. Unless otherwise indicated, there are two geographic regions referred to in describing the various interest categories: the upper Great Lakes (lakes Superior, Michigan, Huron, Erie and the connecting channels) and Lake Ontario and the St. Lawrence River above the dam at Cornwall/Massena and below the dam to Trois-Rivières. **It is important to clarify that this report is not intended to represent a full economic or environmental analysis of high water impacts in 2017. Instead, the intent is to capture the critical types of impacts and get a sense of the geographic distribution to support long-term efforts to validate and improve existing models linking water level changes to impacts and ultimately, evaluate the performance of the outflow regulation strategies that are currently in place. In certain cases, data are still being collected. If and when these datasets become available, the GLAM Committee will look to incorporate the information into future analyses and reports. In general, there is a lack of standard after-event damage survey information collected and reported on by various levels of government. This has been identified as a critical limitation to the GLAM Committee in undertaking model validation activities.**

5.1.1 Performance indicators and coping zones

Six key interest categories are covered in this review, including municipal and industrial water use, commercial navigation, hydropower, shoreline property interests, environmental interests and recreational boating and tourism. All of these sectors are affected by changes in Great Lakes water levels or flows in the connecting channels and all were impacted to varying degrees by high water levels in 2017 across the entire Great Lakes-St. Lawrence Region, particularly on the Lake Ontario-St. Lawrence River system. In documenting impacts and benefits, the GLAM Committee paid particular attention to the existing performance indicators that had been established by the previous IJC studies (both LOSLRS and IUGLS) and had been part of the models used in the evaluation and ultimate selection of the existing regulation plans.

Performance indicators represent a quantifiable measure of the relationship between an economic, social or environmental benefit or cost and different water levels and flows in the Great Lakes-St. Lawrence River system. These relationships must:

- represent something of significance to the interest;
- demonstrate a measurable sensitivity to water level changes; and
- have confidence/certainty in the data and science that support it.

Performance indicators were not meant to be used in isolation or to reflect absolute impacts, rather they were designed to be used in a relative comparison of regulation plan alternatives. They were to represent broader societal impacts and capture outcomes and tradeoffs between interests and over broad geographic scales. A full list of the performance indicators used for both the upper lakes and the Lake Ontario-St. Lawrence River system during the past IJC studies can be found in Appendix 1. The record conditions of 2017 on Lake Ontario and the St. Lawrence River were outside the range of conditions for which data were available to develop the existing performance indicators. Therefore, information from 2017 is critical to support the validation and improvement of a number of the LOSLRS performance indicators and to add new information and give new insights into what is likely to occur under conditions that had only previously been simulated.

Coping zones were water level zones used exclusively during the IUGLS and defined generally by the water level regime (level, range, rate of change, frequency), location and other factors that cause vulnerabilities for a particular interest, such as a lack of resilience. Resiliency can affect any interest's ability to cope with water levels and is defined as the capacity to recover quickly from difficulties (see box below).

The coping zones were defined as a reflection of an interest's ability to "cope" with a given water level regime and included three levels of progressively more challenging water level conditions as follows:

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

The conditions in 2017 on the upper Great Lakes remained within previously defined coping zones established during the IUGLS. Further information on coping zones can be found in Appendix 1.

This section of the report describes each interest category, their general sensitivity to water level fluctuation, and summarized specific positive and negative impacts from the high water levels in 2017. Due to the extensive damages on Lake Ontario and the St. Lawrence River as a result of the record high water levels in 2017, the Annexes have been prepared to provide supplementary details and information for this portion of the Great Lakes-St. Lawrence River system.

RESILIENCY

Resiliency is defined as the ability to recover from or adjust easily to misfortune or change. The GLAM Committee does not use resiliency in the same way as they would a performance indicator or coping zone to evaluate how a change in water levels would affect an interest. Nevertheless, the resilience of an interest plays a big part in how those performance indicators and coping zones are defined. For example, the municipal and industrial interest category tends to be quite resilient to water level changes because the consequences are so large for negative impacts that they tend to be conservative when constructing major plants to ensure service to the public is not interrupted. This, in turn, affects how a performance or coping zone is defined for this interest. Likewise, changes to the commercial navigation industry over the past 10-20 years, such as the inclusion of bow thrusters, improved power-to-length ratios and automatic information systems (AIS), have made them more resilient to water level and flow changes over the years. These changes need to factor back into the algorithms developed for performance indicators in terms of an interest's sensitivity to water level changes.

5.2 Municipal and industrial water use

The municipal and industrial water use impact category broadly considers the impacts of fluctuating water levels on fresh and wastewater treatment for municipalities, industrial users and domestic residential users. It focusses on the importance of having enough water to ensure adequate intake capacity while not having so much water that shoreline infrastructure facilities (e.g. treatment plants) suffer damages.

Total water withdrawals in the upper Great Lakes basin were estimated during the IUGLS at about 112,000 ML/day (29,800 Mgal/day), with four major uses accounting for about 98 percent of the water withdrawals in the upper Great Lakes basin: thermoelectric power generation (75 percent); industrial uses (13 percent); public supplies (nine percent); and, irrigation (one percent). Most of this water is returned to the basin. Consumptive uses (that is, uses that do not return water to the system) account for less than one percent of the outflows (IUGLS, 2012). On Lake Ontario and the upper St. Lawrence River, at the time of the LOSLRS report, it was estimated that about 6.3 million residents along the shores of Lake Ontario and the upper St. Lawrence (both Ontario and the US) rely on water withdrawals from the lake and river and there were about 2.3 million residents who rely on the lower St. Lawrence River (LOSLRS, 2006).

Secure access to clean freshwater has been a driver in development along the Great Lakes-St. Lawrence River. Water withdrawals remain critical for metropolitan areas, customers of public supply facilities, agricultural facilities and the general industry of the Great Lakes and St. Lawrence River. Potential water supply interruptions, therefore, are a concern for the Great Lakes-St. Lawrence River population. Even temporary interruptions can have serious health and financial implications. It is not surprising therefore, that during both the IUGLS and LOSLRS, the IJC found that for the most part, the municipal, industrial and domestic water use category is resilient to water level changes within the historical range (LOSLRS, 2006; IUGLS, 2012). Any vulnerabilities that were found to exist could not be differentiated between alternative regulation plans in either study. Therefore, neither Plan 2012 nor Plan 2014 are expected to make things better or worse for this interest relative to the regulation plans that they replaced. In other words, while impacts are possible at the extremes, they would be expected regardless of the regulation plan. The one exception mentioned was private shore wells, but the data were incomplete and did not allow for a full assessment.

5.2.1 UPPER GREAT LAKES - Municipal and industrial water use

Sensitivity to Water Levels and Outflows: The supply of drinking water and the treatment of wastewater can both be affected by changing water levels. On the upper Great Lakes, quantifiable performance indicators of these impacts were not possible during IUGLS due to the size and scope of the upper Great Lakes and the relatively small differences in levels produced by alternative regulation plans. Instead, water level coping zones were identified to characterize potential operational problems of municipal, industrial and domestic water uses associated with fluctuations in water levels and flows (Bartz and Inch, 2011). Some impacts associated with high water levels include flooding of buildings, erosion and shore protection issues (similar to the coastal interests), infrastructure inundation (such as tunnels) and increased operating costs when infiltration into the plant is higher, thus raising the demand for water (IUGLS, 2012). Impacts associated with low water levels could include increased water quality problems and potential water intake problems if water depths are insufficient. Historically, on the upper Great Lakes, water levels have not caused failures of municipal water intakes and therefore this interest was considered to be fairly resilient to water level fluctuations within the historical range. However, based on surveys of critical water levels reported by many specific facilities along the lakes, extreme levels at or outside the historical range could cause unusable or compromised water intakes, sedimentation problems/increased operations and maintenance requirements and reduced water quality (LOSLRS, 2006; IUGLS, 2012). Potential impacts from extreme water levels at or beyond historical ranges are substantial given the tens of thousands of surface and groundwater intake structures/pipes in place, ranging from high capacity intakes for major metropolitan areas to those for individual household usage. Actions to minimize risks, such as installing flood-proof equipment, improving shore protection, building flood levees under high water or extending intake pipes into deeper water during low water would likely be taken well before a serious crisis condition is reached as the consequences are too great to afford the risk (IUGLS, 2012).

Summary of Observed 2017 Impacts: The GLAM Committee is not aware of high water level impacts directly to municipal water supply systems or wastewater treatment systems found along the upper Great Lakes in 2017.

Model Assessment: For the upper Great Lakes, no specific performance indicator was developed during the IUGLS related to this interest group. This was because the sample size of responses from a survey (questionnaire) of municipal facilities undertaken at the time was not large enough on the various lakes and, in some cases, the survey responses were too vague to develop quantitative relationships to water levels (IUGLS, 2012). Instead, general coping zones guidance was developed (Bartz and Inch, 2011) related to i) the population served by public water systems that are affected at high and low water levels and ii) the number of water withdrawal facilities where problems are expected to occur and/or where operations may cease along with the optimal operating range and levels where modifications are necessary for intakes and outfalls. In 2017, the water levels were within the range that this interest is expected to cope well, based on an understanding developed during the IUGLS. No information was found through media or spot-check phone calls with municipal water facilities that would counter this expectation at this time. While it is expected that the coping zones will need to be reviewed at some point in the future, there was nothing from 2017 that would highlight this as a priority.

Key Findings and Next Steps: Based on the information available, the GLAM Committee is not aware of significant loss of water supply or wastewater service in 2017 due to water level conditions on the upper Great Lakes. Moving forward, the GLAM Committee will look to reassess the coping zones used during the IUGLS and their appropriateness in future assessments.

5.2.2 LAKE ONTARIO-ST. LAWRENCE RIVER - Municipal and industrial water use

Summary of Performance Indicators: There were two primary performance indicators related to municipal and industrial impacts developed during the LOSLRS to capture potential water level impacts to this sector. They were:

- Infrastructure Performance Indicator: "drinking water production plant infrastructure costs required to adapt to critical levels identified" (LOSLRS, 2006)
- Taste and Odor Performance Indicator: "the costs of upgrading municipal drinking water treatment plants to treat taste and odor compounds" (LOSLRS, 2006)

In addition to the identified performance indicators, background information was gathered on other potential impacts as they relate to private self-supplied residential users. Given a lack of data and the relatively small number of users compared with those serviced by the broader public water supply and wastewater treatment facilities (e.g. Figure 5-1), water level criteria were used to identify water levels that were likely to cause problems for self-supply users, but the economic impact was not quantified as part of the overall plan evaluation effort.

Figure 5-1: RC Harris Water Treatment Plant, Toronto, Ontario. Photo Credit: City of Toronto website: https://www.toronto.ca/services-payments/water-environment/tap-water-in-toronto/fast-facts-about-the-citys-water-treatment-plants/.

Sensitivity to Water Levels and Outflows: During the LOSLRS, the general findings for the Lake Ontario and upper St. Lawrence River were that most water levels within the historical ranges could be managed by existing water supply facilities (LOSLRS, 2006). Under extremely low water conditions, the reduced depth of water above intakes leads to reduced plant capacity and this has been identified as a concern for some facilities, particularly in the upper St. Lawrence River. There is also the possibility that taste and odor problems increase under low water conditions, although there are likely other factors that would also contribute to such problems. Under high water conditions, water supply and wastewater infrastructure can be at risk of inundation which reduces service capacity. One particular issue raised in the past on Lake Ontario was the need to sandbag a Monroe County Water Authority pumping station to protect against flooding (LOSLRS, 2006).

On the lower St. Lawrence River, water supply issues relate to taste and odor, frazil ice and reduced intake capacity and these are primarily associated with low water conditions. Three of thirty utilities identified capacity limitations under low water levels. Wastewater treatment plants and outflows can be susceptible to high water conditions but, based on survey results conducted during the LOSLRS, they were not considered overly sensitive and found to be marginal in comparison with the other performance indicators so no high water performance indicator was developed in this category (LOSLRS, 2006).

Summary of Observed 2017 Impacts: High water levels on both Lake Ontario and the St. Lawrence River in 2017 led to some direct impacts for municipal water supply. For example, the Monroe County Water Authority noted that levels were within 1-2 feet of flooding some critical potable water supply infrastructure. Elsewhere in the system and, based on follow up with a number of US water treatment operators, there were also impacts to operations including increased lift station infiltration. While these direct impacts are noteworthy and directly impacted a number of users, the information currently available to the GLAM Committee suggests that most of the larger municipal systems and the millions of customers they serve remained operational throughout 2017 and were generally able to handle the extreme conditions, albeit with adaptive responses in some cases that included sand-bagging. Detailed information is still limited in some areas, particularly on the lower St. Lawrence River, and it is possible that there were impacts that the GLAM Committee is not currently aware of.

On the wastewater side, high water levels created additional operational challenges and caused damages in some areas. In New York, responses from 31 wastewater treatment plants were logged and of those, six reported some degree of negative impacts to plant operations. The most commonly reported impact was storm water infiltration leading to combined sewer overflows and sanitary sewer overflows which could have been the result of high precipitation and runoff and not a direct impact of water levels. Sodus Point in particular reported some sandbagging requirements to protect some lift station facilities. There were also reports of excessive pump operation requirements in the towns of Sodus Point, Clayton and Ontario, NY. In addition to these impacts, a number of operators also reported an increase in the frequency of times when untreated sewage was released and partly attributed that to a higher amount of infiltration into the sewage system due to high water levels. It is unclear, based on the current responses, what other factors (such as excessive precipitation) contributed to those incidences. The City of Hamilton, ON noted that high lake levels reduced the capacity of some of their combined sewer overflow tanks as they were submerged by lake water, particularly their Strachan and Eastwood facilities (City of Hamilton, 2017). There were also many examples where drainage (sewer) capacity was reduced in low lying areas immediately adjacent to the shoreline, requiring operational investments by municipalities (e.g. portions of Sodus Point, Monroe County, Niagara-on-the-Lake, Hamilton, Toronto, etc.).

The GLAM Committee has not yet identified any locations where primary wastewater treatment facilities could not be operated due to the high water conditions. Detailed information is still limited in some areas, particularly on the lower St. Lawrence River, and it is possible that there were impacts that the GLAM Committee is not currently aware of.

Information on impacts to industrial water users is not readily available at this time and information on impacts to self-supply domestic water users is limited. Certainly, there were reports of impacts to shore wells and septic systems (both inundation and erosion of leach beds) and this was reported through the responses received to an online, self-reporting questionnaire distributed to property owners by Conservation Ontario (see box below; Figures 5-2 and 5-3). Based on the on-line questionnaire results, impacts to shorewells were reported most predominately in Prince Edward County and Lennox and Addington County on the Lake Ontario shoreline within the Province of Ontario and in Jefferson and Monroe counties on the New York shoreline. While the reported numbers were higher in the US, a larger percentage of Canadian respondents reporting impacts to shore wells. The GLAM is not able to quantify the extent of those impacts at this time as the GLAM surveys do not represent a statistically representative sample and it was not possible for the GLAM Committee to determine if the impact was directly related to high water levels, or caused by the excessive rain, runoff and high groundwater tables.

Further information on Lake Ontario-St. Lawrence River municipal and industrial impacts can be found in Annex 1-Impact Assessment of this report. There are still gaps in available information and the GLAM Committee is gathering further data from municipal and industrial operators. That work is expected to be completed by April 2019.

SHORELINE PROPERTY OWNERS IMPACTS

In 2017, the GLAM Committee initiated a process to help gather information on impacts from high water conditions on shoreline property owners. The GLAM Committee effort complemented and extended a previous **independent** survey effort undertaken by the New York Sea Grant and Cornell University for the New York shoreline earlier in 2017 (New York Sea Grant and Cornell University, 2018). For the GLAM Committee effort, the IJC contracted Conservation Ontario to develop and implement an on-line, self-reporting questionnaire that property owners could complete (based in part on questions used previously in the New York Sea Grant and Cornell Survey). The questionnaire was designed to gather information on the type and extent of shoreline impacts. Conservation Ontario provided a brief project summary and the GLAM Committee often refers to this as the Conservation Ontario survey. However, the GLAM Committee has continued to work with the results for analysis and reporting purposes and is the basis for a number of maps and graphs in the impact assessment sections of this report.

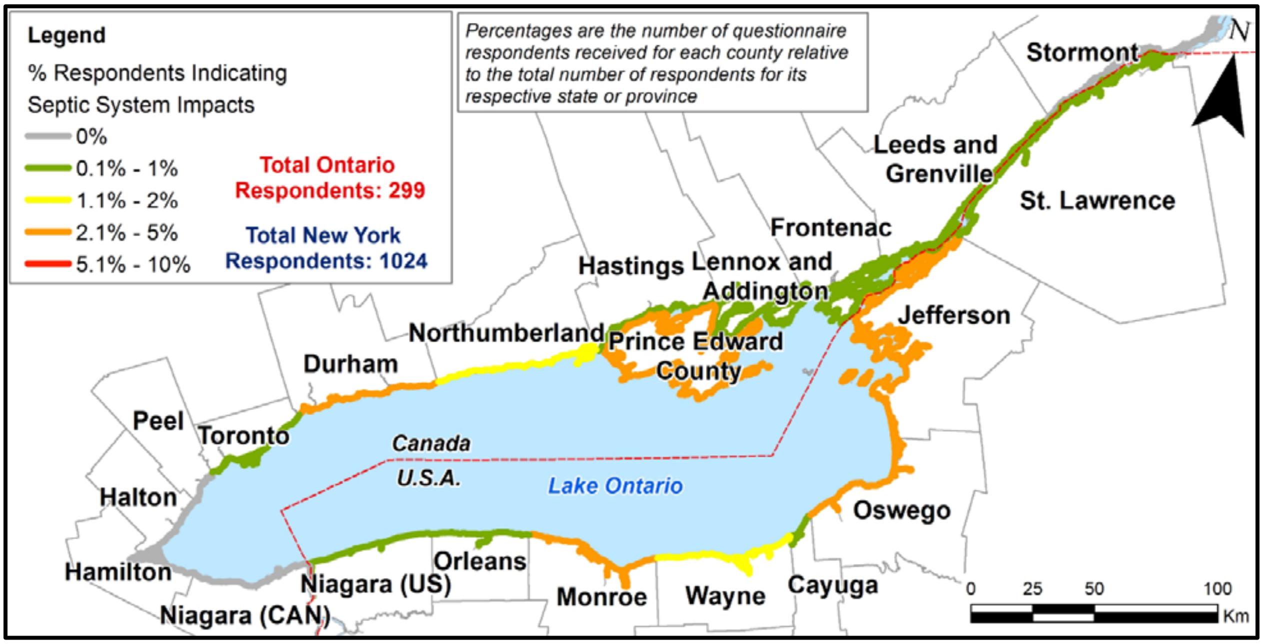
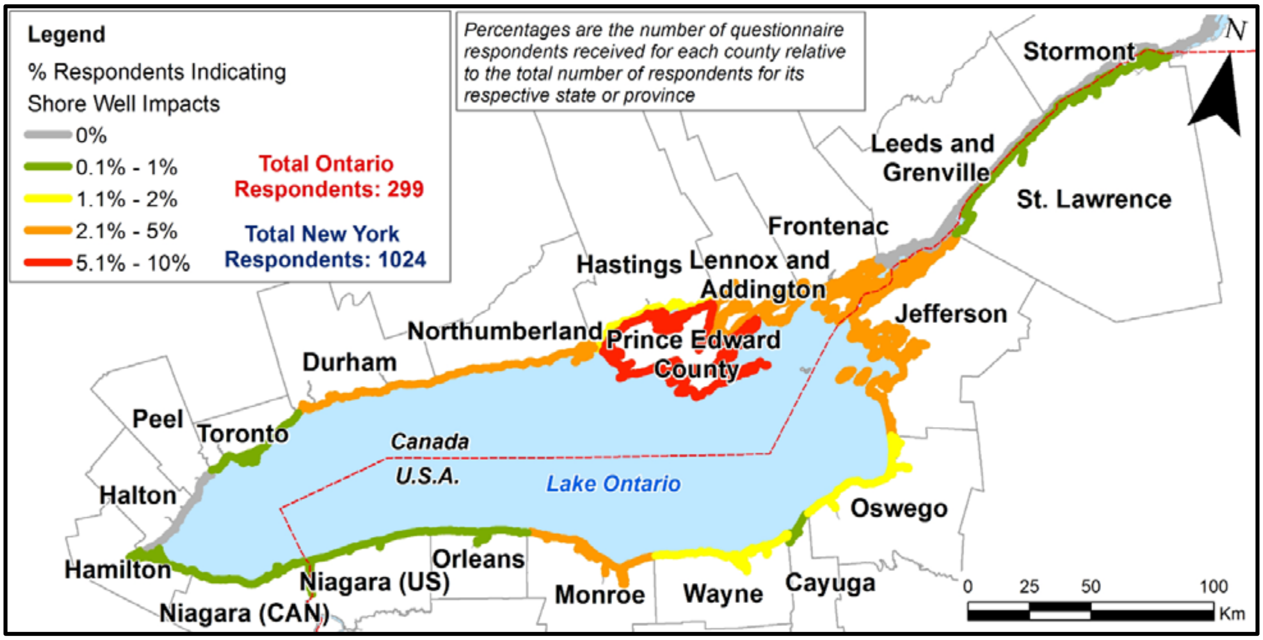


Figure 5-2: Percent of survey responses indicating septic flooding (shown as a relative % by County relative to total number of that reported impact for Country) (Source: ECCC, based on data acquired through Conservation Ontario survey for IJC)



Percentages are the number of questionnaire respondents received for each county relative to the total number of respondents for its respective state or province

Figure 5-3: Percent of survey responses indicating shore well flooding (shown as a % by County relative to total number of that reported impact for Country) (Source: ECCC, based on data acquired through Conservation Ontario survey for IJC)

Model Assessment: Based on the information and performance indicators developed during the LOSLRS, the vast majority of municipal water supply and wastewater services would be expected to remain operational during high water levels within the historical range. Water levels exceeded historic maximums in 2017 but, based on the limited preliminary information available (mainly from direct follow up with a few operators from the US shoreline), it appears that the vast majority of service on Lake Ontario was able to be supplied in 2017, which is consistent with the conclusions in the LOSLRS. However, there were reports of specific operational challenges and adaptive responses in some locations, as well as more general challenges with drainage in low lying areas serviced by municipal sewer networks on Lake Ontario that are not captured in the current performance indicators and require further assessment by the GLAM Committee to determine whether they should be represented in the impact models, and if so, how. In addition, 2017 conditions may shed light on potential high water impacts to self-supply domestic water users that were not captured in the impact models developed during the LOSLRS. It is expected that similar issues would have been observed on the lower St. Lawrence River, but the GLAM Committee has little information available for lower St. Lawrence River impacts at this time. Efforts are underway to initiate a contract to survey a number of municipal and industrial facilities on both Lake Ontario and the St. Lawrence River and gather further information in support of longer-term GLAM Committee activities. The GLAM Committee has little validation information available regarding industrial water users and it is not yet clear how that gap will be filled. Once gathered, further processing and review of the impact information is needed before a full comparison can be completed between results from the existing models and observed conditions.

Key Findings and Next Steps: Based on the limited information currently available to the GLAM Committee, there were impacts and operational responses required in a number of locations on Lake Ontario and the St. Lawrence River due to high water levels in 2017 that caused direct impacts to some users. However, users of larger municipal water and wastewater systems were able to rely on the necessary services in 2017 despite the extreme high water conditions. Less information is currently available regarding self-supply residential users and industrial users. Based on responses to the self-reporting survey, impacts in those categories were not evenly distributed along the Lake Ontario shoreline.

There were no reported impacts to industrial water users due to the 2017 events, but this is not to say there weren't any. Industry responses to enquiries were incredibly sparse. It is not conclusive to say that the handful of responses indicating no impacts is an accurate representation of the entire industrial community on Lake Ontario and the St. Lawrence River.

The performance indicator for evaluation of municipal and industrial water users on the Lower St. Lawrence River is "based on the cost of upgrading municipal drinking water treatment plants to treat taste and odor compounds" and "based on costs required to adapt plants to lower than critical levels" and while no high water level concerns were expressed for water treatment plants, high water levels were suspected to have an impact on wastewater treatment plants in the case of floods. Even in this situation, most of the wastewater outfalls on the St. Lawrence River are equipped with check values protecting them from backflow (LOSLRS, 2006 - Annex 2). Information on the costs of any plant upgrades or renovations was unattainable from 2017, highlighting the challenges in assessing impacts to this sector. Given the lack of data for this sector, the GLAM Committee is seeking to collect information from municipal and industrial operators on the Lake Ontario – St. Lawrence River system on impacts and thresholds associated with 2017 conditions to support long-term adaptive management activities.

5.3 Commercial navigation

Commercial navigation captures domestic and international fleets of bulk carriers, tankers, barges and other commercial ships transporting goods in the Great Lakes-St. Lawrence Seaway system (IUGLS, 2012; IJC, 2014) as well as ocean-going vessels that call on the Port of Montreal (Figures 5-4 and 5-5). There are four key geographical sections that are considered for commercial navigation: the upper Great Lakes from Lake Erie above the Welland Canal through to Duluth, MN on Lake Superior; Lake Ontario (and the Welland Canal connecting Lake Erie to Lake Ontario); the Lake Ontario Section of the St. Lawrence Seaway to Montreal (Montreal Harbour to Lake Ontario); and the St. Lawrence Navigation Channel (Port of Montreal to Trois-Rivières) which can accommodate ocean-going vessels larger than those that can transit the Seaway. An estimated 237,868 jobs and $35 billion in economic activity have been attributed to the Great Lakes-St. Lawrence River system (not including the economic benefits of container movements to and from the Port of Montreal to overseas markets) (Martin and Associates, 2018). Commerce transiting the St. Lawrence Seaway portion (Lake Erie to the Port of Montreal) supported 92,661 jobs and $12.9 billion in economic activity. The Port of Montreal is the highest volume container port in eastern Canada and one of the fifteenth largest in North America. This port handles more than 35 million tons of cargo annually and over 1.2 million Twenty Foot Equivalent Units (TEUs) containers (Port of Montreal, 2018). The Port of Montreal supported 2,673 direct jobs in 2017 (Martin and Associates, 2018)

During the IUGLS, in consultation with experts of the Great Lakes -St. Lawrence River navigation community, the IJC concluded that the current Lake Superior outflow regulation plan, Plan 2012, would provide additional economic benefits in terms of transportation costs to commercial navigation interests. The plan was compared under a wide variety of wet and dry water supply conditions with the old regulation plan (Plan 1977A) and was found to provide a more robust plan that performed better under a wide range of potential future water supply scenarios. During the LOSLRS, the IJC, in consultation with experts of the Great Lakes -St. Lawrence River navigation community, concluded Plan 2014 would provide about the same benefits as Plan 1958-DD by including rules to support adequate levels for full-draft ships at all points in the navigation channel, from Lake Ontario to Lake Saint-Louis. It would also maintain about the same transportation costs related to the need to light-load ships as a result of limited draft depths during low water levels and similar costs related to delays from high velocities during high outflows.

Figure 5-4: Port of Montreal. Photo credit: Montreal Port Authority, 2012.

Figure 5-5: Map of the Great Lakes –St. Lawrence Seaway

5.3.1 UPPER GREAT LAKES – Commercial navigation

Sensitivity to Water Levels and Outflows: Outflow regulation under Plan 2012 affects water levels and flows throughout the upper Great Lakes system, most notably in the St. Marys River and including the "Rock Cut" channel on the west side of Neebish Island, south of Sault Ste. Marie, MI where water levels are particularly sensitive to changes in outflows from Lake Superior as well as low water periods that occur during relatively dry periods (Figure 5-6). Commercial navigation is particularly sensitive to low water conditions, which can require reduced navigation speeds and draft and a reduction in cargo carried. The shipping industry in the upper Great Lakes generally benefits from higher levels, as ships can carry more cargo with fewer trips. The above average water levels throughout the Great Lakes-St. Lawrence system in 2017 should, therefore, have been generally beneficial to commercial shipping, but this is only when moderately high water levels are observed, as was the case for the upper Great Lakes in 2017. Impacts increase with more extreme levels and several expensive mitigation measures must be imposed to maintain safe navigation, as was experienced on the lower part of the system on Lake Ontario and the St. Lawrence River in 2017, but not on the upper Great Lakes. Higher water levels also can damage and disable loading/unloading facilities and impact safe operation of navigation locks if levels reach the top of approach walls or lock gates (IUGLS, 2012).

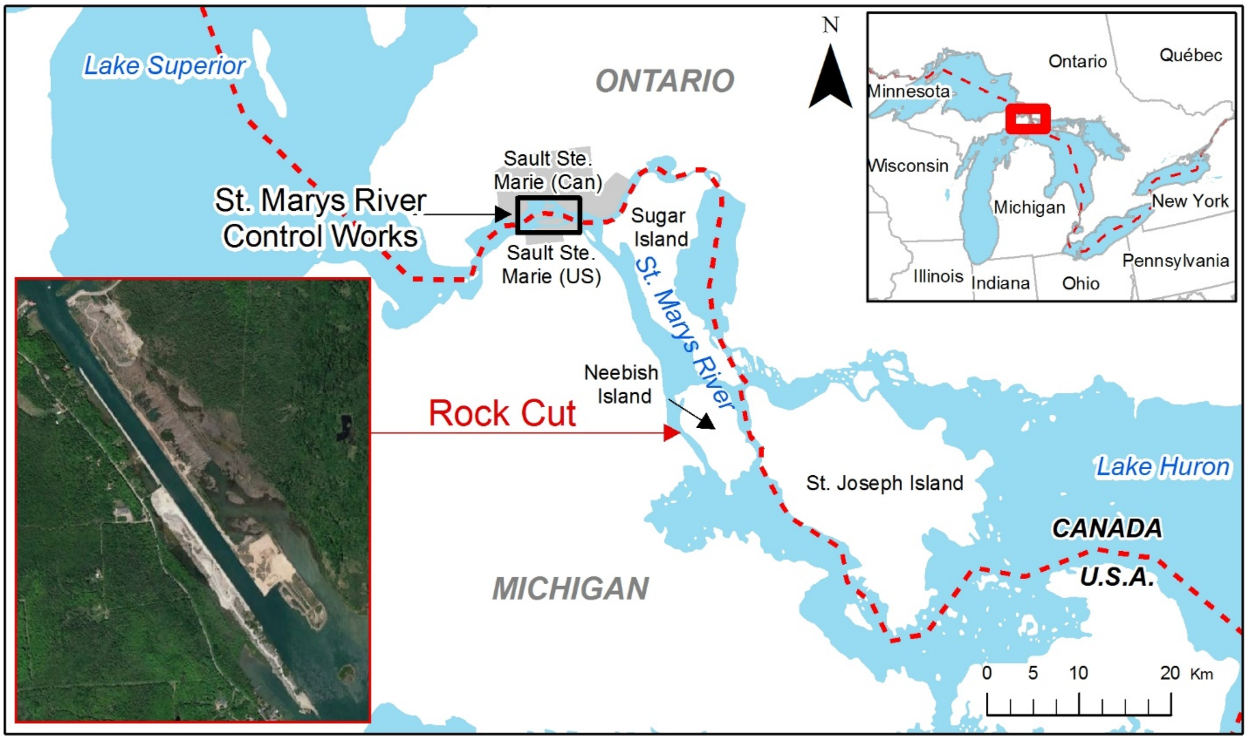


Figure 5-6: Location of "Rock Cut" leading into the St. Marys River (Source: ECCC)

Summary of Observed 2017 Impacts: The year 2017 saw higher water levels on all the Great Lakes. On the upper Great Lakes, a particular area of concern for shippers is typically the St. Marys River and Rock Cut (Figure 5-6). Flow, velocity and depth may limit the carrying capacity in these locations more so than the dock depths, however there were no impacts on the upper portion of the system found in 2017.

Table 5-1 compares the monthly freight tonnage passing through the St. Marys Falls Canal for 2016 and 2017. Single trip tonnage records were set in August and September 2017 at the Soo Locks. These higher monthly tonnages were mostly a result of the economic demand for raw material and not a direct result of higher water levels; however, the higher water levels provided the opportunity for the single trip tonnage records to occur. Had levels been below chart datum, the tonnage records would not have been set.

Table 5-1: Freight Tonnage moved through the St. Mary Falls Canal in 2017 (Source: US Army Corps of Engineers, Detroit District, Soo Area Office)

Freight Tonnage moved through the St. Marys Falls Canal			
Month	**2016 Net Tons**	**2017 Net Tons**	**Increase/Decrease**
March	999,703	1,423,568	423,865
April	6,214,977	7,045,959	830,982
May	7,159,615	8,125,048	965,433
June	7,540,657	8,552,164	1,011,507
July	7,236,489	8,692,701	1,456,212
August	7,446,741	8,645,393	1,198,652
September	7,789,090	8,946,754	1,157,664
October	7,315,668	7,676,940	361,272
November	6,844,907	7,882,489	1,037,582
December	6,783,280	7,076,676	293,396
January	2,148,641	1,264,176	-884,465
Total	67,479,768	75,331,868	7,852,100

Model Assessment: During the IUGLS, an economic performance indicator was developed for commercial navigation based on shipping costs along each route at different depths in each calendar month. Coping zones were also developed for the interest based on “ideal conditions” for the shipping industry (Zone A) and those at which the impact from changing water levels would begin to arise. These coping zones were developed on a lake-wide scale (one for each upper Great Lake) and for the southwest pier of Lake Superior (St. Marys River). Based on this assessment, the levels and flows experienced during 2017 were expected to provide generally positive conditions for shipping and were within the “A” coping zone and range of water levels the shipping industry would find tolerable.

The USACE Detroit District maintains a database to track tonnage passing through the Soo Locks. The GLAM Committee members are working with the Soo Lockmasters and USACE Federal Navigation team to collect monthly tonnage data and historic annual tonnage data to compare to lakes Superior and Michigan-Huron water levels (with respect to chart datum). In order to capture some of the inter-lake shipping routes, federal harbor data can be gathered from the USACE Detroit District Operations Office and Federal Navigation team to determine which docks are most susceptible to varying water levels. A quick analysis of the monthly tonnage data and water level data from the past six years is shown in Figure 5-7. Note the slight increase in tonnage in 2014, which followed a number of consecutive low water years (2000-2013).

Although this is a narrow dataset (only six years), it is unlikely that regulated water levels are the main determinant of shipping traffic through the Soo Locks. There are economic and market supply and demand factors to be considered. Was there a high demand for a specific commodity in 2014, for example? Was there an economic reason? Further analysis of general sector trends would be prudent for commercial navigation.

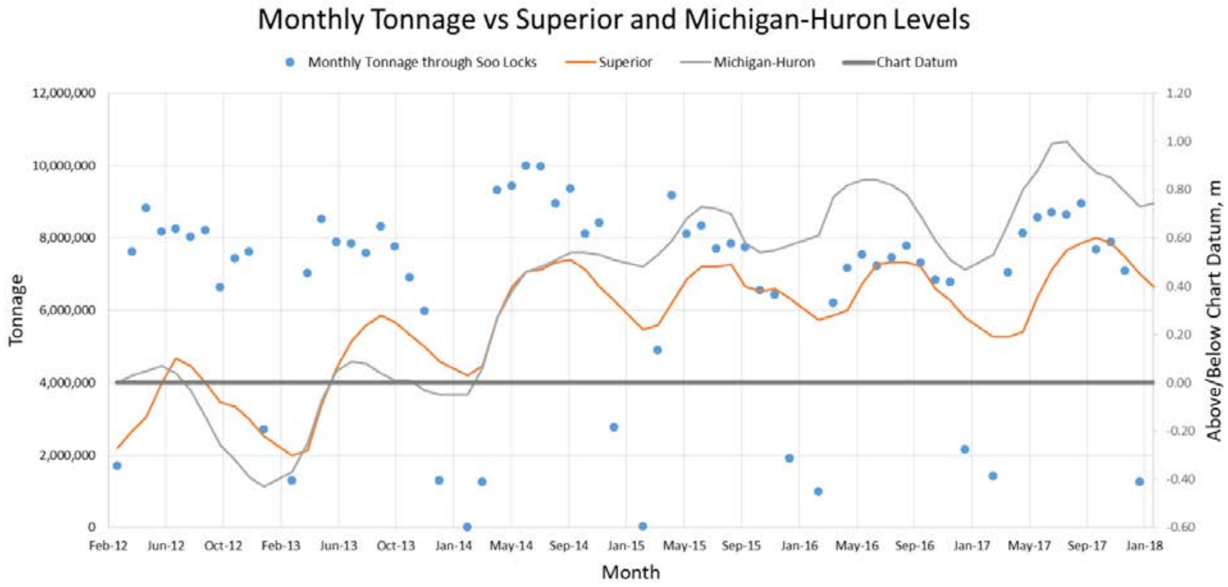


Figure 5-7: Monthly tonnage on Lake Superior and Lakes Michigan-Huron (Source: USACE, Detroit District)

The GLAM Committee was already considering the need for a new model of shipping costs, largely because the data used to develop the previous IUGLS performance indicators are outdated and do not capture the technological advances on some ships which allow them to transit more efficiently and safely. As well, navigation impacts in one area can have corresponding or related effects elsewhere in the system, so a system-wide model to replace the existing separate Lake Ontario – St. Lawrence and upper Great Lakes models makes sense.

Key Findings: On the upper Great Lakes, 2017 levels were within the “A” coping zone which means that the commercial docks inventoried during the IUGLS had sufficient dock depths and dock heights for ship accessibility. Levels during 2017 ranged from 45 cm (1.5 ft) to 1.2 m (4 ft) above chart datum across the upper Great Lakes which is within the criteria for increased water levels while maintaining minimum dock heights. The one exception was at the Detroit River where the reported three-foot increase in level would be acceptable for 96% of the docks. Levels on Lake St. Clair (the Detroit River reference point) were 0.76 m to 1.2 m (2.5-4 ft) above chart datum which would mean some docks inventoried during the IUGLS would be inaccessible due to flooding. However, there were no reports of such incidents. It is possible that the reference point of Lake St. Clair may be too conservative and needs to be replaced with Low Water Datum elevations for the Detroit River, specifically. Further investigations will occur in the future. As well, as discussed in the model assessment section, a full Great Lakes-St. Lawrence River commercial navigation model should be considered.

5.3.2 LAKE ONTARIO-ST. LAWRENCE RIVER – Commercial navigation

Sensitivity to Water Levels and Outflows: Outflow regulation under Plan 2014 affects water levels and flows throughout Lake Ontario - St. Lawrence River system downstream to about Trois- Rivières, and commercial navigation occurs and is affected by these conditions throughout this area, including the Montreal to Lake Ontario (MLO) portion of the St. Lawrence Seaway and at the Port of Montreal. Commercial navigation is particularly sensitive to low water conditions, which can at times require reduced navigation speeds and draft reductions, which result in reduced cargo carried and increased costs. Therefore, critical commercial navigation priorities on the Lake Ontario - St. Lawrence River system include the need to reduce the risk of low water levels throughout the system and maintain the continued ability of the board to accommodate, as necessary and when conditions permit, transit of particular vessels through short-term minor deviations. The stability and predictability of water levels, high or low, can also be a critical factor, particularly in the St. Lawrence River, as loading decisions are sometimes made weeks in advance for international vessels arriving in the Port of Montreal and those transiting the Seaway. Stable and predictable levels help to minimize risks of groundings, loss of control, collisions, oil/chemical spills and issues related to safe transit velocities. In terms of high water impacts, high levels typically result in higher outflows and velocities in the St. Lawrence River, which can also be a serious concern to commercial navigation due to increased risks (of groundings, loss of control, collisions, oil/chemical spills) and issues related to safe transit velocities. If water levels at Iroquois Lock were to reach 75.61 m (248 ft.), the lock would be flooded, and its operation would no longer be possible, stopping shipping until levels fall below this threshold.

Summary of Observed 2017 Impacts: The year 2017 saw the highest flows ever recorded over a sustained period of time on the St. Lawrence River. These flows required the shipping industry to take exceptional measures to ensure safe transit and prevent a shutdown of the Seaway. High water level problems which lead to velocity issues in portions of the Seaway have been a concern in the past and were among the primary issues during the 2017 record high water level conditions (with record outflows of up to 10,400 m^3/s). As Lake Ontario levels declined and high flows remained, the Seaway was also concerned with low levels in Lake St. Lawrence.

The biggest commercial navigation impact in 2017 related to the exceptional flows in the St. Lawrence River and the implementation of a series of mitigation measures (i.e., restrictions imposed and services added by the Seaway to ensure safe vessel transits could continue despite the challenging conditions). These measures included:

- speed restrictions between Iroquois Lock and Tibbets Point (imposed starting 2 May)
- caution that fenders on approach wall at Iroquois Lock may not be visible (3 May)

- additional speed restrictions for the St. Lawrence River from Lake Saint-Louis to Lake Ontario (8 May and 15 May)

- no meeting or passing permitted in critical areas (American and Brockville Narrows, Wiley-Dondero Canal; 16 May revised 19 May)

- request to exercise caution when navigating in areas of high cross currents (Galop, Toussaint and Ogden Islands, Copeland Cut and Polly's Gut; 16 May)

- request for mariners to operate at the lowest safe speed to minimize wake, particularly near shoreline areas (16 May)

- zero tolerance for ships' draft in excess of the maximum permissible draft and reminder to operate at the lowest safe speeds to minimize ship wake, particularly when navigating close to shore (13 June)

- a number of transit requirements (13 June), including:
  - requirements that all ships equipped with a bow thruster shall have the bow thruster operational when transiting the Montreal to Lake Ontario section of the Seaway;
  - all Tall Ships and Tows (Tug/Barge) transiting the Montreal to Lake Ontario section of the Seaway shall be capable of making a minimum of 8 knots through the water;
  - no transits of Dead Ship tows permitted; and
  - ships unable to transit safely at these flows may be subject to transit restriction

- assignment of ship inspectors to mission-critical navigation monitoring (13 June), cancelled (23 June)

- modifications to critical areas identified as no meeting or passing zones (American and Brockville Narrows and Wiley-Dondero Canal; 13 June)

- tug assisted ships at Iroquois lock as and when requested (14 June)

- no ship meets downstream of Beauharnois Lock 3 (14 June) due to high outflows from Pointe des Cascades control dam and the increased cross-currents

- request to exercise caution when navigating in additional identified critical areas in the vicinity of Cardinal and Canada Island (20 June)

- draft reduction to 8.0 m for upbound vessels in the Montreal to Lake Ontario (MLO) section (27 June)

Table 5-2 provides a list of the mitigation measures taken and the timeline for implementation, while Figure 5-8 illustrates Lake Ontario water levels and outflows during the period that mitigation measures were in effect.

Table 5-2: Timing of Seaway Imposed Mitigation Measures

SEAWAY-IMPOSED MITIGATION MEASURE	DATES IN 2017 MEASURE WAS APPLICABLE (NOTE: only key dates included here to shorten timeline illustration)																						
	5/2	5/3	5/7	5/8	5/14	5/15	5/16	5/18	5/19	6/12	6/13	6/14	6/20	6/22	6/23	6/27	7/23	7/24	8/10	8/11	8/22	9/14	10/2
Speed restrictions Iroquois Lock to Tibbets Point	■	■	■																				
Notice that Iroquois Lock fenders may not be visible		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
Further speed restrictions (South Shore Canal to Tibbets Point)				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
Further speed restrictions (Brockville Narrows to Prescott)						■	■	■	■	■	■	■	■	■	■	■	■	■					
No meeting/passing in critical areas							■	■															
No meeting/passing in critical areas (revised)									■	■													
No meeting/passing in critical areas (revised)											■	■	■	■	■	■	■	■	■	■	■		
Caution for navigating in high cross current areas							■	■															
Caution to minimize wakes							■	■															
Reminder to minimize wakes											■	■	■	■	■	■	■	■	■				
Zero tolerance for exceeding maximum permissible drafts											■	■	■	■	■	■	■	■	■				
Bow thrusters must be operational											■	■	■	■	■	■	■	■	■	■	■	■	
Tall Ships & Tows capable of 8-knot minimum											■	■	■	■	■	■	■	■	■	■	■	■	
No Dead Ship tows											■	■	■	■	■	■	■	■	■	■	■	■	
Transit restricted for ships unable to transit safely											■	■	■	■	■	■	■	■	■	■	■	■	
Ship inspectors reassigned to monitor navigation											■	■	■	■									
Tug assisted ships at Iroquois lock as and when requested												■	■	■	■	■	■						
No meets downstream of Beauharnois Lock 3 (high outflows/cross-currents)												■	■	■	■	■	■	■	■	■	■	■	■
Caution for strong currents Cardinal to Canada Island													■	■	■	■	■	■	■	■	■	■	■
Upbound draft reduction to 8.0 m																■	■	■	■				
Lake Ontario water level (m IGLD 1985)	75.58	75.59	75.74	75.76	75.84	75.85	75.85	75.87	75.86	75.82	75.81	75.80	75.77	75.76	75.80	75.80	75.65	75.66	75.50	75.49	75.37	75.09	74.92
Lake Ontario outflow (m3/s)	7250	7010	6210	6390	7910	8320	8720	9210	9260	10190	10210	10290	10400	10400	10420	10390	10390	10390	9880	9920	9870	8960	8620

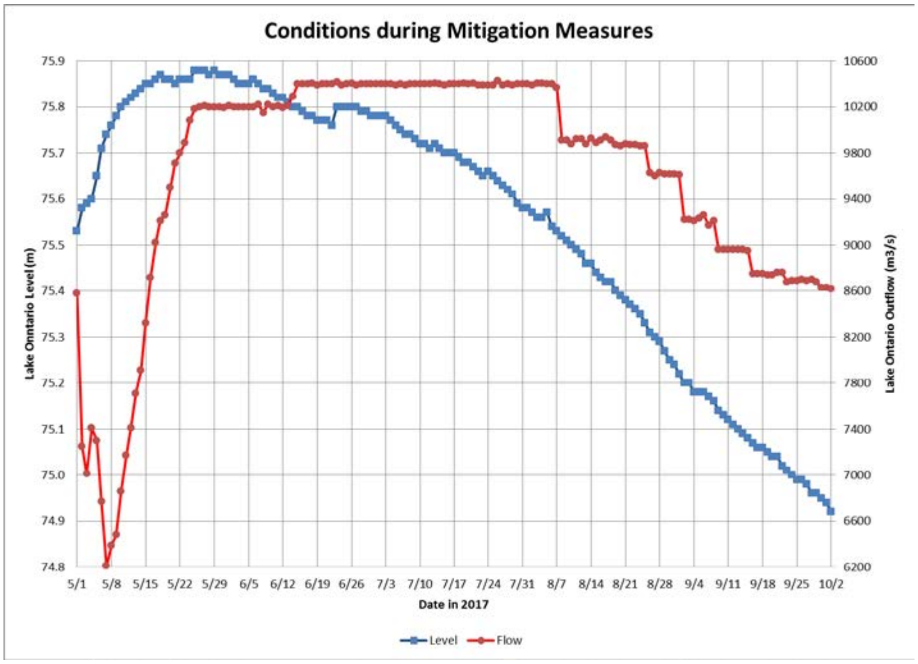


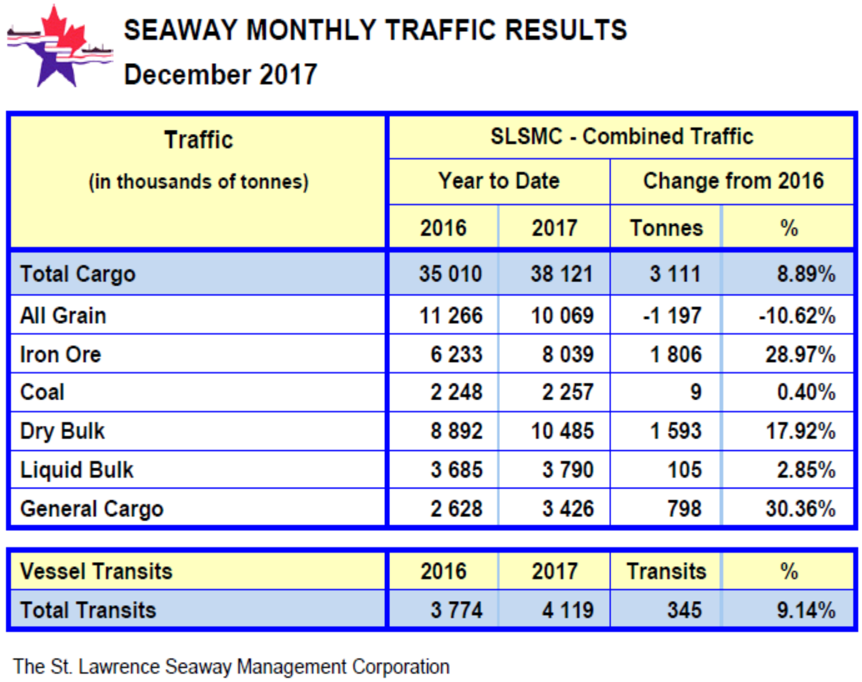
Figure 5-8: Graph showing Lake Ontario water levels and outflows during the period that mitigation measures were in effect.

These mitigation measures resulted in the maintenance of safe navigation in more challenging conditions. Decreased maneuverability, ship speed management and increases in ship rental costs were the main impacts to the trade. Fuel costs also went up as a result of the delays. In their report on "Navigation at High Flows – 2017", the St. Lawrence Seaway Management Corporation (SLSMC,2018) reported that transit times increased by two or more hours from the typical 24-hour upbound transit or 22-hour downbound transit times through the MLO section, as ships took the necessary precautions to safely navigate the system (especially during the period when flows were 10,200 m^3/s or higher). Iroquois Lock proved to be the most impacted by the high flows as vessel approaches to the lock both downbound and upbound were considerably more difficult. The tug that was made available for assistance was used on a regular basis, either assisting with the use of lines or simply being on stand-by in the event it was needed. Sixty-one percent of vessels requested tug assistance, with more requests by downbound vessels.

Another impact, albeit a lesser one, was the reduced number of "walk-throughs" performed at Iroquois Lock (i.e., ships moving through the locks without the use of mooring lines). Typically, there are approximately 1500 walk-throughs per year at Iroquois, but in 2017 there were only 72 recorded walk-throughs (all in March and April, prior to the higher flows). This translated to slower lockage time as lock personnel had to secure mooring lines. There was also reduced availability of ship inspectors for ship inspections due to their reassignment to the critical command center in the SLSMC Operations Center from 13 to 23 June, so that a marine officer would be on duty at all times. Nevertheless, despite the mitigation measures imposed and the challenging conditions many ships faced in 2017, the St. Lawrence Seaway reported 4,119 vessel transits, up nine percent from 2016. Total cargo transported was also up almost nine percent from 2016 (Table 5-3).

The Port of Montreal had some minor impacts from the high water levels, most notably some pavement and concrete were damaged at the port due to inundation and erosive action during the spring. As well, some ships needed to be moved around the port to avoid their hulls riding up onto the docks. Power to many docks had to be cut as a safety measure from 7 to 17 May 2017, when water levels reached +3 m (+9.8 ft) above chart datum at Pier 1. Despite these impacts, the Port of Montreal generally benefited from the high water levels, reporting record loads of 37.8 million tons (Mt) in 2017. This broke the previous record, set in 2016, of 35.4 Mt.

Table 5-3: Statistics on commercial navigation traffic through the Seaway (Source: St. Lawrence Seaway Management Corporation, 2017)



SEAWAY MONTHLY TRAFFIC RESULTS
December 2017

Traffic (in thousands of tonnes)	SLSMC - Combined Traffic			
	Year to Date		Change from 2016	
	2016	2017	Tonnes	%
Total Cargo	35 010	38 121	3 111	8.89%
All Grain	11 266	10 069	-1 197	-10.62%
Iron Ore	6 233	8 039	1 806	28.97%
Coal	2 248	2 257	9	0.40%
Dry Bulk	8 892	10 485	1 593	17.92%
Liquid Bulk	3 685	3 790	105	2.85%
General Cargo	2 628	3 426	798	30.36%

Vessel Transits	2016	2017	Transits	%
Total Transits	3 774	4 119	345	9.14%

The St. Lawrence Seaway Management Corporation

Model Assessment: High velocities in the Seaway between Ogdensburg and Long-Sault would be expected under conditions such as those experienced in 2017 as would variable water levels at different points in the river due to the high discharges. In the existing commercial navigation model, such conditions would result in an increase in transportation costs through the system (a negative impact) due to increased fuel usage, longer transit times and in some cases reduced loading capacity. The record water level and flow conditions of 2017 offered a rare opportunity to measure ship performance and impacts to commercial navigation under high channel velocities on the St. Lawrence River. Mitigation measures taken by the shipping industry in 2017 all relate to transportation delays/costs. Mitigation measures taken by the industry due to high velocities and the associated costs of such measures could help in the development of a new system-wide commercial navigation model. An updated model would allow for further assessment of the existing Plan 2014 L-Limit rules established for safe navigation and additional discussion is included in the Annexes to this report. It is not yet clear if a performance indicator using transportation costs will be possible because impacts to individual shipping companies and cargo owners are not readily available in a form that can be shared. Mostly due to the fact that these results concern highly proprietary details on business contracts and commercial trade patterns. It may be that some other metric is necessary and further work on this will be required.

Key Findings: While commercial navigation experienced impacts due to high velocities on the St. Lawrence River, they also were able to tolerate higher flows than expected or than had ever occurred before without shutting down navigation. Overall, despite mitigation measures, it was a very productive year for the commercial navigation sector, largely due to economic demand.

The GLAM Committee did not validate the model using the 2017 level and flow data to measure how well it estimated shipping impacts in these extraordinary conditions but may do so in the future as part of an effort to improve the navigation model.

The data used to develop the transportation cost performance indicator for commercial navigation on Lake Ontario and the St. Lawrence River is out of date and needs updating/modifying and this should be considered a high priority. In order to accomplish this, the GLAM Committee intends to review the transportation cost performance indicator based on information gained in 2017 to update the performance indicator for the shipping sector. As noted in the model assessment section, it is not yet certain if transportation costs will be possible due to highly proprietary details on business contracts and commercial trade patterns. It may be that some other metric is necessary and further work on this will be required.

5.4 Hydropower

The hydropower generation interest represents “owners/operators of the hydroelectric generating stations on the Great Lakes-St. Lawrence River system and the value of energy produced”. On the upper Great Lakes, there are two hydropower generating stations located on the US side of the St. Marys River, at Sault Ste. Marie, MI – the US government and Cloverland Electric Cooperative (CEC) stations. There is one station on the Canadian side, the Francis H. Clergue Generating Station, owned and operated by Brookfield Renewable Energy, Inc., at Sault Ste. Marie, ON. The three stations on the St. Marys River have a combined capacity of about 115 MW. The IJC’s Orders of Approval govern use of water by hydropower stations along the St. Marys River and the IJC’s ILSBC ensures outflows are released from Lake Superior in accordance with these Orders.

Further down the system there are three hydropower plants located on the Niagara River separating the upper Great Lakes from Lake Ontario because of the Niagara Escarpment. The Robert Moses dam (owned and operated by NYPA) is located at Lewiston, NY and has a total generating capacity of about 2675 MW (Figure 5-9). On the Canadian side, Sir Adam Beck 1 and Sir Adam Beck 2 generating stations (owned and operated OPG) are located across the border at Queenston, ON and have a total generating capacity of about 2,000 MW. These stations generate much more electricity than those on the St. Marys River because of the higher head made possible by the drop over the Niagara Escarpment and the higher flow of the Niagara River. Several smaller generating plants, with a total capacity of about 180 MW, also use the waters of the Welland Canal. The amount of water available for the plants on the Niagara River and Welland Canal depends on Lake Erie’s level and its outflow as well as the Niagara River Treaty of 1950.

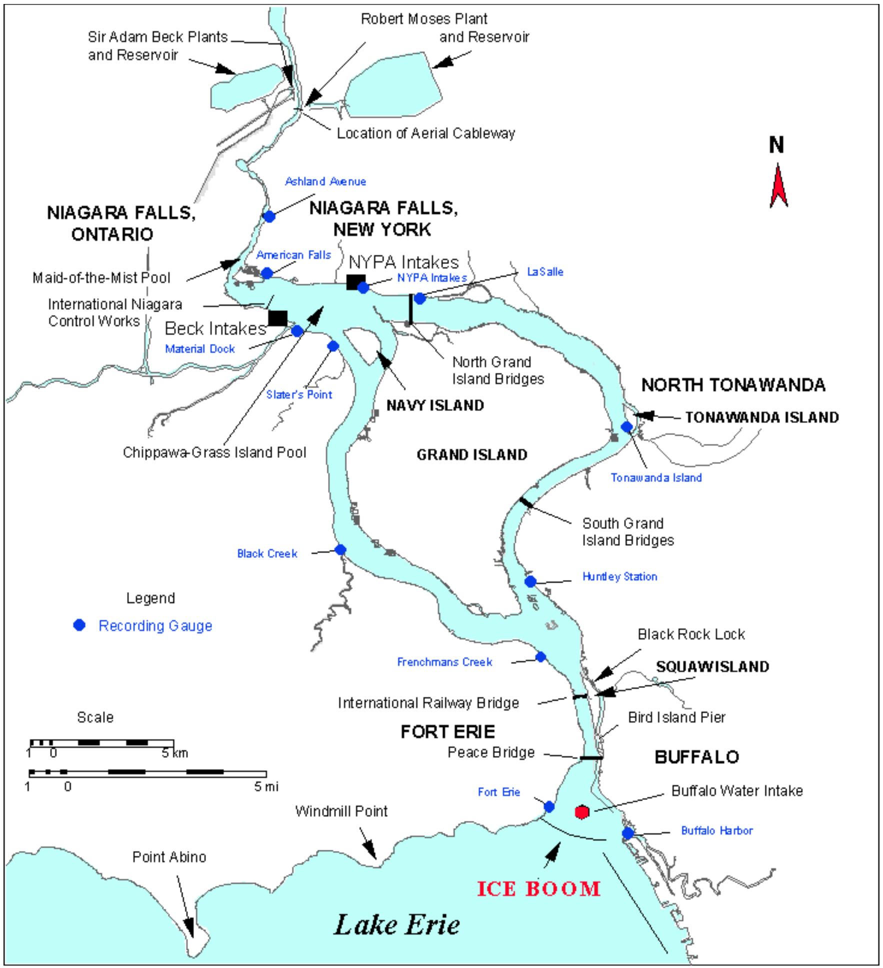


Figure 5-9: Locations of Beck and Moses Dams (Source: INBC 130th Semi-annual report: 28 March, 2018)

Moving down the system, two hydroelectric generating stations are located on the international section of the St. Lawrence River located between Massena NY and Cornwall ON, including the Robert Moses station owned and operated by the NYPA and the Robert H. Saunders station owned and operated by OPG. Together, these stations are known as the Moses-Saunders Dam. Further downstream at the outlets of Lake St. Francis are the Beauharnois and Les Cedres stations of Hydro-Quebec (IJC, 2014). Combined, these power plants have a generating capacity of 3820 MW (1957 MW at the Moses-Saunders and 1853 MW at Beauharnois-Les Cedres) and produce enough energy to meet the needs of about two million homes.

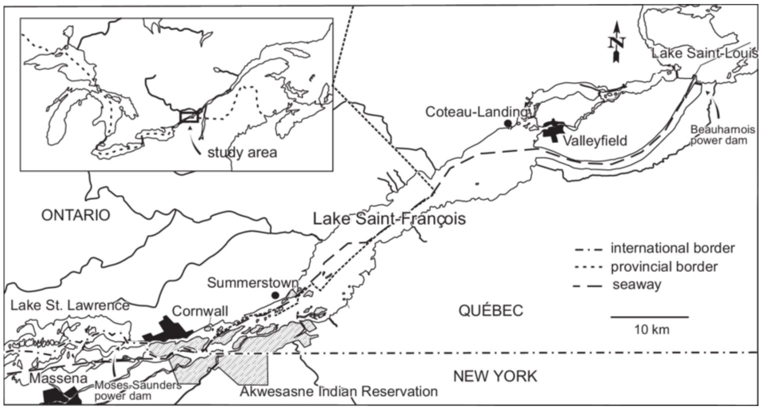


Figure 5-10: Locations of Moses-Saunders and Beauharnois Dams (Source: ECCC)

5.4.1 UPPER GREAT LAKES - Hydropower

Sensitivity to Water Levels and Outflows: The amount of electricity that the hydropower stations produce depends on available head (*i.e.*, the difference in water levels upstream and downstream of the plants) and the amount of flow through to the stations. In some cases, high water conditions enable hydropower operators to increase power generation. However, very high levels and flows can have adverse impacts on their operations. For example, very high lake levels and corresponding outflows can result in "excess" water diverted through the spillway and thus a missed opportunity to generate additional power due to lack of available hydropower capacity (IUGLS, 2012). Similarly, high water levels downstream, which can be compounded by high flow through a station/spillway, can result in lower headwater and higher tailwater elevations and therefore reduce the operating head on the station and reduce hydropower generation. Low water conditions tend to have greater impact on hydroelectric generation, forcing stations to operate below capacity and reducing revenues (IUGLS, 2012).

Following the IUGLS, it was noted that hydropower plant maintenance activities can also be a cause of reduced hydropower capacity during high water periods, and this can result in large, frequent fluctuations in St. Marys Rapids flow and water levels and unintended and potentially adverse outcomes in the St. Marys Rapids unless strategies can be developed to address them. The effects of Lake Superior outflow regulation on any changes in the Lake Erie levels and Niagara River flows that result from different Lake Superior regulation plans are small, particularly in comparison to the much greater effects of changes in water supply, and Plan 2012 does not have any significant impact on the power generation on the Niagara River.

Summary of Observed 2017 Impacts: Owing in part to multiple other factors, the upper Great Lakes water levels and flows did not have a significant impact on hydropower operations at the Cloverland, Brookfield or US Government plants during 2017, although a significant storm event in late October 2017 did lead to water levels approaching critical levels at the Cloverland plant for a short period of time, requiring a temporary response. Scheduled maintenance at plants and work in the Cloverland Electric Company canal resulted in significant reductions in hydropower capacity which have required reduced flows through the Cloverland plant, as has been the case for multiple years during the recent period of relatively high outflows, which required regulation plan deviations. Maintenance activities at the Brookfield Renewable power plant also resulted in outages which affected regulated outflows. The outages have been analyzed for their impacts to regulated outflows and effects of these outages on the St. Marys Rapids have attempted to be addressed in the Board of Control's deviation strategy. The US Government Plant had no concerns regarding operations and power production at current levels and did not attribute any issues to water levels. They reported their operation is driven by the market and demand for power.

Flows in the Niagara River have experienced an increase beginning in 2015. As a result of the weather conditions seen in the Lake Erie basin during April and May of 2017, the water level of Lake Erie rose quickly at the beginning of May. The impact of the higher water levels were compounded by more frequent and sustained southwest winds pushing water and ice into the head of the Niagara. As a result, the flows in the Niagara River were some of the highest experienced since 1998. Despite these factors, the management of the CGIP and the International Niagara Control Works (INCW) above Niagara Falls resulted in no falls flow violations in 2017. Also, the level of the CGIP is regulated under the INBC's 1993 Directive. The unusual conditions in 2017 did not keep the power entities from operating the INCW to adhere to the requirements of the 1993 Directive. The INBC oversees the operation of the control works by the power entities, and the board has been in communication with the power entities to get feedback on how the high water levels impacted the operation of the control works. Though the increased flows had no overall impact on the regulation of the CGIP and subsequent power production, they did create some challenges with respect to Maid of the Mist Pool levels. The power entities worked with the tour boat operators in the Maid of the Mist Pool to establish a protocol regarding these levels. The power entities made careful considerations of their operations to reduce adverse effects on the water levels in the Maid of the Mist Pool during tour boat operations.

Power entities' compensation rates and mechanisms are confidential, so it is not possible to put benefits and impacts in dollar terms with respect to 2017 conditions. OPG 2017 Public Revenue Statement noted that OPG generated ~ 1TW more energy across all of its facilities in 2017 than 2016. This increase in generation was primarily driven by increased water availability in Eastern Ontario (St. Lawrence, Ottawa and Madawaska Rivers). At the Saunders generating station, OPG generated slightly more energy than forecasted in 2017. However, there was an increase in energy production that did not have a direct economic benefit to OPG. The regulatory framework in which the Saunders generating station operates within prevents OPG from economically benefitting due to any favorable difference between forecast and actual water availability. Similarly, NYPA's St. Lawrence – FDR Power Project generated ~11 percent more energy than forecast in 2017. However, NYPA did not realize an economic benefit from the increased generation due to depressed market prices for the energy. In fact, NYPA's revenue fell by 20 percent between 2016 and 2017.

Model Assessment: A model assessment of the upper Great Lakes was not performed this reporting period. If the hydropower performance indicators are to be used to quantify economic impacts in the future, an updated energy market value analysis should be completed since the existing model uses prices developed during the IUGLS. In addition, the lack of ability to acquire revenue data from hydropower production may mean the performance indicator needs to be revisited.

Key Findings: The upper Great Lakes water levels and flows did not have a significant impact on hydropower operations on the St. Marys River in 2017. The above-average water levels and outflows through the St. Marys River, along with continued maintenance activities in both Canada and the US, resulted in flows available for hydropower production that often exceeded the capacity of the plants and any surplus water was not used for generation and instead was released through the St. Marys Rapids.

A reassessment of the energy market value and the inability to acquire economic information has implications to the hydropower performance indicators moving forward.

5.4.2 LAKE ONTARIO-ST. LAWRENCE RIVER - Hydropower

Sensitivity to Water Levels and Outflows: Outflow regulation affects water levels and flows throughout the Lake Ontario-St. Lawrence River system which, in turn, has impacts on hydropower generation. Hydropower generation is particularly sensitive to low water conditions, which results in decreased generation. The stability and predictability of water levels and outflows can be a critical factor, particularly in the St. Lawrence River, as generation forecasts and market prices are affected by changing conditions and uncertainty of forecasting. Extreme high water supplies and resulting high levels, as were experienced in 2017, can also be a concern due to issues such as increased spillage, head loss, deferral of planned maintenance, increased operations and maintenance and other associated increased costs.

Following the LOSLRS, it was concluded that, under Plan 2014, the slightly higher and more natural seasonal autumn through spring Lake Ontario levels that benefit coastal ecosystems also would slightly increase the hydraulic head and thus, energy production at the Moses-Saunders power plants. Plan 2014 can also slightly increase the amount and value of hydropower produced at the Hydro-Quebec plants, as there tends to be less spillage of water and a higher percentage of the water can pass through the Beauharnois generating station. Although the higher Lake Ontario levels also would slightly reduce the head at the Niagara power plants, the net effect would be to increase the production of hydropower at all these plants by about 0.4%, or enough to supply the needs of about 8,000 homes. During LOSLRS, the primary performance indicator used (as advised by the economic experts) was the increase in the value of hydropower energy caused by a change in regulation plans. In addition, important metrics, termed the stability and predictability of flows, were developed. More-stable releases change less from week-to-week, while more-predictable releases change less from month-to-month. When possible, hydropower producers will take turbines out of production for maintenance only when the water release can be routed through other turbines that remain in service. A large, unexpected release increase may require spilling part of the release (that is, releasing the water but not running it through a turbine to create electricity). Plan 2014 provides slightly more stable and predictable releases, thereby reducing the chance of energy losses during turbine maintenance compared with plan 1958-DD.

Summary of Observed 2017 Impacts: 2017 saw the highest flows ever recorded over a sustained period of time through the Moses-Saunders dam on the St. Lawrence River, resulting in greater than forecasted energy production, but requiring the power entities to take measures to keep units running for extended periods of time to minimize the need for increased spillage of water. The plants were run at full available capacity for months, requiring some important maintenance activities to be deferred to later dates and while additional maintenance cannot be considered a "cost" (as running units more equates to additional compensation from increased power generation), it must be noted that there can be considerable cost overruns when plants are run for extended periods and generating units suffer breakdowns. Additionally, operation and maintenance costs for some activities were higher than initially forecasted due to the higher flow. For example, mobilizing crews to perform extra dam or spillway operations and increased debris clearing in the forebay resulted in higher operating costs in 2017.

Model Assessment: In its 2014 report on Plan 2014, the IJC estimated a market value of the roughly 25 million MWh of energy generated from the hydropower dams on the St. Lawrence River as approximately $1.5 billion USD a year at a market rate of $60/MWh (based on a previous estimate provided by Synapse Energy Economics Inc. in 2005 (IJC, 2006)). It should be noted that 2017 rates in each of the three jurisdictions (New York, Ontario and Quebec) were likely considerably lower than this. GLAM recognizes that this market value estimate is likely overestimated nowadays and will seek updated information if possible. In its 2006 report, the LOSLRS calculated an economic baseline for hydropower under Plan 1958-DD as the economic surplus (i.e., net operating revenues minus economic cost of capital, before deduction of taxes, transfer payments and special pricing) of $250 million USD for Moses-Saunders, and $100 million USD for Beauharnois-Cedars. This calculation does not consider the value of energy that may have been foregone at other sites due to the increase in generation at Moses-Saunders. Since the load did not necessarily increase, the generation at other plants would have decreased. Again, GLAM recognizes that these previous estimates are likely inflated nowadays and will seek updated information with respect to Plan 2014 when performing future plan evaluations. As with the upper Great Lakes, inability to acquire dollar values from hydropower production means the performance indicator needs to be reevaluated by the GLAM Committee moving forward.

Key Findings: Though increases in energy production were realized in 2017 through the Moses-Saunders dam, owing to the high outflows and some periods of increased head at the plant, the hydropower sector also saw some adverse impacts related to the high water, such as losses to production opportunity due to increased spillage of water, increased operating costs, and the need to defer maintenance on various equipment. Future work will require a reassessment of the energy market value and hydropower pricing. Increased flows at hydropower projects resulted in several associated impacts to the hydropower sector. Mobilizing crews more frequently for additional gate operations raised the costs for operations in 2017. Additional gate operations also carry an associated incremental yet immeasurable increase in maintenance costs due to wear and tear on the mechanical and electrical equipment employed to raise and lower the gates.

Due to the inability to collect the data necessary to assess the existing performance indicators, it is necessary to develop a strategy for modifying or replacing the existing indicator. The existing performance indicator is “value to society of energy produced – based on megawatt hours by quarter month, valued using estimated market values for each quarter month of the year” (LOSLRS, 2006). As stated, power entities’ compensation rates and mechanisms are confidential. Without the estimated market values per quarter month, it is not possible to assess this performance indicator with the information available. It will also be useful for GLAM to complete assessment of potential errors in the Long Sault Dam rating curve, including the need for further flow verification measurements. The rating curve should be updated as necessary to improve the accuracy and precision of reported spillage rates.

5.5 Coastal

The coastal impact category is focused on direct impacts to shoreline infrastructure, primarily residential, along the Great Lakes and St. Lawrence River shoreline. The coastal impact sector is defined as individuals and organizations with a direct interest in the property along the shorelines and connecting channels of the Great Lakes and the St. Lawrence River (riparian property), particularly private property owners (IUGLS, 2012; IJC, 2014). During IUGLS, there were an estimated 93,400 properties along the upper Great Lakes shorelines and connecting channels (63,700 in the United States and 29,700 in Canada) (IUGLS, 2012). Based on the 2006 IJC’s LOSLRS report, the Lake Ontario and the St. Lawrence River are estimated to have approximately 25,000 properties directly along or within close proximity to the Lake Ontario and upper St. Lawrence River shoreline and approximately 60% of the Lake Ontario-St. Lawrence River shoreline is devoted to residential land use. Of these, approximately 3,000 are estimated to be located below the elevation of 76.2 m (250 ft) and at risk of flooding (LOSLRS Annex2, 2006). On the lower St. Lawrence River, approximately 5,770 single-family dwellings fall within the 1-100 year flood zone (IJC, 2014). High water levels and wind driven waves which can lead to flooding of property and infrastructure, contribute to accelerated bluff recession rates (erosion) and reduce the lifespan of existing shoreline protection used to stabilize shorelines. Areas of the Great Lakes exposed to large waves are considered open coast shoreline and in those areas, wave action can be a significant contributor to shoreline impacts when combined with high water levels, storm conditions and short-term storm surge. These conditions can contribute to accelerated bluff recession, damage existing shoreline protection, damage and/or destroy homes and other structures on shoreline properties and lead to storm induced flooding which can result in significant damages over the duration of the storm event. Since Great Lakes water levels can remain elevated for prolonged periods of time (weeks to years), multiple storm events can occur during an extended period of high water levels. Low water level conditions typically reduce the threat of flooding for shoreline property owners and can lead to an apparent reduction in bluff recession rates, although the conditions can also lead to increased scouring at the base of bluffs and at the toe of shore protection which can increase vulnerability in subsequent high water periods (Baird, 2004). There can also be low water issues associated with exposure of mudflats, water access issues, etc. (Baird, 2010).

5.5.1 UPPER GREAT LAKES - Coastal

Sensitivity to Water Levels and Outflows: Based on the IUGLS, the IJC concluded that Plan 2012 for the outflows of Lake Superior would provide modest benefits to the coastal interest group based primarily on reductions to the total costs of maintaining shoreline protection in lakes Superior and Michigan-Huron. While this was the primary performance indicator assessed, consideration was also given to high water level and low water level statistics and the robustness of the regulation plan in its capacity to meet particular regulation objectives under a broad range of plausible future hydrological scenarios, including those related to climate change.

Coping zones were developed in the IUGLS to help evaluate regulation plan options by allowing plan formulators to predict the impacts from extreme water levels. Zone A captures a range of water level conditions that the interest would find tolerable, Zone B a range of water level conditions that would have unfavorable though not irreversible impacts on the interest, and Zone C being a range of water level conditions that would have severe, long-lasting or permanent adverse impacts on the interest. The coastal working group further defined zones A, B, and C relative to coastal sensitivities and economics based on US and Canadian sites along the upper Great Lakes (see Table 5-4).

Table 5-4: Summary of coastal coping zones defined by the Coastal Zone Technical Working Group (IUGLS, 2012)

	Zone A	**Zone B**	**Zone C**
Adaptation	Interests should largely be adapted to conditions in this range, having already built some shore protection structures. If levels persist for several years at the extremes of this zone, there is the risk that interests will adapt to a narrower range and neglect or breach shore protection structures or build in locations unsuitable in the long-term.	Adaptation to levels in this zone may be limited and require construction of additional shore protection; structure modification; dredging beyond maintenance dredging; temporary repurposing or temporary loss of use of shoreline or set-back requirements.	Adaptation within this zone may require shore protection and building modifications beyond the means of most; major infrastructure modifications such as moving roads or major structures; permanent loss or relocation at some locations is possible.
Most Vulnerable Hot Spot	Cohesive bluffs with little beach to protect them from high water and storm surge. Places with existing shore protection if these are not maintained or are breached.	Cohesive bluffs with little beach to protect them from high water and storm surge. Places with or adjacent to existing shore protection, that may not be adequate for more extreme conditions.	Cohesive bluffs with little beach to protect them from high water and storm surge. Places with or adjacent to existing shore protection, that may not be adequate for more extreme conditions.
Ability to Recover	Can adapt to and recover from most damages that occur in this range. In some areas, however, there is the potential for significant bluff failure that could result in permanent loss.	Generally able to recover but may have some significant losses due to high water level related erosion. Capital investments made to adapt to this zone may not be able to increase resilience to future Zone B levels.	Some interests may not be able to recover completely, particularly those affected by water level related dune and bluff erosion.
Severity of Net Financial Loss	Generally minimal loss in this range, but potential for significant localized loss if storm surge causes bluff to fail.	May be significant but most are able to pay cost out of revenues, financing and insurance claims.	Substantial losses, in some cases exceeding ability of organizations or individuals to repay. Those that do rebuild likely to require borrowing from future assets to

	Minimal to moderate, depending on cost of maintenance and degree of neglect of existing shore protection.		cover the net costs. May result in request for federal emergency aid.
Suggested Indicators for Assessing Thresholds	Permits for shore protection (USACE/State); media reports of damages; insurance claims; set-back requirements and other local land use regulations.		

Summary of Observed 2017 Impacts: Water levels in all of the upper Great Lakes were above average throughout 2017. Lake Superior was well above average throughout the year and, with the exception of November, remained within 10 cm (3.9 in) of the maximum recorded monthly water level from June to December 2017. This high water level combined with a couple of major storms at the end of October 2017 led to significant coastal flooding and erosion of public and private property. On October 24, the largest wave recorded in the past 30 years occurred near Marquette, MI with offshore wave heights peaking near 9.1 m (30 ft) and measured wind gusts at 124 km/h (77 mph). Examples of some of the impacts are shown in Figures 5-11 to 5-16. There is less information on impacts on the Canadian shoreline but, based on information provided by staff from the Ontario Ministry of Natural Resources and Forestry, there were some local flooding issues where the Chippewa area meets Lake Superior in December of 2017. Otherwise, there were few reports of impacts.

Figure 5-11: Powerful waves from 27-Oct-2017 big storm chewed into the dunes along Lake Superior on Duluth's Park Point between -about 800 and 900 Lake Avenue South, turning them into a line of "cliffs". Photo credit: Bob King / rking@duluthnews.com - http://www.duluthnewstribune.com/news/4351737-park-point-residents-assess-damage-worry-about-future-storms.

Figures 5-12 and 5:13: 24-October-2017 storm causing wave run-up to wash large stone and debris up on Lakeshore Blvd. in Marquette, MI. Photo credit: Great Lakes Coastal Reporting Tool (http://superiorwatersheds.org/report-erosion-hazard.

Figure 5-14: Erosion along the Lake Michigan bluffs in Mount Pleasant, WI prompted property owner to tear down a teetering garage. Property owner lost 6-8 feet of property since April 2016. Photo credit: Sears, M. Milwaukee Journal Sentinel, 2016.

Figure 5-15: Reported coastal erosion at Ontonagon Township Park and Campground. For the past three years staff have been monitoring the rate of erosion and measured 120-ft of shoreline loss since 2014. Erosion has caused closure of selected campsites and impacts to power utilities. Photo credit: Superior Watershed Partnership and Land Trust – Great Lakes Coastal Reporting Tool.

Figure 5-16: Shoreline inundation at a park in Sault Ste. Marie, Ontario in October 2017. Photo credit: https://www.sootoday.com/local-news/high-water-on-st-marys-river-15-photos-748392.

There were also reports of localized flooding along the St. Marys River in Sault Ste. Marie during a wind event in October, 2017 (see Figure 5-16) and the ILSBC issued news releases throughout the summer and fall of 2017 cautioning users of some expected flooding of low-lying areas of Whitefish Island and that some recreational trails and features in these areas would likely be inundated (http://ijc.org/en_/ilsbc/) (see Figure 5-17).

Figure 5-17: Recreational trails on Whitefish Island prone to flooding in 2017 (picture taken in 2014). Photo credit: ECCC.

As shown in Figure 5-18 below, water levels in 2017 on Lake Superior hovered near or above the High A-B transition coping zone. The expected sensitivities described in Zones A and Zone B (see Table 5-4) appear to be representative of 2017 media reports of coastal erosion, flooding, and impacts of shoreline protection.

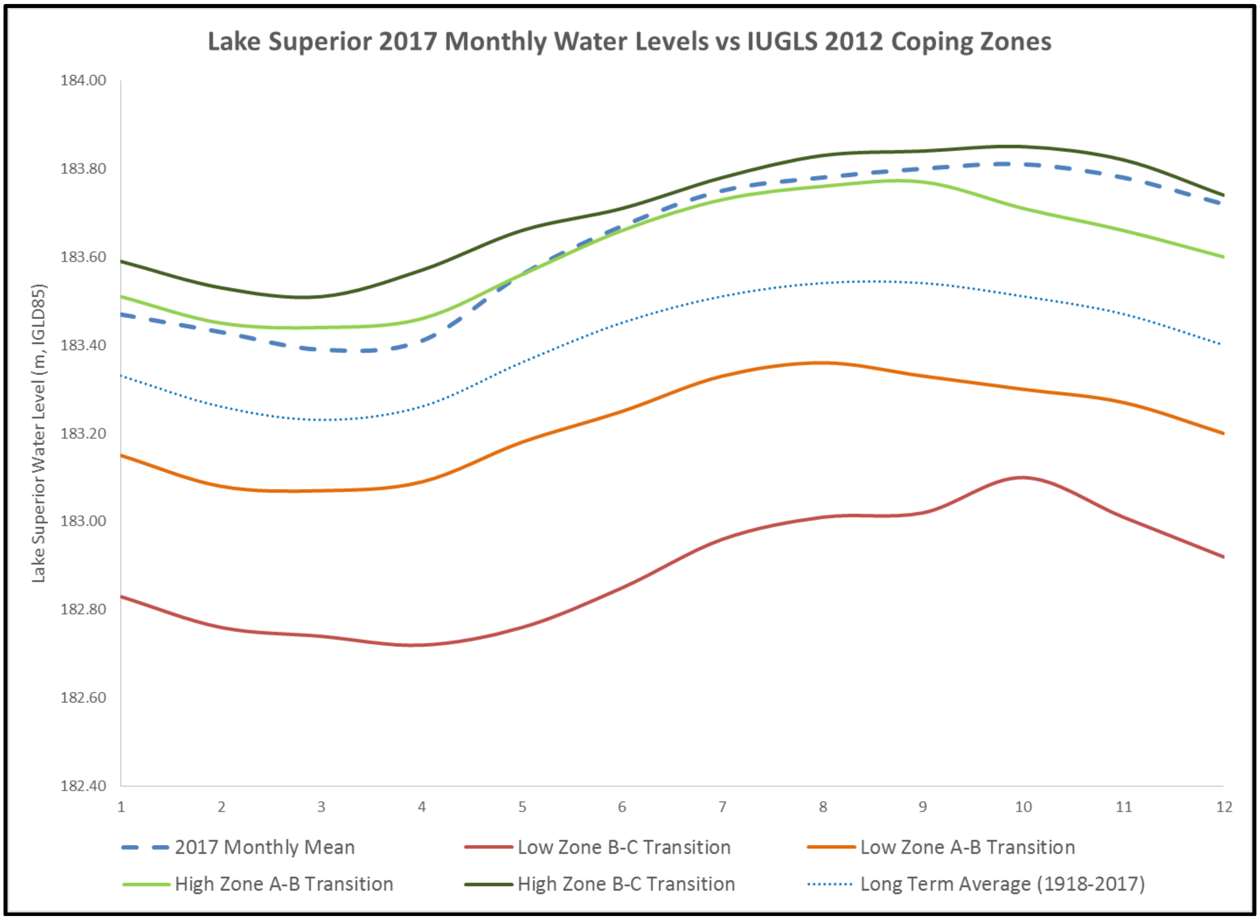


Figure 5-18: Comparison of Lake Superior 2017 Monthly water levels relative to the coastal coping zones that were established for Lake Superior in the 2012 IUGLS. (Source: USACE Detroit)

Figure 5-19 is a summary of permit applications received by year from USACE-Detroit District Regulatory office on Lake Superior, whose regulatory footprint includes all of the Michigan shoreline of Lake Superior. Minnesota and Wisconsin shorelines are under the regulatory jurisdiction of USACE- St. Paul District. The figure summarizes the number of permits for new, replacement and improvement permits of shoreline projects (i.e. groins, seawall, rip-rap, etc.) relative to the lakewide elevation of that year. As water levels on Lake Superior have begun to rise since 2013 or approach the high coping zones, so has the number of permit applications.

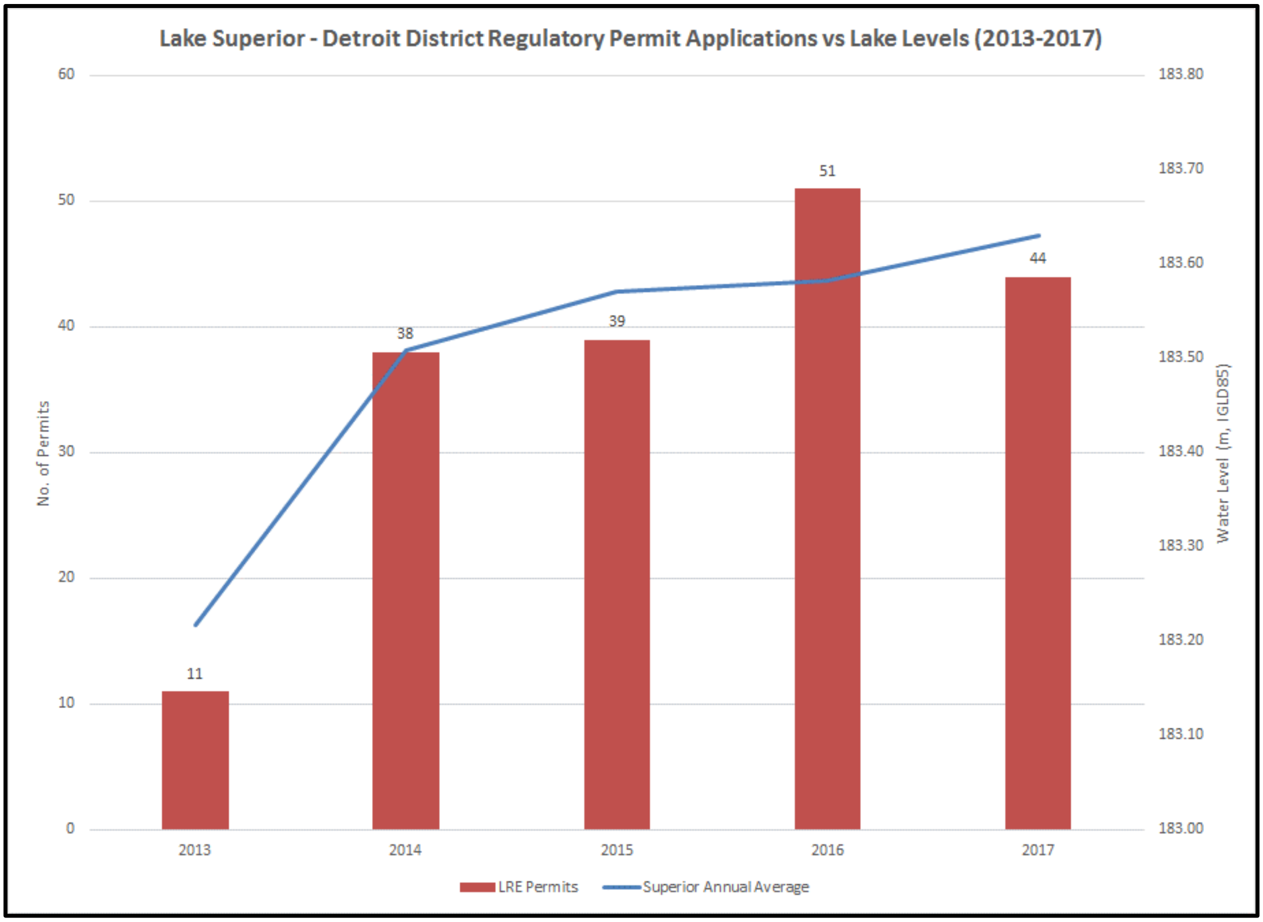


Figure 5-19: Comparison of permit applications per year received by USACE's Detroit District Regulatory Office (LRE) versus annual average water level for Lake Superior. Permit applications summarized in this graph fall under Code of Federal Regulation 33 Part 322 – Permits for Structures in or Affecting Navigable Waters of the US focusing on project types that fall under shore protection (i.e. seawall, groin, riprap placed for shore protection, etc). (Source: USACE, Detroit District)

Lakes Michigan-Huron remained above average throughout the year, but at least 38 cm (~15 in) below the maximum recorded levels. While it is expected that higher rates of erosion are occurring compared with the low water level years throughout the 2000s, there were little to no indications based on media reports or discussions with shoreline managers of flooding or unusually high erosion or shore protection structure damages found. Nottawasaga Valley Conservation Authority, located on the south shore of Georgian Bay, reported that on November 16, 2017, higher lake levels combined with strong northwest winds caused the main beach area at Wasaga Beach to be flooded, with flooding of the edge of the public road in this area. The Town used temporary sand dykes along the beach to attempt to mitigate against the high water levels and wave uprush. There were also various reports of increased problems due to shoreline erosion along the Lake Huron shoreline of Ontario.

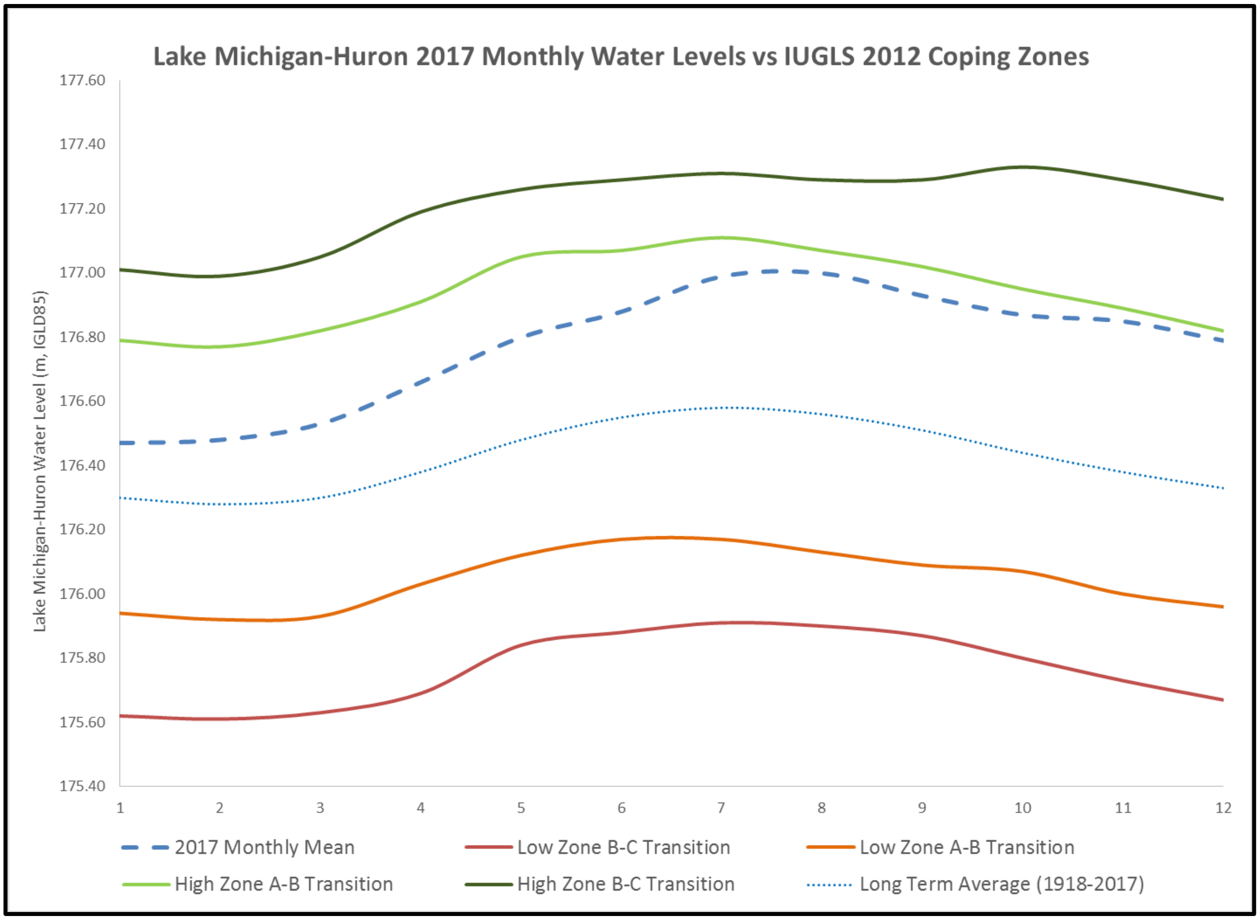


Figure 5-20: Comparison of Lake Michigan-Huron 2017 monthly water levels relative to the coastal coping zones that were established for Lake Michigan-Huron in the 2012 IUGLS. (Source: USACE Detroit)

Water levels in 2017 on Lake Michigan-Huron stayed within the tolerance of the low and high coping zones previously defined during the IUGLS, nearing the High A-B transition coping zone in the late fall (Figure 5-20). The expected sensitivities described in Zones A and Zone B (see Table 5-4 above) appear to be representative of 2017 media reports of coastal erosion, flooding and impacts of shoreline protection.

Lake Erie also remained high throughout the year and was within 15 cm (~6 in) of monthly record high water levels in May 2017 and within 21 cm (~8 in) of the maximum level on Lake Erie of 175.04 m (574.3 ft) International Great Lakes Datum (IGLD) recorded in June 1986. There was a notable increase of permit applications through the USACE-Buffalo District Regulatory office for Lake Erie shore protection structures when compared with both 2015 and 2016 (Figure 5-21). On the Canadian shoreline, the Lower Thames Conservation Authority reported issues of the dyke overtopping at Rondeau Provincial Park and some homes experiencing shore protection failure in June, 2017. Essex Region Conservation Authority reported a spike in applications for shoreline repairs and shoreline damages on the east coast of Pelee Island and along the Lake Erie shoreline west of Point Pelee between Leamington and Kingsville (Essex Region Conservation Authority, personal communication, June 13, 2017).

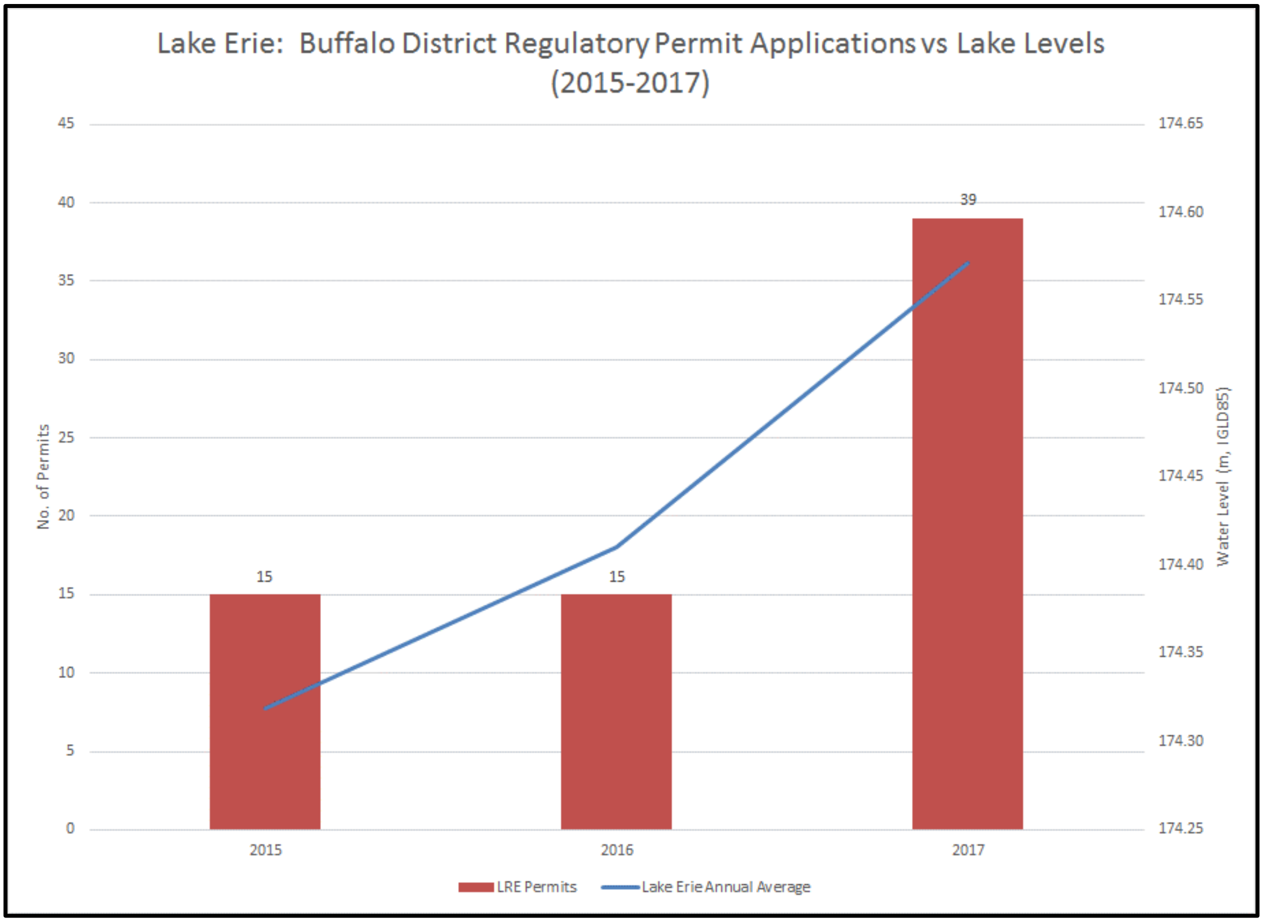


Figure 5-21: Lake Erie permit applications for Buffalo District compared with water levels (2015-2017) (Source: USACE Detroit District)

Long Point Conservation Authority reported a lack of beach at the provincial park and erosion of exposed shore protection. Water levels in 2017 on Lake Erie hovered near or above the High A-B transition coping zone (Figure 5-22). The expected sensitivities described in Zones A and Zone B (see Table 5-4 above) appear to be representative of 2017 media reports of coastal erosion, flooding and impacts of shoreline protection.

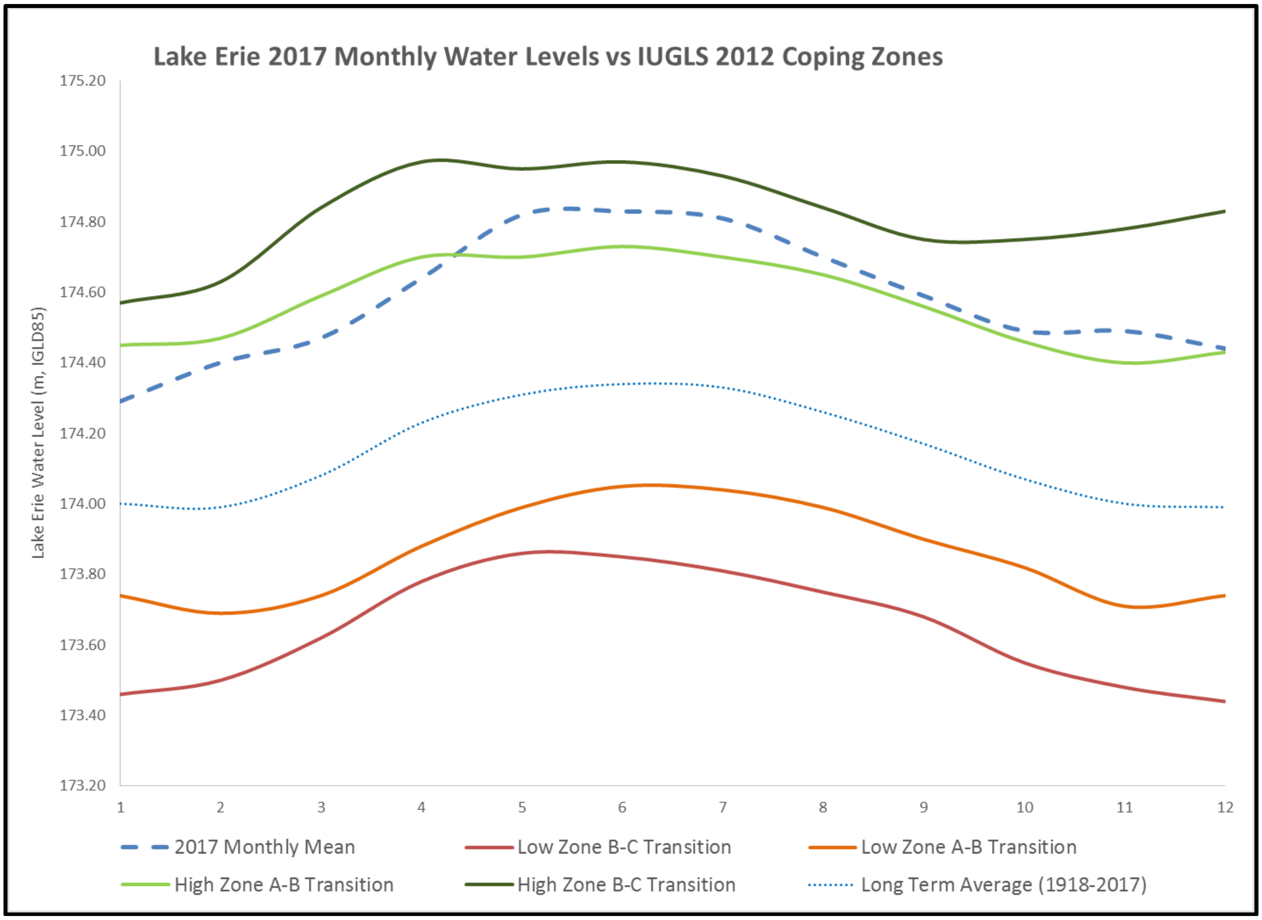


Figure 5-22: Comparison of Lake Erie 2017 monthly water levels relative to the coastal coping zones that were established for Lake Erie in the 2012 IUGLS. Water levels of 2017 on Lake Erie hovered near or above the High Zone A-B transition for the coastal coping zones. (Source: USACE Detroit)

Model Assessments: The primary performance indicator used to compare coastal impacts associated with alternative regulation plans during IUGLS was the cost of maintaining existing shoreline protection. In addition to the modelled indicator, coping zones were developed as a more general approach to comparing plan performance. Within the supporting documentation of the 2012 IUGLS, a number of suggested ways were listed for assessing the high and low thresholds of the coastal coping zones. For high water coping zones, it was suggested to monitor resident flood damages by magnitude ($) and spatial distribution, which could be done through insurance claims reporting or complaints to local municipalities. Another possible way to track indicator and coping zone outcomes was the implementation of new shore protection or replacement of existing protection by tracking of permit issuance and construction value. The latter approach was attempted for the upper Great Lakes for 2017 using best available information for USACE's regulatory offices, but without collecting information related to costs. Further efforts in this regard need to be evaluated and prioritized by the GLAM Committee as it is not yet clear how beneficial this information could be in the on-going plan review.

Another important consideration when evaluating plan performance is the impact the outflow decisions have on Whitefish Island. Whitefish Island is Batchewana First Nations land, and is primarily recreational with hiking trails, small pavilions and visitor information booths. The island is located immediately downstream of the Compensating Works gates adjacent to the rapids and substantial portions of the island flood as more gates are opened. While flooding of the island is unavoidable and expected under higher gate openings, the board attempts to minimize impacts to the island when possible. During the IUGLS, there was no specific indicator developed for Whitefish Island coastal impacts, most notably, flooding of recently developed areas of the Island. The GLAM Committee considers a Whitefish Island flooding performance indicator an important priority and included the initiation of its development in the FY18 work plan. However, progress was limited and the work will continue in FY19 and possibly beyond depending on available resources.

Key Findings and Next Steps: Coastal impacts on the upper Great Lakes were primarily storm driven. While all the lakes were above average, the shoreline interests were primarily able to cope with the levels experienced. There are no existing coastal performance indicators for the St. Marys River where the implications of a change to the regulation plan may be the greatest and this is something that the GLAM Committee should explore further. It had been identified as part of previous GLAM Committee work plans, but progress has been limited so far.

5.5.2 LAKE ONTARIO-ST. LAWRENCE RIVER - Coastal

Sensitivity to Water Levels and Outflows: During the development of Plan 2014, the IJC concluded that coastal damage would occur no matter the regulation plan, but that Plan 2014 would increase damages to coastal interests on Lake Ontario and the upper St. Lawrence River when compared to the previous regulation plan (1958-DD). Model results suggest most of the expected damage would be realized in the cost of maintaining shore protection structures with only very minor increases expected to flooding and erosion damages on Lake Ontario over the previous regulation plan. Based on an assessment of potential flooding damages to downstream interests on the lower St. Lawrence River (downstream of the Moses-Saunders dam), these interests are vulnerable to water level changes, but there were no differences found in impacts or benefits between the old regulation plan and Plan 2014.

There were three primary performance indicators used during the LOSLRS to represent impacts to coastal property owners along the Lake Ontario shoreline for the comparison of regulation plan options, including:

- First floor flooding of residential buildings;
- Erosion to developed (i.e. with building) but unprotected land; and
- Shore protection maintenance costs.

The first-floor flooding performance indicator was applied to all shoreline areas in the database including many of the larger embayments around the lake. However, due to the importance of wind and waves in combination with water levels, the erosion and shore protection maintenance indicators were applied to only the open coast shorelines and not to the shoreline within protected embayments or the Bay of Quinte where wave action was considered minimal. On the upper St. Lawrence River from the Thousand Islands through to the Moses-Saunders dam, the primary performance indicator was first floor flooding of residential buildings.

On the St. Lawrence River downstream of the Moses-Saunders Dam, the primary performance indicator was first floor residential flooding, although there were also non-economic metrics on the lower river such as kilometers (miles) of roads flooded. In simplest terms, all the Lake Ontario, upper St. Lawrence River, and lower St. Lawrence River coastal performance indicators generally equate high water levels with increased maintenance costs to shoreline property owners.

Summary of Observed 2017 Impacts: ***NOTE - Much of the information currently available to the GLAM Committee to assess these impacts is descriptive and anecdotal, and efforts will be ongoing to further quantify impacts going forward. To support the current assessment, the GLAM Committee gathered information from a variety of sources including aerial imagery, shoreline site visits, damage reports by various agencies, media reports, and permitting summaries. As has been noted in previous sections, the GLAM Committee also worked with Conservation Ontario to develop and implement an online, self-reporting questionnaire for shoreline property owners to seek direct input on the kinds of problems faced due to high water levels in 2017. The questionnaire method was not considered a statistically representative sample, so it is not possible to test for statistical differences in results from the different sub-groups (e.g. Canada vs. US). An overall description of impacts is provided here with further details and regional descriptions provided as reference in the Annex 1-Impact Assessment.***

Record high water levels in 2017 directly impacted property owners along the Lake Ontario and St. Lawrence River shoreline. Damage to homes, properties, and shore protection structures due to flooding and erosion were widespread across the Lake Ontario shoreline. By mid-April of 2017, coastal impacts were being commonly reported along the Lake Ontario shoreline and extensive media attention surrounding the coastal damages heightened in May and June as water levels rose rapidly and reached record high levels. Impacts continued to be reported through the summer and into the fall months, although at a reduced rate. Reports of flooded homes, roads, driveways, trails, lawns, emergency response and extensive sandbagging efforts to protect houses and properties made the news. Reports of shoreline erosion and loss of beaches, vegetation and property (e.g. land, decks and docks) were common. There were also reports of shore protection structures failing or being damaged by the high water conditions making property owners even more vulnerable to the high water conditions. States of emergency were issued in many locations including all U.S. counties bordering the Lake Ontario and upper St. Lawrence River shoreline.

On the Canadian shoreline, a local state of emergency was declared for a portion of the Clarington shoreline as well as all of Prince Edward County. The Mohawks of the Bay of Quinte also declared an emergency for their territory in response to the high water levels. On the lower St. Lawrence River, emergencies were declared in numerous municipalities in May 2017 during the peak flood conditions. Table 5.5 lists the municipalities, separating ones directly on the St.

Lawrence River from those on the north shore of Montreal Island that were more directly influenced by record high outflows from the Ottawa River. It should be noted that there are many other municipalities on the lower St. Lawrence River that suffered from flooding issues but did not declare states of emergency. They dealt with the situation on their own.

Table 5-5: Municipalities in the Province of Quebec with local states of emergency during the peak flood conditions of May 2017 (Source: Urgence Quebec, 2017),

Municipalities located on the St-Lawrence/Lake Saint-Louis and impacted by the water management of Lake Ontario
Région Mauricie-Municipalité Yamachiche
Région Lanaudière-Municipalité Sainte-Geneviève-de-Berthier
Région Lanaudière- Municipalité Saint-Barthélemy
Région Lanaudière- Municipalité Saint-Ignace-de-Loyola
Région Lanaudière- Municipalité Lavaltrie
Région Lanaudière- Municipalité La Visitation-de-l ’île-Dupas
Région Lanaudière- Municipalité Berthierville
Région Montérégie – Municipalité Pincourt
Région Montérégie – Municipalité L’ïle Perrot
Région de Montréal - Ville de Montréal (portions of Montréal also border Lake of Two Mountains)
Municipalities located on Lake of Two Mountains (primarily influenced by Ottawa River flow):
Région Laval- Ville de Laval
Région Laurentides- Municipalité Saint-Eustache
Région Laurentides- Municipalité Deux-Montagnes
Région Montérégie- Municipalité Rigaud
Région Montérégie - Municipalité L’île Cadieux
Région Montérégie – Municipalité Terrasse-Vaudreuil
Région Montérégie – Municipalité Pointe Fortune

Flooding was the most commonly reported impact by respondents of the self-reporting survey relative to the total number of responses in each Country, followed by erosion and damages to shore protection structures (Figure 5-23). Survey respondents indicated the degree to which they were impacted by the high water levels (1 being low, 10 being high). A higher proportion of the US respondents indicated an impact level of 8, 9, or 10 while a higher proportion of Canadian respondents indicated an impact of 7 or lower (Figure 5-24).

Adaptive actions were taken in many locations to counteract the impacts of the high water to varying degrees of success. Based on observations from USACE emergency response site visits, there were situations where local authorities, residents and business owners were unfamiliar with correct methods of employing sandbag defenses and flood water pumping methods, thus causing the improper installation of these defenses (USACE Buffalo District site visit reports: e.g. Sodus Point, NY, May 19, 2017).

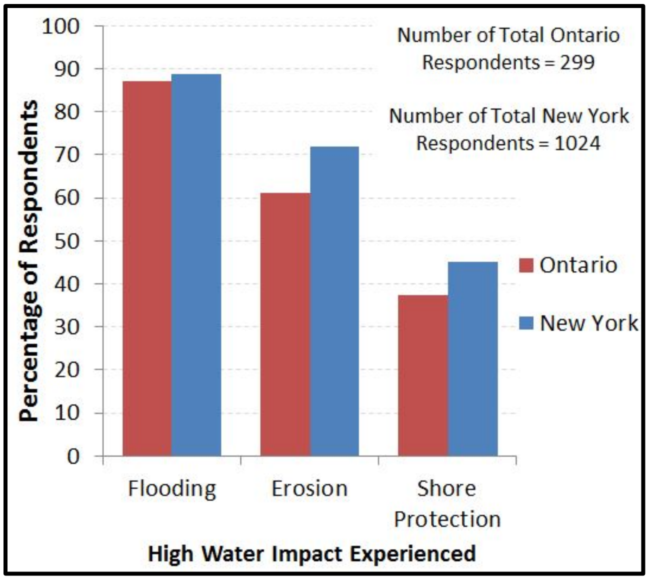


Figure 5-23: Percentage of New York (US) and Ontario (Canada) respondents on Lake Ontario reporting flooding, erosion and shore protection impacts (Source: ECCC, based on data acquired through Conservation Ontario survey for IJC)

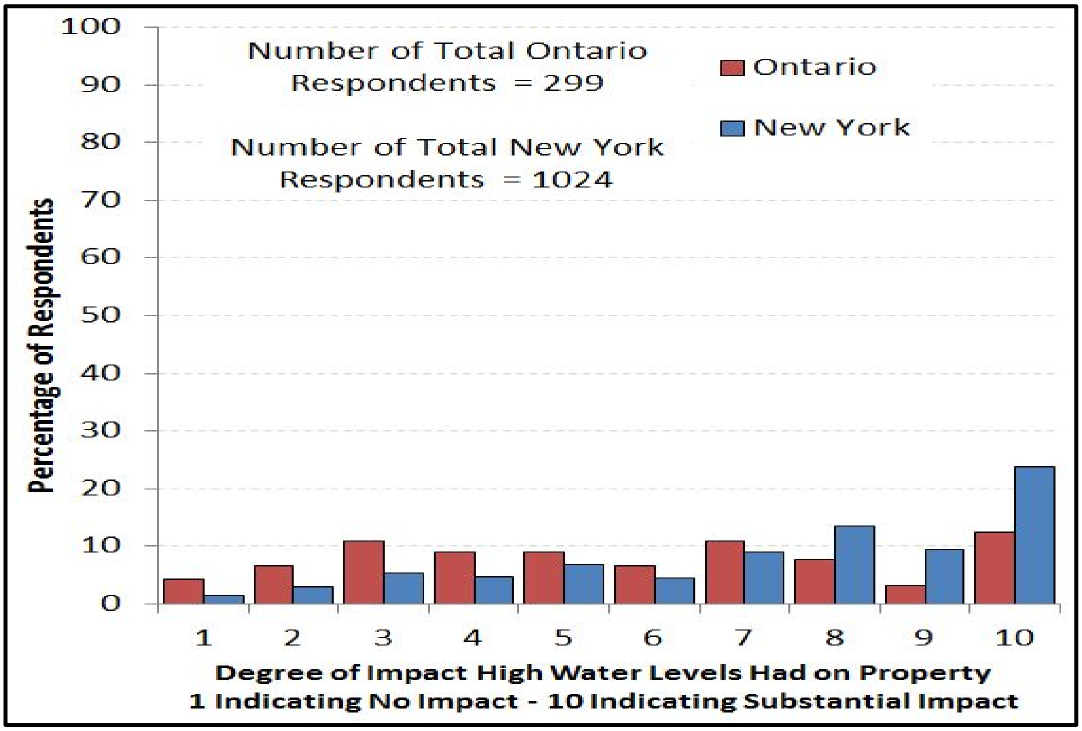


Figure 5-24: Degree of impact due to high water levels as identified by survey respondents (Source: ECCC, based on data acquired through Conservation Ontario survey for IJC)

A number of media reports also highlighted the psychological impacts of flooding to people that live along the shoreline. A recent report by the Intact Centre on Climate Adaptation (June 2018) highlights both the worry and stress associated with flooding and the need to take time off to deal with flood related response (Decent and Feltmate, 2018). While the Decent and Feltmate report focuses on flooding based on short-term rainfall events in an urban environment, similar issues were experienced by flooding victims along the shoreline as illustrated by comments received through the Conservation Ontario survey. One respondent referred to it as “a truly devastating experience” and there were a couple of responses noting the stress of needing to constantly monitor the situation to ensure pumps were working. Another respondent said, “It was also quite stressful as we didn’t know when or if the water would recede and how it would affect our property” and another noted “the length of time of the flood was a horrendous experience”. Related to the responses on stress was the personal financial toll, including the concern about the long-term implications.

Flooding - Lake Ontario and the Upper St. Lawrence River: Flooding of residential property and buildings along the Lake Ontario shoreline was observed with particularly hard-hit areas including the Olcott and Greece shoreline, Sodus Point, Fair Haven, and stretches of Oswego and Jefferson County on the US side as well as portions of Toronto Island, Clarington, Brighton, and Prince Edward County on the Canadian side (See Figure 5-25). Photographic examples of impacts are provided in Figures 5-26 to Figure 5-29. On the upper St. Lawrence River, shoreline flooding was observed on both the Canadian and US shoreline, particularly in the Thousand Islands area. While flooding was the most prominent impact reported on Lake Ontario and the upper St. Lawrence River in the self-reporting questionnaire, the type of flooding varied, with the most commonly reported impact to lawns and docks and a small percentage reporting first floor flooding (Figure 5-30). A separate and independent survey, undertaken by New York Sea Grant and Cornell University earlier in 2017, also reported a much lower percentage of first floor flooding when compared with other flooding impacts (New York Sea Grant and Cornell University, 2018). Evidence from the aerial imagery and site visits indicated a high degree of sandbagging efforts to prevent first floor flooding in the more vulnerable areas and 35% of respondents in Ontario and 40% of respondents in New York who experienced flooding also indicated taking this step to protect their property. According to the survey results, property owners that undertook adaptive actions such as sandbagging, pumping and clean-up reported that their costs to undertake such actions were generally less than $1,000.

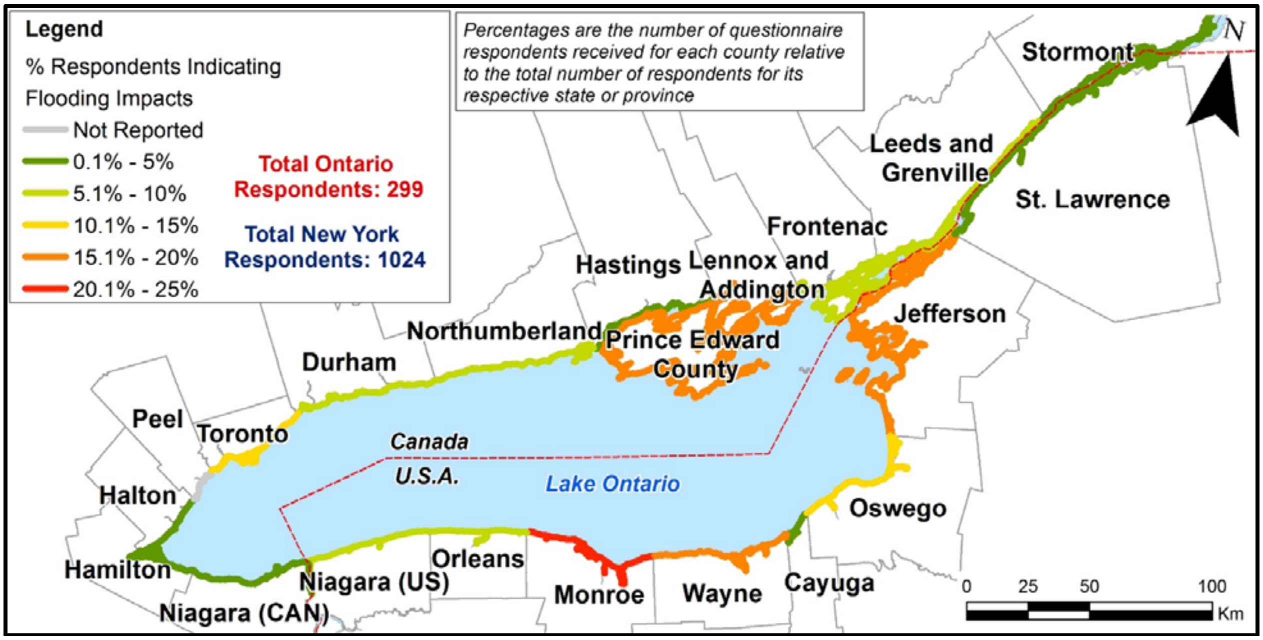


Figure 5-25: Flooding impacts, by county or municipality (based on a relative scale using the number of flooding impacts in each county relative to the total number of responses for the country in which that county falls) (Source: ECCC, based on data acquired through Conservation Ontario survey for IJC)

Figure 5-26 and 5-27: US shoreline flooding photos submitted through shoreline survey. Photo credits: Kevin Herrick, taken July 7, 2017 (left); Robert Rutz, taken April 30, 2017 (right).

Figure 5-28: Sandbagging on Toronto Island, May 26, 2017. Photo credit: ©Toronto and Region Conservation (TRCA)

Figure 5-29: Cedar Crest Beach Road. The photo on the left was taken May 25, 2017. Photo credit: Clarington Fire and Emergency Services. The photo on the right was taken June 14, 2017. Photo credit: ECCC.

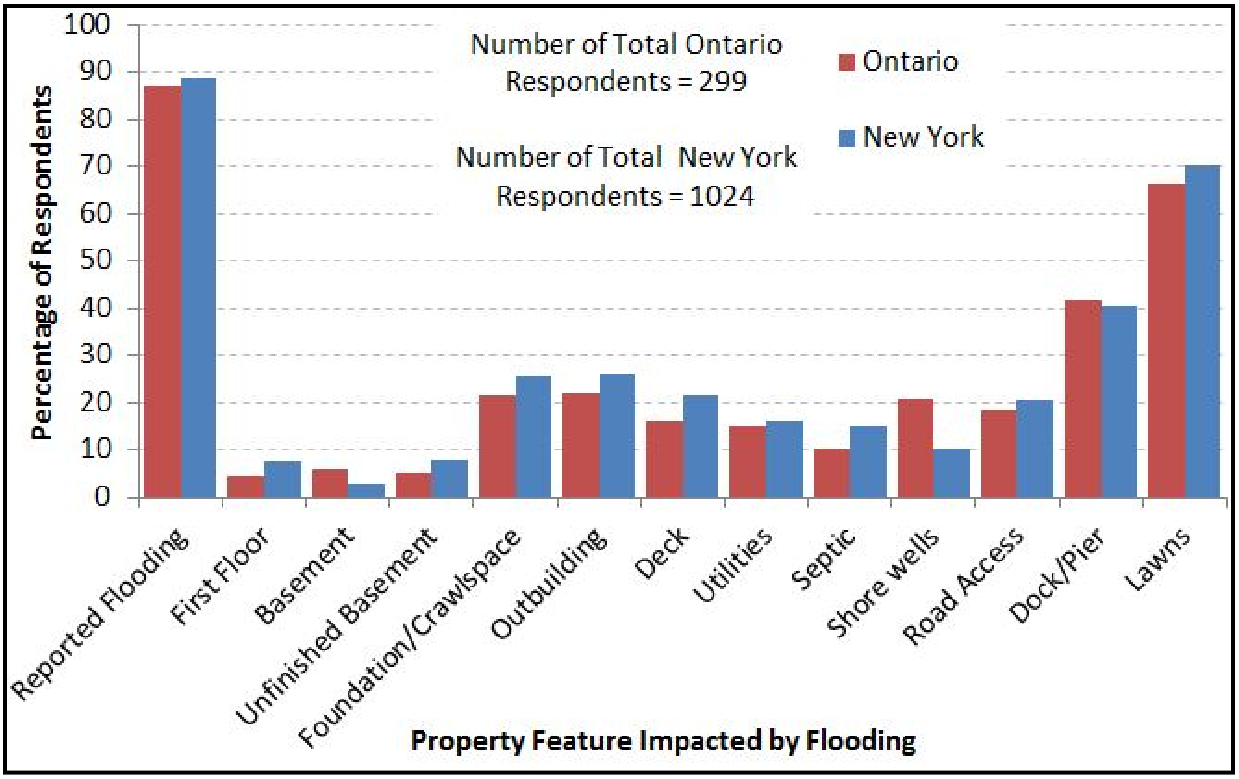


Figure 5-30: Types of flooding impacts reported by US and Canadian respondents to Conservation Ontario questionnaire (reported as percentage of respondents by province or state) (Source: ECCC, based on data acquired through Conservation Ontario survey for IJC)

<u>Flooding - Lower St. Lawrence River:</u> Downstream of the Moses-Saunders dam, the most significant and extensive flooding occurred during the Ottawa River freshet in early May. Flood damages associated with high St. Lawrence River levels (which were driven by a combination of record Ottawa River flows and high flows through the St. Lawrence, which were being set in an attempt to balance high levels and flooding upstream and downstream) occurred in the Lake Saint-Louis area as well as the Sorel and Lake Saint-Pierre area downstream to Trois-Rivières. Oblique imagery collected by Transport Canada during the flood peak was used to provide a general assessment of some of the more critically impacted areas. Those areas are highlighted in Figure 5-31 and an example of the imagery from the Sorel area is included for reference (Figure 5-32). Based on this visual assessment it was clear that entire neighbourhoods were affected and according to municipal reports over two thousand homes were either directly impacted or isolated as a result of the flooding on the lower St. Lawrence River. Municipal reports during the flooding period indicated over 1100 homes were evacuated across 24 municipalities, either because of flooding in the community or because access to roads was cut-off due to the flooding (Source: Centre des Opérations Gouvernementales, 2017). There were numerous examples of extensive sandbagging efforts. Record high outflows from Lake Ontario beginning in late May 2017 kept levels high and near flood levels much longer than they would have been otherwise on the St. Lawrence River near Montreal. While there were media reports of costs associated with flooding in the Province of Quebec during the spring event, it was not possible to differentiate

costs associated only with the St. Lawrence River from those on the Ottawa River and other parts of the province.

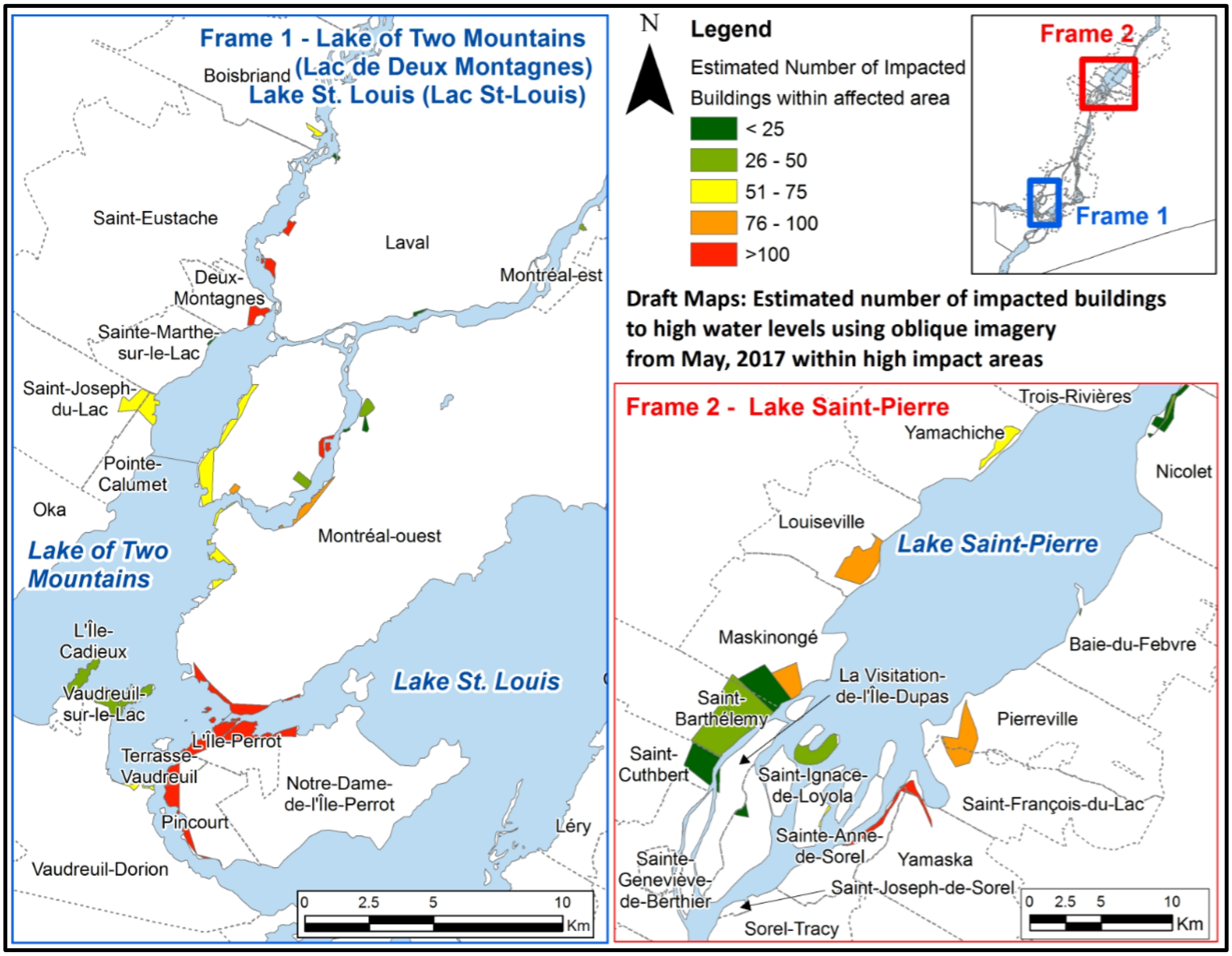


Figure 5-31: Preliminary map of high concentration building impacts identified through oblique imagery review (Source: ECCC/IJC estimates based on aerial imagery collected through the Transport Canada National Aerial Surveillance Program in May 2017.)

Figure 5-32: High water in the Chenail-du-Moine area near Sorel on May 9, 2017. Photo credit: Transport Canada National Aerial Surveillance Program, 2017.

Shoreline Erosion – Lake Ontario-Upper St. Lawrence River: Shoreline bluff recession (erosion) was evident from the aerial imagery and site visits in many locations along the Lake Ontario shoreline and appeared to be due to the combination of high water levels, wave action and saturated ground conditions from persistent rainfall in many areas. Based on the responses to the self-reporting survey for shoreline property owners, erosion impacts were more commonly reported in counties/municipalities on the south, east and northeast shoreline of the lake relative to the total number of survey responses in each country (Figure 5-33). Most commonly, residents reported loss of shoreline that directly impacted their property to varying degrees including loss of vegetation, loss of access to the beach/water and other infrastructure that was directly adjacent to the shoreline (Figure 5-34). In the most extreme cases, homes and buildings needed to be evacuated due to risk that the building itself would possibly fail (i.e. collapse or be condemned), although based on the information currently available to the GLAM Committee from the sources listed earlier, this did not appear to be a common occurrence relative to the overall number of buildings directly adjacent to the Lake Ontario shoreline. A high percentage of respondents in New York State indicated “other” as one of their impacts, suggesting impacts were not captured by the pre-defined categories in the survey. However, a review of the responses in the “other” category indicates that many US respondents included “shore protection damages” within this category. For reporting purposes, responses to questions on shore protection are discussed separately in the next section.

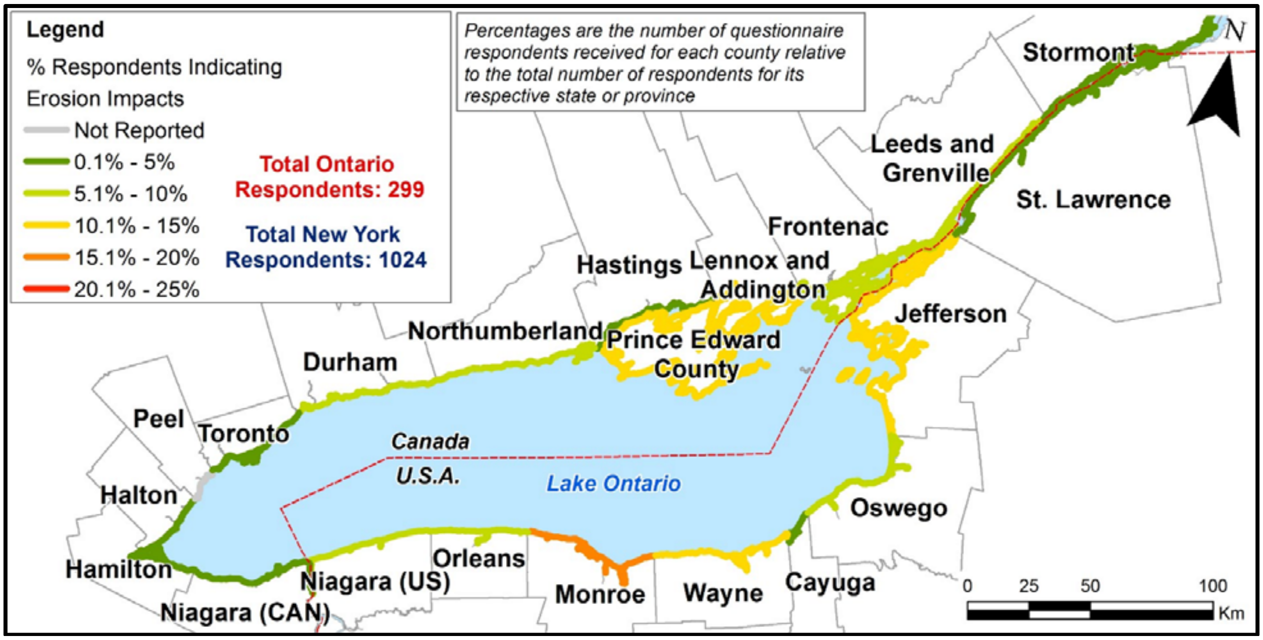


Figure 5-33: Survey responses indicating erosion impacts, by county or municipality (based on a relative scale using the number of erosion impacts in each county relative to the total number of responses for the country in which that county falls) (Source: ECCC, based on data acquired through Conservation Ontario survey for IJC)

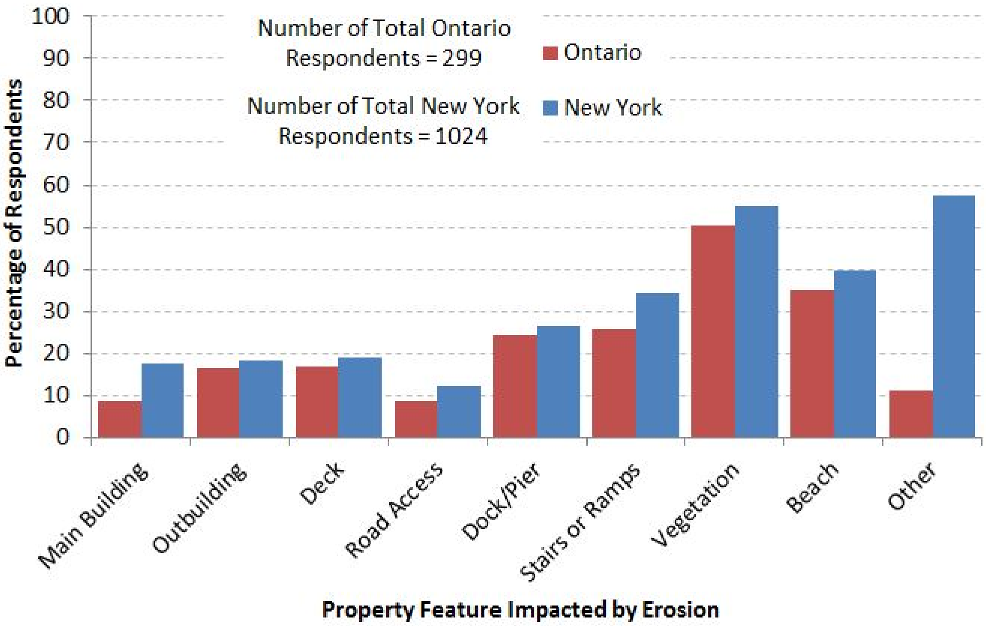


Figure 5-34: Percent of respondents indicating property features impacted by erosion (Source: ECCC, based on data acquired through Conservation Ontario survey for IJC)

Public lands and shoreline trails were also damaged by erosion (Figure 5-35). Such impacts would not be captured by the erosion performance indicator developed during the LOSLRS as that indicator only considers properties with buildings on them. A number of park properties required immediate action to stabilize the shoreline and protect further loss of land and direct impacts to infrastructure such as trails.

Figure 5-35: Shoreline erosion at Confederation Beach Park, City of Hamilton (photo taken May 17, 2017). Photo credit: City of Hamilton.

Shoreline Erosion – Lower St. Lawrence River: A detailed study on shoreline erosion on the lower St. Lawrence River is being undertaken through partner agencies. The GLAM Committee was not able to acquire the detailed project scope since it is not yet available. Further effort will be required to pursue this information in the future.

Shoreline Protection Impacts – Lake Ontario-Upper and the St. Lawrence River: Damages were observed to existing shoreline protection structures in many locations including private residences and public shorelines (Figure 5-36 and 5-37). Given the replacement value of shoreline protection, overall costs associated with these impacts appear to be high. For example, the City of Toronto estimated potential repair requirements of $7.38 million as a result of high water level conditions in 2017 (City of Toronto, 2018). Based on the responses to the Conservation Ontario self-reporting survey, the Canadian counties with the highest percentage of reported shore protection impacts relative to the overall response rate were Northumberland and Prince Edward County. On the US shoreline, both Monroe and Jefferson Counties had a high percentage of the total respondents in this category (Figure 5-38).

Figure 5-36: Overtopping of shore protection, Stoney Creek, ON. Photo credit: ECCC, May 2017.

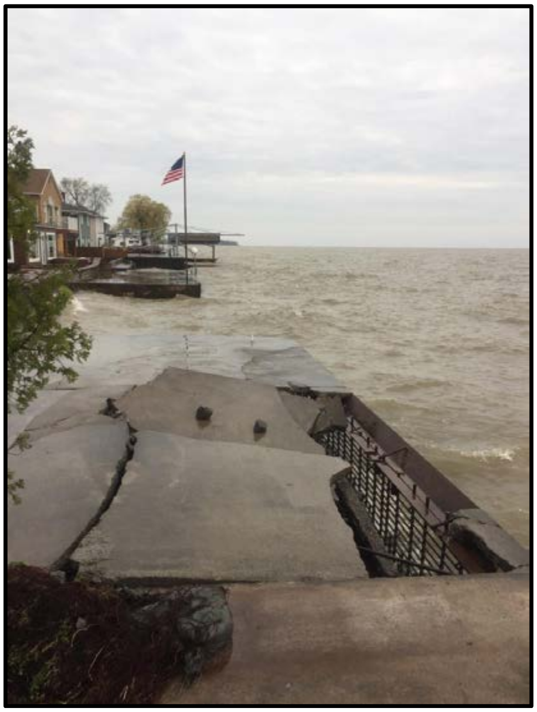


Figure 5-37: US shoreline shore protection photos submitted through shoreline survey. Photo credit: L. Frosini, taken May 21, 2017.

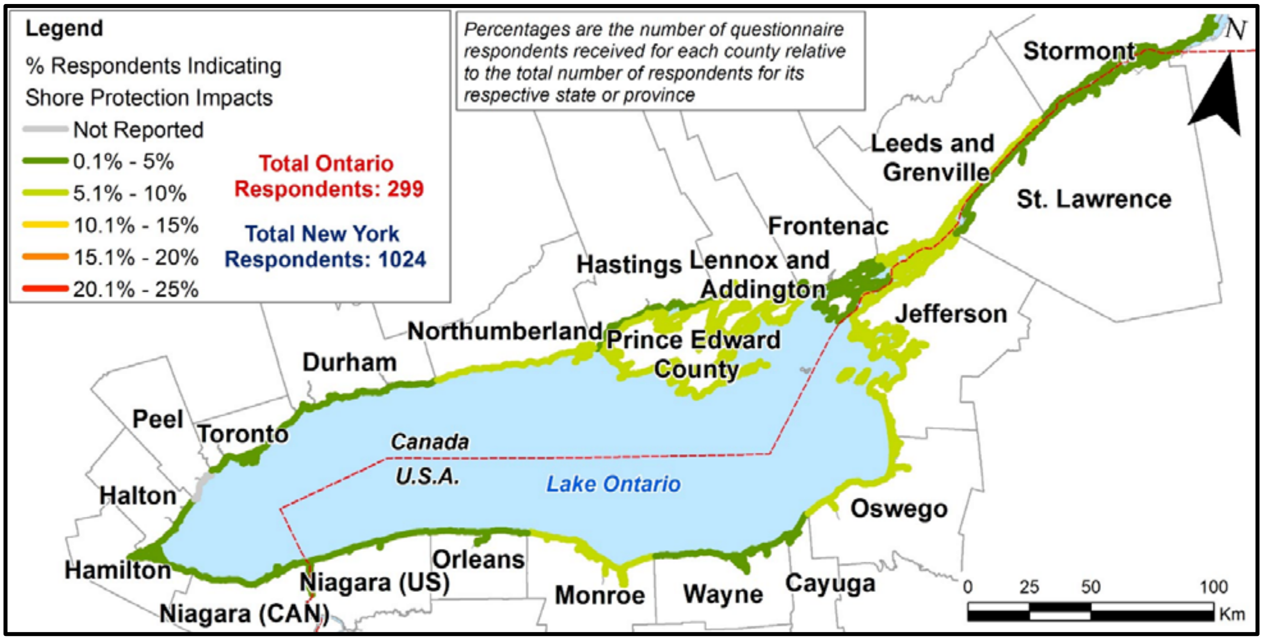


Figure 5-38: Survey responses indicating shore protection impacts, by county or municipality (based on a relative scale using the number of shore protection impacts in each county relative to the total number of responses for the country in which that county falls) (Source: ECCC, based on data acquired through Conservation Ontario survey for IJC)

<u>Shoreline Protection Impacts – Lower St. Lawrence River</u>: As flooding was the performance indicator used on the lower river during the LOSLRS and the primary adverse impact experienced in 2017, the GLAM Committee has not pursued information on impacts to shoreline protection structures on the lower St. Lawrence River. A detailed study on shoreline erosion in the lower St. Lawrence River is being undertaken through partner agencies and the GLAM Committee will be able to follow this study. The detailed project scope is not yet available. Further effort will be required to pursue this information in the future.

Model Assessment: The three primary performance indicators representing impacts to coastal property owners on Lake Ontario are first floor flooding of residential buildings, erosion to developed but unprotected land and shore protection structure maintenance costs. The primary performance indicator on the St. Lawrence River is first floor flooding. The GLAM Committee has only completed a preliminary comparison of performance indicator results to the available descriptive information of coastal impacts based on similar high years from the historical record and from water supply scenarios. Based on the existing models, it was expected that there would be first floor flooding damages at various locations along the Lake Ontario and upper St. Lawrence River shoreline under 2017 water level conditions (~250 individual properties) and that first floor flooding damages would increase quickly as water levels rose above 75.6 m (248 ft). It was also expected that shore protection maintenance would represent some of the greatest coastal impacts due to the total number (over 4,500) and value of existing shore protection and the significant costs required to make repairs if damaged. Erosion rates were also expected to increase above long-term rates necessitating new shoreline protection in areas where it was not previously installed. On the lower river, first floor flooding of homes and inundation of roads directly along the St. Lawrence River were expected at levels observed in 2017. The existing model suggests the greatest impacts along the St. Lawrence River would be downstream of Montreal in the Sorel and Lake Saint-Pierre areas which seems to be consistent with what was observed on the lower river during late April and early May of 2017 when low-lying areas were inundated. Overall, the types of impacts observed in 2017 appear to be consistent with broad categories used to represent potential regulation plan impacts to shoreline property owners throughout the Lake Ontario – St. Lawrence River system but further assessment is required to determine how closely actual impacts aligned with the modelled estimates of at-risk locations. It is important to note that no performance indicators are designed or able to capture all potential impacts. They are developed as indicators of response under various water level conditions and the intent was not to quantify all impacts, but to have indicators that could potentially differentiate regulation plan alternatives.

While much of what was observed in 2017 was consistent with the broad characterizations of the existing performance indicators, the record high water levels of 2017 on Lake Ontario and the St. Lawrence River also led to related impacts that are not directly captured by existing performance indicators. For example, the cost to install new shore protection to protect public infrastructure such as shoreline trails and park facilities was not considered in the shore protection performance indicator that only addressed protecting homes or buildings. The flooding indicator did not consider impacts beyond those related to first floor inundation, such as flood water surrounding homes or impacting crawl spaces and storage buildings, inundation of secondary buildings (e.g. sheds or garages), and the extensive sand bagging operations and expense. In the on-line property survey, first floor flooding represented a fairly small percentage of the number of individuals reporting flooding impacts which is consistent with expectation but also suggests there are a range of other potential flooding concerns that are not directly assessed in the model and are of concern to property owners. Finally, a number of media reports also highlighted the psychological impacts of flooding to people that live along the shoreline and this was also reflected in answers to the on-line shoreline survey where people also noted stress related to the personal financial toll, including the concern about the long-term implications (see the LOSLR Annex 1-Impact Assessment for more details). While it may not be possible to incorporate such psychological impacts into a measurable performance indicator, it is important to recognize these impacts in the context of significant high water events.

Recognizing again that performance indicators are to be representative of impacts, but will never capture all impacts, further processing and review of the impact information is needed before a comparison can be completed between results from the existing models and observed conditions. In addition, further review of the performance indicators is needed to make sure the most significant impacts observed under actual water level conditions are adequately represented.

Key Findings and Next Steps: On Lake Ontario and the St. Lawrence River, impacts from record high water levels were widely distributed across the lake and river shorelines, although there were particularly hard-hit areas. To date, much of the information available to document impacts is descriptive rather than quantitative and based on self-reporting surveys, photographs and interpretation of aerial imagery. The GLAM Committee is awaiting formal reporting by various state and provincial agencies on 2017 impacts and so a comprehensive database of the distribution of property level impacts is not currently available.

The conditions in 2017 caused significant impacts to coastal interests throughout the entire system. Coastal property owners on the US and Canadian shores of Lake Ontario and the St. Lawrence River as well as property owners along the lower St. Lawrence River all experienced damages due to flooding, erosion and failed shoreline protection structures. Assessment of the aerial imagery datasets, Conservation Ontario questionnaire results, and site visit reports indicate that the most commonly reported impacts were flooding, followed by erosion and then impacts to shore protection structures.

Based on the information currently available to the GLAM Committee in the form of questionnaire responses, aerial imagery datasets and site visit reports, there is reasonable confidence in the reporting of the types of impacts and the areas affected. However, information is not yet available to quantify a specific number of properties impacted due to a number of factors, such as the inherent uncertainty in the reliability of the questionnaire responses and the possibility of error in the aerial imagery assessment. To this end, there are a number of measures that could be taken to improve the evaluation of the coastal performance indicators:

- Consider whether the current definitions of the performance indicators need to be reevaluated based on observed response to actual system conditions. For example, should the erosion metric be applied where shoreline protection infrastructure other than residential buildings were at risk in 2017;
- Study the correlation of areas employing sandbag defenses and the number of instances of first floor flooding in those areas; and
- Continue efforts to obtain official statistics on flood damages and use these data to validate the modeled estimates of first floor flood damages at various static lake levels. A level of 75.6 m (248 ft) and below is especially significant to consider in this analysis due to reports of coastal properties being damaged at these levels.

5.6 Ecosystem

The ecosystem interest broadly captures “the biological components of the natural environment of Great Lakes and the St. Lawrence River, together with the ecological services they provide to people who live and work in the region” (IUGLS, 2012; IJC, 2014). This includes habitat conditions influenced by water level and flow conditions, notably nearshore coastal wetland habitats, as well as the bird, fish, mammals, invertebrate, amphibian and reptiles that are directly impacted by water level and flow conditions on Lake Ontario and the St. Lawrence River for some critical portion of their life cycle.

5.6.1 UPPER GREAT LAKES – Ecosystem

Sensitivity to Water Levels and Outflows: On the upper Great Lakes, a range of possible indicators were considered across the large geographic area that could be used to represent potential regulation plan impacts, both positive and negative. While water level fluctuations affect varying habitats and species differently, some general characteristics were identified and expected responses associated with water level changes on the upper Great Lakes as well as flows in the St. Marys River. Through the development of an Integrated Ecological Response Model 2 (IERM2) and associated coping zones, potential vulnerabilities and benefits from changing water levels were characterized to broadly compare regulation plan alternatives.

Coastal wetlands in the Georgian Bay area were found to be particularly sensitive to low water levels during the IUGLS, partly because of the geomorphology of the shoreline and the limitations due to the Precambrian Shield and natural shelf that would allow wetlands to migrate downslope. Questions were raised during that time as to whether wetlands would be able to recover when high water returned. The GLAM Committee is aware of research that has been conducted and is awaiting results which should be released soon.

Generally speaking, detailed performance indicators were not practical during the IUGLS given the limited impact that regulation of outflows can have on the upper Great Lakes system. The one exception was to the St. Marys River. While specific ecosystem performance indicators were not developed for the St. Marys River during the IUGLS, some priority items were identified for follow-up from the IUGLS to validate assumptions. Three of these priorities for the St. Marys River included:

- Verifying the potential benefits of slowing the speed of gate setting changes at the Compensating Works to reduce the risk of fish and other aquatic animals from being flushed out of or stranded in the St. Marys Rapids; and
- Determining whether additional environmental benefits could be achieved by increasing the minimum gate setting to increase the wetted surface area and provide additional habitat in the St. Marys Rapids.

Summary of Observed 2017 Impacts: Coping zones for ecosystem interests established in the IUGLS are different from ones in the other five interests in two ways. First, the high and low water levels that cause problems for municipal water systems, navigation, hydropower, coastal development and recreational boating are generally good for ecosystems. Second, ecosystem coping zone definitions are generally complex, often combining water level, time of the year and persistence. The existing tools from the IUGLS to measure the impacts of NBS and water level to the 34 individual ecosystem indicators is best set up to compare regulation plans that were studied and not annual water level variations of the recent past (IERM2 Coping Zone Calculator). Development of a different tool to evaluate recent annual changes in water level respective to the established IUGLS ecosystem indicators is a task for future GLAM efforts.

Further studies by ECCC are underway examining the potential impacts of climate changes and water levels on Great Lakes coastal wetlands. Results will not be available for another four years.

Model Assessment: Through the development of the Integrated Ecological Response Model 2 (IERM2) and associated coping zones during the IUGLS, potential vulnerabilities and benefits from changing water levels were broadly characterized and used to compare regulation plan alternatives. It was generally concluded during IUGLS that the small differences between regulation plans tested did not result in detectable ecosystem response on Lake Superior and Lakes Michigan-Huron. However, with the implementation of Plan 2012, one of the areas that was identified to potentially be sensitive to changes in a regulation plan were ecosystems on the St. Marys River. To begin to address this specific area, a two-dimensional hydrodynamic model was developed covering the full extent of the St. Marys River by USACE. Work in 2017 focused on recreating the gated flow scenarios from 2015. In 2015, a partial-gate strategy was implemented to more evenly spread water across the rapids. These scenarios were contrasted with a more traditional full-gate opening approach. Water depths and velocities were computed on an approximate 4 m (13.1 ft) grid throughout the rapids. These data combined with LiDAR, photogrammetric data, temperature and limited biological data were compiled using an IERM developed for the St. Marys Rapids. The IERM predicts areas where various fish species are likely to spawn and their fry are able to survive. Work is expected to continue in the future with the goal of optimizing habitat based on the St. Marys Fisheries Task Group. For example, a US Geological Survey (USGS) Biological Station team received funding for fiscal year 2018 from USEPA for a three-year sampling plan to collect larval fish in the St. Marys Rapids. The collected samples and recorded species will be used as future validation for the UGL-IERM2 model relative to target species for spawning in the rapids (lake sturgeon, whitefish, and walleye). In addition, a proposal request for 2018 (via the IJC's International Watersheds Initiative) has been made to support the collection of sidescan sonar identifying substrate throughout the St. Marys Rapids and St. Marys River. The project will produce a map that will detail locations of silt/clay/mud, sand, cobble or bedrock in the project area. The spatial locations of substrate will build finer resolution in the IERM ecohydraulic model and improve prediction of target species spawning habitat and influences of water level and velocity changes in the rapids.

Modeling work is expected to continue with the goal of optimizing habitat based on ecohydraulic model outputs and insight from St. Marys Fisheries Task Group.

Key Findings and Next Steps: It is clear that GLAM needs a fully functional eco-hydraulic model in the St. Marys Rapids to establish the impacts of various release scenarios on the spawning habitats of native species. While an IERM2 model is currently under development, it is not ready to produce reliable results at the time of this report. Once the model has been updated, calibrated and validated then results can be used to guide the potential development of environmental performance indicators for the St. Marys Rapids. Also, there is currently research underway in Georgian Bay by McMaster University and additional studies being done by ECCC that may help validate assumptions that water level fluctuations are beneficial to wetland health.

5.6.2 LAKE ONTARIO – ST. LAWRENCE RIVER – Ecosystem

Sensitivity to Water Levels and Outflows: Thirty-one ecosystem performance indicators were developed covering Lake Ontario, the upper St. Lawrence River (above the dam) and lower St. Lawrence River (below the dam) during the LOSLRS. These indicators were chosen by experts based on their sensitivity to water levels changes, their significance in terms of ecosystem function and services to a region and based on the confidence in the scientific results. Coastal wetlands provide an ecologically important and biologically diverse transitional zone between open water and land. The coastal wetland meadow marsh indicator for Lake Ontario was established as a fundamental indicator of ecosystem response to water level changes as it provides diverse wetland vegetation reflecting the history of the range and duration of water level changes and provides important species habitat.

There have been many studies over the past twenty years indicating that the suite of performance indicators developed for the initial study would respond, to varying degrees, to extreme water levels and flows. A period of high water levels, for example, as occurred in 2017 on Lake Ontario, is expected to have the effect of forcing a wetland’s shrub zone to a higher elevation and allowing expansion of the meadow marsh communities. Monitoring how coastal wetland habitats change with respect to elevation is important for teasing apart the influence of water-level management and other factors that play a role in habitat change, such as invasive species, alterations to adjacent upland areas, or other changes in hydrologic inputs. However, from a resourcing perspective it is not feasible to investigate the responses of all the LOSLRS performance indicators to the 2017 conditions. Therefore, efforts were concentrated on identifying which of these indicators would be most affected and which indicators were already being monitored. Indicators theorized to show a large response to a high water level event including those which were being monitored in 2017, such as meadow marsh, are reported on in this section and in more detail in Annex 1-Impact Assessment. Efforts to develop methods for long term monitoring programs to collect data on indicator response in the future were taken and fully detailed monitoring programs are currently in the works.

Following the LOSLRS, it was concluded that, under Plan 2014, a more natural variability in water levels would produce significant environmental gains when compared to the previous plan 1958-DD. The strong correlations between plant types and flooding history provide the scientific evidence. In order to effectively assess the impacts of the 2017 event on the ecosystem, several efforts were tracked. Surveys of wetland plant communities were done in prescribed areas on Lake Ontario where surveys had been conducted in recent years. Surveys prior to 2017 provide a comparative baseline for the performance of meadow marsh in 2017. Additionally, various federal, state and provincial government agencies that were conducting studies on relative fish and animal species that make up some of the performance indicators were willing to collaborate their findings and provide a snapshot of how those indicators performed in 2017. On the lower

St. Lawrence River, while there are numerous ecosystem indicators that are sensitive to water level changes, there is not expected to be a significant change in water levels from the old plan to the new plan. Nevertheless, the extreme events of 2017 provide a good test of modelled results.

When discussing the impacts of high water to the ecosystem performance indicators, it should be emphasized that many of the environmental indicators are responding to seasonal and multi-year cycles and take time to respond. Many of the performance indicators currently being monitored are expected to see measurable impacts due to a high water event over several years and not within a matter of months. This fact remains a challenge for the GLAM Committee. It is impossible to report on some of the ecosystem impacts from the 2017 high water event on Lake Ontario and the St. Lawrence River until they have come to fruition. For this report, the ecosystem section focuses on data collected to date and the results of models and expert opinion on expected outcomes. Follow-up monitoring will be needed to determine if these outcomes are realized over the coming years.

Summary of Observed 2017 Impacts: The impacts from the 2017 event on Lake Ontario and the St. Lawrence River are largely unclear at this point. Some early results from wetland monitoring efforts are indicating some vegetation response is occurring even within the high water year. Model results on the lower river are mixed. There is much data collection and analysis remaining to be done. Data collected in 2017 can be used to inform comparative years in the future. Observed impacts to the wetland plant communities are summarized in the surveys of 32 specific sites around the entire Lake Ontario shoreline. Results from this survey are summarized in the Annex 1-Impact Assessment.

The efforts of wetland surveying by the Canadian Wildlife Service (CWS) and New York Department of Environmental Conservation (NYDEC), supported by the IJC’s International Watersheds Initiative, include some information on the initial impacts to wetland plant communities at elevations above typical meadow marsh communities. NYDEC and CWS have committed to share data and pursue analysis using the peer-reviewed ordination method used to delineate wetland plant communities. A summary of the CWS and the New York Natural Heritage Program (under NYDEC) surveillance efforts are included in Annex 1-Impact Assessment. It is noted that the full extent of inundation of these higher elevation communities were not expected to be realized for this year’s monitoring effort, however, early indication from this year’s monitoring does indeed indicate some vegetation response. Further monitoring in the coming years will be necessary to determine how these vegetation responses are reflected in future years.

Several additional performance indicators were expected to be impacted due to the 2017 conditions. At this point, no data have been collected on these performance indicators to corroborate the anticipated impacts. Further efforts are being pursued to establish responses from these performance indicators. Additional performance indicators expected to be impacted due to the 2017 conditions are as follows:

- Changes in bird nesting habitat due to the availability of specific plant species sought by endangered/ threatened bird species;

- Typha (cattail) die-back due to long term exposure to high water as predicted in the wetlands model;
- Possible invasion of Phragmites to replace cattails after disturbance;
- Fish spawning increase due to expanded spawning habitat; flooding increases size of the nearshore, providing more cover for fish spawning and survivability;
- Shorelines experiencing heavy tree loss creating debris fields and the associated impacts to water quality and/or species habitat; and
- Shoreline changes such as cut-back of dunes and subsequent habitat loss for dune nesting birds, and the breaching of barrier beaches causing the exposure of protected wetlands to open lake waves.

The GLAM Committee is currently actively engaged in the development of long-term monitoring programs to collect response data on specific performance indicators. As part of this effort, the project on state of science of remote sensing for ecosystem indicators is currently underway (an IJC International Watersheds Initiative project (Ryerson, 2018)) and should provide some specific methodologies to establish long term monitoring programs that the GLAM Committee could manage with its limited resources.

Modelling Assessment: The LOSLRS developed an extensive IERM covering 32 environmental indicators, notably nearshore coastal wetland habitats, as well as the bird, fish, mammals, invertebrate, amphibian, and reptiles that are directly impacted by water level and flow conditions on Lake Ontario and the St. Lawrence River for some critical portion of their life cycle. In order to identify the specific performance indicators on Lake Ontario and the upper St. Lawrence River impacted by 2017 conditions, two approaches were employed. The first was an analysis of the original LOSLRS performance indicator algorithms linking outcomes to water levels and a comparison of the thresholds associated with those algorithms and the observed 2017 conditions indicating impacts to specific species indicators. The second was an analysis of the IERM model results employing a representative water supply year from the historic series to represent the conditions observed in 2017.

The LOSLRS performance indicator algorithms were developed with the input of various professional experts that set metrics for some of the more critical species indicators. In order to establish which species were likely impacted by the 2017 conditions, an assessment of the water level fluctuations and static quarter month levels was done with respect to the individual indicator's algorithms identified to be key environmental indicators in the LOSLRS. These algorithms define specific conditions during quarter month time frames that are expected to impact the performance of that species in that year. For example, during quarter months 18 through 26 (roughly the 2nd week of May through the 2nd week of July), Lake Ontario water level fluctuations exceeding a raise or drop of more than 0.2 m (0.66 ft) per quarter month (approximately 1 week) are expected to negatively impact the wetland birds Least Bittern and Black Tern, which are considered species at risk and designated as Vulnerable by MNRF and Threatened or Endangered by NYSDEC. The 2017 conditions did not exceed a 0.2 m (0.66 ft) fluctuation in any specific quarter month within the targeted timeframe, therefore there was no negative impact forecasted by the algorithm for these species. Another factor in the success rate of these wetland birds is the mean water depth below nests within the emergent marsh areas of wetlands. For nesting to be successful, Least Bittern need a mean water depth between 0.2 meters (0.66 ft) and 1.0 meter (3.28 ft) below their nest. The mean elevation of emergent marsh for all types of hydrogeomorphically classified wetlands in 2017 was 74.92 m (245.80 ft), as established in the 2017 field sampling analysis of the US wetlands. In 2017, Lake Ontario crested at 75.88 m (248.95 ft) in quarter month 21 which translates to a mean water depth of 1.04 m (3.41 ft) within the emergent marsh zone. This is slightly above the algorithm's anticipated maximum water depth below nests for Least Bittern at several different study locations in the sensitive quarter month time frames. Therefore, Least Bittern's reproductive potential was identified by the algorithm to be negatively impacted by the 2017 conditions. The Least Bittern was the only key environmental indicator assessed to be negatively impacted by 2017 conditions.

The second method's modeling runs performed on the ecosystem performance indicators revealed that a comparative high water year selected from the historic set of water supplies produced the most impacts in the performance indicators of the Least Bittern, Virginia Rail, Black Tern, and upper St. Lawrence River muskrat housing density. The original study algorithm placed significant impact on these bird species related to high water events occurring during the months of May, June and July. This, of course, means that the 2017 event would be expected to significantly benefit these performance indicators. Though the exploratory model results indicated significant positive impacts to muskrat housing density, the study algorithm emphasized impacts to this performance indicator during high water events from September through February. While water levels were significantly lower in the fall compared to their record high spring and early summer levels, they did remain well above average into the fall months. The NYDEC has a monitoring program ongoing for muskrat which could help validate the algorithm for this performance indicator in future years, but data for muskrats was unavailable prior to the finalization of this report.

Lake Ontario Wetlands algorithm

The IERM calculates wetland vegetation elevation response based on Lake Ontario water levels using the:

- *dewatering elevation* (highest peak quarter-month water level) for vegetation response to dry conditions; and
- *flooding elevation* (fourth highest quarter-month water level around the peak to represent the highest month of flooding) for vegetation response to wet conditions.

High water levels such as those experienced in 2017 are expected to flood and result in the die-off of upland shrubs and trees and meadow marsh up to the flooding elevation. The flooding elevation as described above for 2017 is 75.81 m IGLD85 (248.72 ft) and the IERM algorithm predicts the Cattail-dominant meadow marsh plant community would rise in elevation up to 75.81 m IGLD 85 (248.72 ft). The IERM algorithm is currently programmed to have vegetation respond to water levels from the year before, in other words the die-off of upland shrubs and trees and meadow marsh would be expected to occur in 2018, one year after the 2017 high water levels. The 2017 conditions cause the IERM algorithm to predict that meadow marsh and upland vegetation will remain unaffected in 2017 by high water levels. Those plant communities would be expected to die-off up to 75.81 m IGLD 85 (248.72 ft) in 2018 in the IERM algorithm. This is discussed further in the Annex 1-Impact Assessment.

Lower River IERM Analysis for 2017: Several environmental performance indicators were developed during the LOSLRS that aimed to quantify/qualify the impacts of discharge regulation on fauna and flora on the lower St. Lawrence River. The 11 indicators presented in the Annex 1-Impact Assessment are the key indicators selected from a large number of environmental indicators (more than 200) developed for the Lower St. Lawrence River that were found to be the most sensitive, significant and having the greatest level of certainty in terms of the science and model results. Model results of the 2017 conditions on these 11 indicators can be found in the Annex 1-Impact Assessment and indicate a mix of positive and negative scores across the performance indicators demonstrating what would be expected by the model under these conditions. The GLAM Committee has not yet been able to track down any monitoring data to help verify the model results.

Key Findings and Next Steps: When discussing the impacts of high water to the ecosystem performance indicators, it should be emphasized that many of the environmental indicators are responding to seasonal and multi-year cycles and take time to respond. Many of the performance indicators currently being monitored are expected to see measurable impacts due to a high water event over several years and not within a matter of months.

Field data from the surveillance of the Canadian wetlands done by CWS in 2017 (IJC International Watershed Initiative project) show a reduction of percent cover of meadow marsh from 2015. This is to be expected as the flooding of these species during the growing season affect the meadow marsh species, resulting in smaller coverage area of this particular vegetation guild. It should be noted that shifts in guild extent resulting from 2017 water level conditions will not be immediately evident as there is a lag in response from the various plant communities. In order to ensure that the wetland response to 2017 conditions is adequately monitored and recorded, GLAM has contracted with CWS in 2018 to conduct monitoring of wetlands at 16 sites in Canada. The objective of the 2018-2019 collection effort is to assess the vegetation zonation at the 16 sites. Data collected from this monitoring effort will provide a data set that can be leveraged to track the wetlands response to the 2017 conditions over time. It is imperative for model validation and future evaluation of the wetland response performance indicator on Lake Ontario that these data are collected over the next few years.

In addition to the immediate need for field surveys, GLAM is actively exploring potential methods for long term monitoring programs that can be applied to various ecosystem performance indicators. During GLAM's 2017 data collection efforts, the need for monitoring data of the species-specific performance indicators on the lower St. Lawrence River was identified. There was no available monitoring data from 2017 with which results of the lower St. Lawrence IERM model runs could be verified. It is essential to develop a plan to collect data on the lower river species performance indicators so we can validate the model results in the future. Remote sensing technologies are being explored to help inform this effort and a remote sensing subject matter expert workshop was held on March 26th and 27th of 2018 (Ryerson, 2018). This effort will be dependent upon taking the first step to identify the performance indicators that are best suited to a long term monitoring plan and developing the monitoring plan around that small set of indicators.

5.7 Recreational boating and tourism

The IUGLS looked at water level impacts to recreational boating activity, marinas and coastal tourism including cruise ship traffic (IUGLS, 2012). There was one recreational boating and tourism performance indicator used to evaluate regulation plans during the IUGLS. The indicator was the change in availability of boat slips across the study area and was represented as a Pass/Fail score based on whether changes were considered disproportionate for a particular lake or region. The coastal tourism and cruise ship sectors were not represented by a performance indicator. Data on boating activities and trends is fairly limited and was identified as an area that required further investigation through adaptive management (IUGLS, 2012).

During the LOSLRS, the recreational boating interest group was defined as including “pleasure boating and fishing, marinas and the commercial cruise ship industry” (IJC, 2014). As noted in the IJC’s Plan 2014 report, “Analysis undertaken for the IJC’s Lake Ontario-St. Lawrence River Study found that recreational boaters in the US and Canada spent an estimated $430 million on boating-related trips taken on Lake Ontario and the St. Lawrence River in 2002.” (IJC, 2014). The primary performance indicators were total possible boating days lost and net economic value lost (willingness-to-pay). These measures provide an estimate of both recreational loss and economic loss as water levels change (IJC, 2006). The willingness-to-pay performance indicator was developed based on estimates of days boated and net economic value by water reach, country (US or Canada), water access method (private dock, marina, launch ramp, charter boat), boat type (sail or power), and boat length class. Net economic value was estimated based on boat owners’ willingness-to-pay for boating over and above what they are already paying. The performance indicator was applied based on geographic regions that included Lake Ontario, the upper St. Lawrence River broken into three sections and referred to as Alexandria Bay, Ogdensburg, and Lake St. Lawrence and the lower St. Lawrence River which was divided into the Lake Saint-Louis, Montreal, and Lake Saint-Pierre sections (see Figure 5-39).

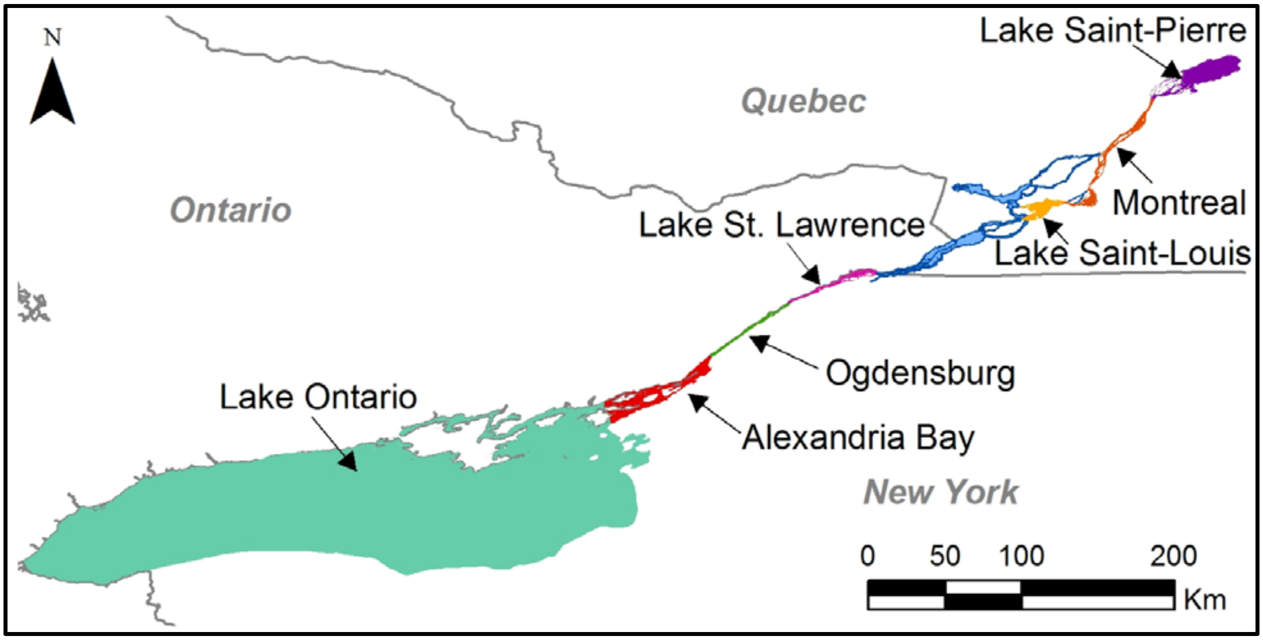


Figure 5-39: Recreational boating reaches as used for the LOSLRS recreational boating performance indicator (Source: International Lake Ontario – St. Lawrence River Study Board, 2006, Annex 2)

Tourism was considered during the LOSLRS as part of the Recreational Boating and Tourism Technical Working Group activities. However, as noted on page 39 of Annex 2 of the LOSLRS (2006), "the economic advisors to the study recommended that the tourism-related IMPLAN (Impact Analysis and Planning model) results not be used because they were not comparable with measures used by other interest groups." As a result, the primary indicator for recreational boating and tourism impacts was the willingness-to-pay indicator of recreational boating activity.

5.7.1 UPPER GREAT LAKES – Recreational boating and tourism

Sensitivity to Water Levels and Outflows: While boaters and marina operators are sensitive to water level fluctuations on the upper Great Lakes, including both low and high water levels, marina operations were found to be more dramatically impacted by low water levels when compared to high water levels (IUGLS, 2012).

During the IUGLS, coping zones (for explanation, see Section 5.1.1) were developed to describe potential impacts under varying water levels for the recreational boating sector (Table 5-6).

Table 5-6: Summary of Rec Boating Coping Zones relative to Marina Slips. (Source: IUGLS 2012)

	Zone A	Zone B	Zone C
Max WL (m)	Superior: 184.3 Michigan-Huron: 177.3 Erie:174.8	Superior: There is a jump from Zone A to C between 184.3 and 184.6 Michigan-Huron: 177.3 (According to 'Out of Business' and 'Slip Loss' numbers, there is a jump from Zone A to Zone C after 177.3) Erie: 174.8 – 174.95	Superior: > 184.6 Michigan-Huron: > 177.6 Erie: > 174.95
Min WL (m)	Superior: 182.8 Michigan-Huron: 176.1 Erie: 173.61	Superior: 182.5 Michigan-Huron: 175.5 Erie: 173.61 – 173.46	Superior: <181.9 Michigan-Huron: < 175.2 Erie: <173.46
Rate of Change	Quick drops or rises are generally considered a negative as interest does not have time to adjust	A quick return to Zone A regime would be beneficial. A further drop/rise, or prolonged period at this elevation could push interest to Zone C	Any length of time in Zone C would make it difficult for many of the marinas to remain operational
Slip Loss	Less than 5%	5% - 30%	Greater than 30%
Adaptation	Interest will take action to protect investment even within this zone, however, expenditures are within expectations	Property owners likely to take action to protect their investment. Could make them more resilient next time levels are at extremes and help them within Zone A levels	Existing adaptation not sufficient shore protection overtopped or useless because levels are so low. Hazard zones have been exceeded.
Suggested Indicators for Assessing Thresholds	Slip losses and interview responses regarding 'out of business' levels	Slip losses and interview responses regarding 'out of business' levels	Slip losses and interview responses regarding 'out of business' levels

The IUGLS found that recreational boating would not be measurably impacted by a change from Plan 1977A to Plan 2012 (no disproportional losses). This was based on a measure of the usability of boating slips and a pass/fail score based on whether one region of the system might suffer dis-benefits relative to another region.

Summary of Observed 2017 Impacts: Generally speaking, slightly above average water levels on the upper Great Lakes are considered beneficial to the recreational boating sector as they allow recreational boats to get in and out of marinas and harbors more easily. However, no data have been gathered to date by the GLAM Committee to document negative or positive impacts of above average water levels in 2017 on the recreational boating and tourism sector. There were no negative reports to the ILSBC in 2017 and water levels in 2017 fit within the IUGLS defined coping zones for recreational boating (Figures 5-40 to 5-42). There has been no formal validation of these coping zones since the 2012 IUGLS.

Water levels in 2017 on Lake Erie hovered near or above the Zone A Max transition coping zone. The expected sensitivities and slip losses described in Zones A (< 5 % slip loss) are closely representative to 2017 media reports where there were some temporary negative impacts to floating docks but no permanent loss or damage to slips and access.

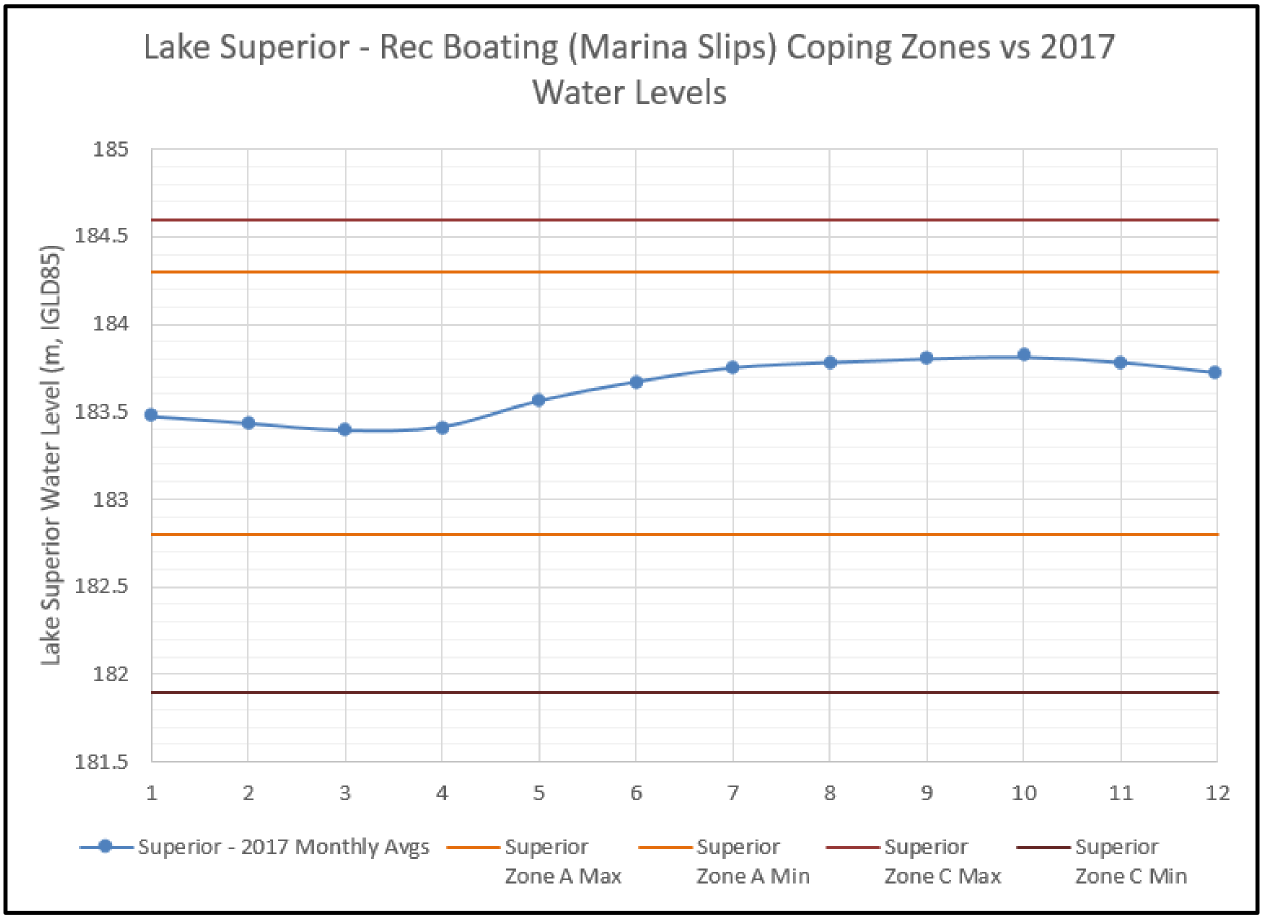


Figure 5-40: Coping zones for Lake Superior Recreational Boating (Marina slips) compared with 2017 water levels (Source: USACE, Detroit District)

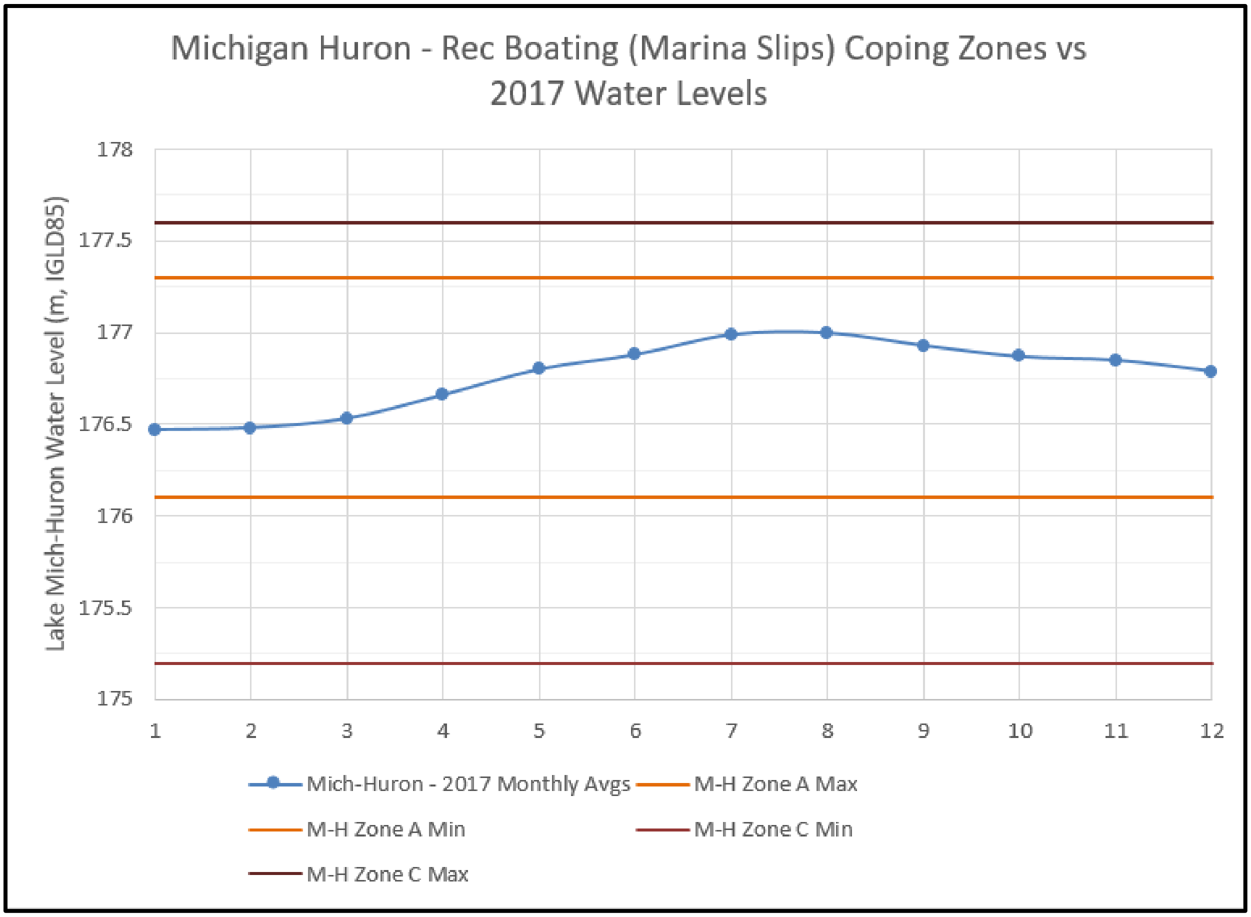


Figure 5-41: Coping zones for Lakes Michigan-Huron Recreational Boating (Marina slips) compared with 2017 water levels (Source: USACE, Detroit District)

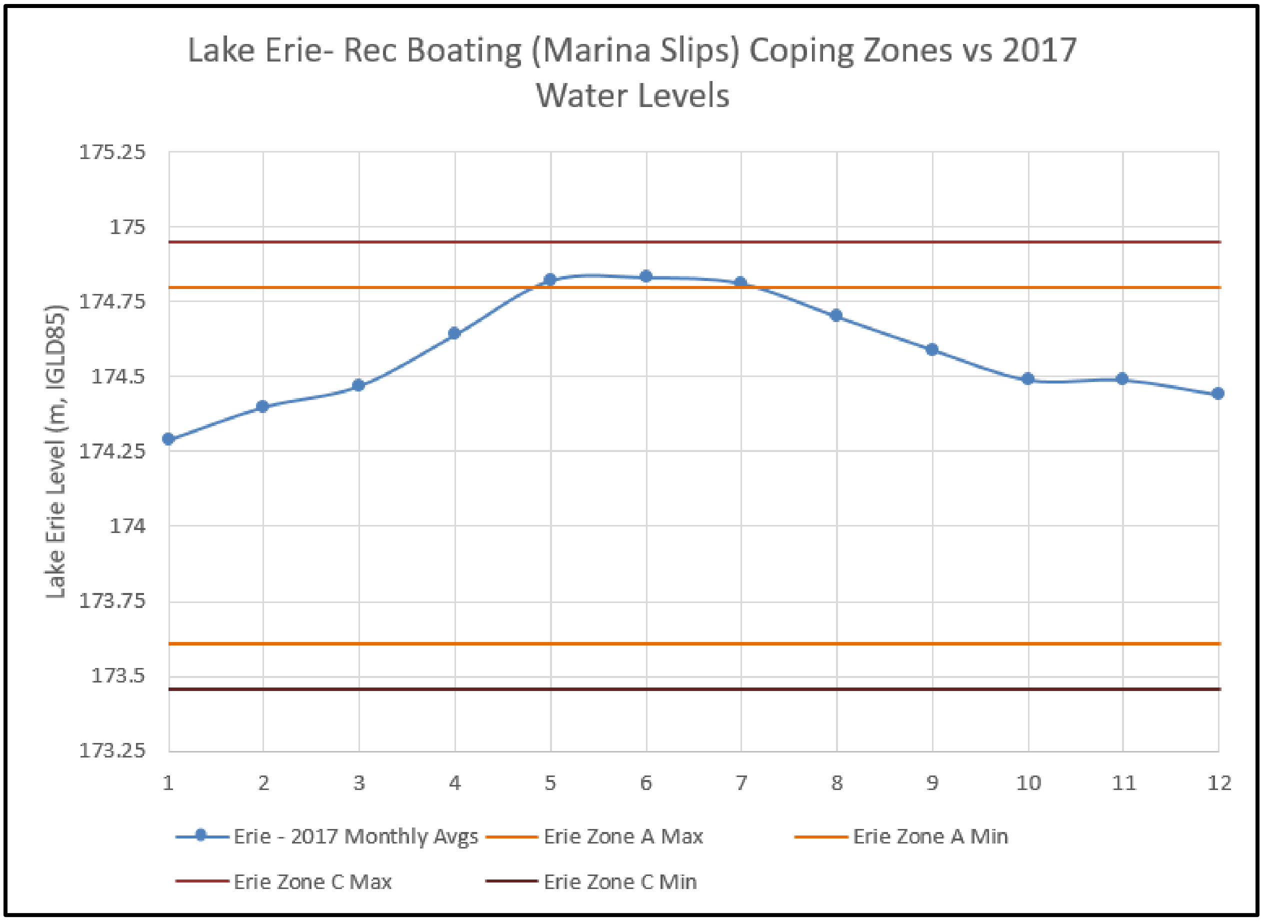


Figure 5-42: Coping zones for Lake Erie Recreational Boating (Marina slips) compared with 2017 water levels (Source: USACE Detroit)

Model Assessment: There has been no attempt by the GLAM Committee to validate either the one performance indicator used during the IUGLS, which was the change in availability of boat slips across the study area represented as a Pass/Fail score, or the coping zones developed during the IUGLS. Consideration of this will be given future attention as the GLAM Committee grapples with needs and priorities, as this sector is minimally affected by the regulation plan.

Key Findings and Next Steps: Recreational boating and tourism activities on the upper Great Lakes did not appear to be negatively impacted in 2017, with the exception of some impact to Lake Erie marina operators. Otherwise, it would appear the levels of 2017 have been generally positive for recreational boating. Given that this interest is not particularly sensitive to Lake Superior outflow regulation changes, it is not yet clear how much effort will be applied to this sector in future analyses, or whether existing information is sufficient.

5.7.2 LAKE ONTARIO-ST. LAWRENCE RIVER – Recreational boating and tourism

Sensitivity to Water Levels and Outflows: As with the upper Great Lakes, recreational boaters on Lake Ontario and the St. Lawrence River are sensitive to both low and high water levels. In the development of the LOSLRS performance indicators, impacts during lower water periods were considered particularly critical as recreational boating activity declines and even stops in some places. This is due to low water levels reducing the ability to use boat launches or causing docks to no longer be usable due to limited draft for the types of boats that would normally use such facilities. Of course, impacts are also experienced under high water conditions such as those observed in 2017 as recreational boating opportunities are reduced where water levels inundate non-floating docks or boat ramp facilities. Impacts can vary from site to site with some locations with deeper water and floating docks able to tolerate greater water level variability compared with locations with shallow water and/or non-floating docks (see Figure 5-43). Recreational boating activity varies seasonally and during the LOSLRS, willingness-to-pay estimates were adjusted monthly from April to October. The vast majority of boating activity typically takes place between late June and early September making water levels during that period particularly important to this sector when comparing overall regulation plan performance.

Figure 5-43: Platform added to fixed dock to gain access to sailboat, Oak Orchard Creek in Orleans County. Photo credit: Diane Kuehn, 2017.

During the LOSLRS, the IJC concluded based on their analyses of various water supply sequences, that Plan 2014 could reduce average recreational boating benefits on Lake Ontario and the river upstream of Ogdensburg, NY and increase them on Lake St. Lawrence and the river downstream of the Moses-Saunders dam. However, further consultation with the interest during public meetings and hearings revealed considerable support from upper St. Lawrence River boaters because of the greater chance of higher water levels in the fall which would extend the boating season and because many had floating docks which are less sensitive to water level fluctuations.

Summary of Observed 2017 Impacts: ***NOTE - Much of the information currently available to the GLAM Committee to assess these impacts is descriptive and anecdotal and efforts are ongoing to further quantify impacts. To support the current assessment, the GLAM Committee gathered information from a variety of sources including a review of available oblique imagery acquired during the high water period (Figure 5-44) and responses to the Conservation Ontario self-reporting survey (Figure 5-45), as well as public reporting by marinas through their social media sites. An overall description of impacts is provided here with further details and regional descriptions provided as reference in the Annex 1-Impact Assessment.***

Recreational boating opportunities were reduced in many areas of the Lake Ontario, upper St. Lawrence, and lower St. Lawrence River shoreline during the extreme high water levels of 2017. In general, recreational boating impacts appeared to be most common in Monroe and Wayne Counties along with Prince Edward County and portions of the upper St. Lawrence River. Impacts were experienced in other areas as well but did not appear to be as concentrated. Many marinas experienced significant impacts to operations as non-floating docks were inundated (e.g. Figure 5-46) and other facilities (e.g. electrical hookups) were damaged. Given the extreme high water conditions, many locations with floating docks were also negatively impacted or required short-term modifications to maintain access. Many state, provincial, and municipal boat ramps were impacted leading to prolonged closures in some cases. It is possible that above average water levels later in August and into September and early October combined with nice weather allowed for some additional boating activity in that period compared to typical years, but further work is required to verify that possibility.

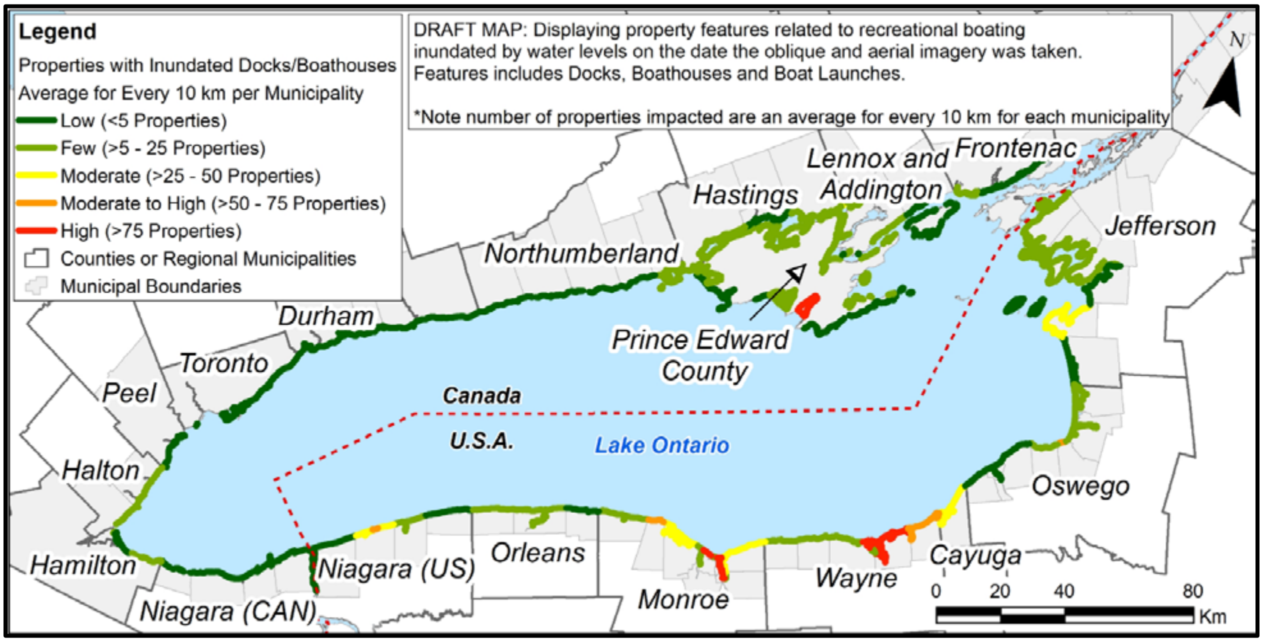


Figure 5-44: Representation of impacts identified through oblique imagery review (Source: ECCC/IJC estimates based on aerial imagery collected through the Transport Canada National Aerial Surveillance Program in May 2017)

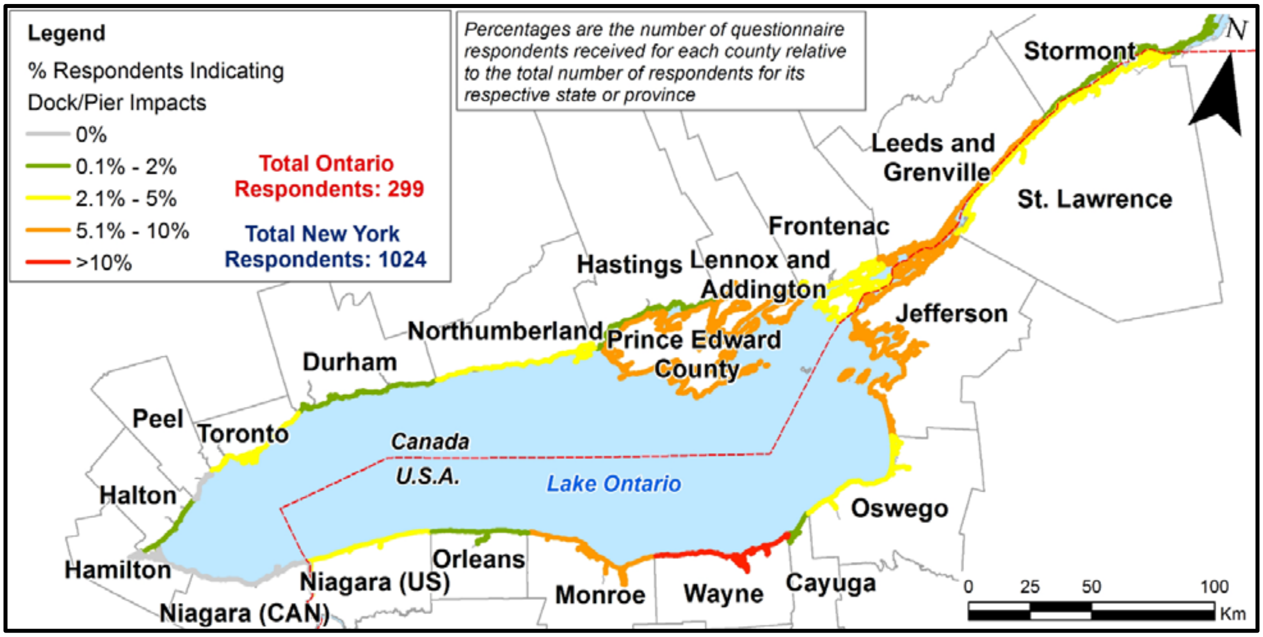


Figure 5-45: Percent of survey responses indicating dock/pier flooding (shown as a relative % by County relative to total number of that reported impact for Country) (Source: ECCC, based on data acquired through Conservation Ontario survey for IJC)

Figure 5-46: Kingston Yacht Club, June 14, 2017. Photo credit: ECCC.

In the Lake St. Lawrence area, water level impacts varied widely throughout the boating season. As with Lake Ontario and the upper St. Lawrence River in the Thousand Islands area, extreme high water conditions early in the year (May, June) led to inundation of docks and boating facilities and a reduction in boating opportunities. However, record high outflows starting in late May and continuing through July caused a drawdown of water levels in the Lake St. Lawrence area. As Lake Ontario levels continued to decline through the summer and outflows remained very high, low water level problems were observed on Lake St. Lawrence which required a short-term flow reduction over the October 6-October 8, 2017 weekend to allow boat haul-out, a situation not untypical in any given year and under the previous regulation plan.

On the lower St. Lawrence River, high water levels during May directly impacted boating facilities and, in turn, recreational boating opportunities (Figure 5-47). High outflows throughout late May, June and into July kept water levels near record levels in the Lake Saint-Louis area but the GLAM Committee does not currently have information on how recreational boating opportunities were impacted during that period. The same can be said for recreational boating downstream in the Montreal and Lake Saint-Pierre reaches. The GLAM Committee is working with the IJC to initiate a contract to gather further information in this area through a survey of marina operators and that information will support long-term GLAM Committee model validation efforts.

Figure 5-47: Beaconsfield Yacht Club showing inundation to a portion of the shoreline facilities on May 7, 2017. Photo credit: (left) Transport Canada - National Aerial Surveillance Program, (right) Jacob Bruxer, ECCC, May 5, 2017.

Tourism impacts were reported throughout the system and included loss of beach and facility access at state, provincial, and municipal parks, along with impacts to lodging and other private shoreline facilities. In the Thousand Islands area of the upper St. Lawrence River, over 82% of tourism operations responding to a survey conducted by the 1000 Islands International Tourism Council reported some degree of negative impact due to high water levels (1000 Islands International Tourism Council, 2017). As well, tour boat operators in the Thousand Islands area saw a reduction in passengers during the peak flood periods. There were many reports of loss-of-use impacts to public parks along the shoreline including the need to move festivals or shut down sites altogether. For example, Toronto Island was closed for 88 days from May 4 to July 30, 2017 with a loss of ferry revenues alone being estimated at $4.50 million (City of Toronto, 2018).

Model Assessment: All recreational boating willingness-to-pay curves developed during LOSLRS indicated a loss in recreational boating opportunity under high water conditions with the upper threshold at which boating impacts occur and the sensitivity to high water conditions differing for each geographic reach (see Annex 1-Impact Assessment for a further example). This appears consistent with anecdotal information from 2017 as there were many reports in the media and otherwise about negative operational impacts during the period and a reduction in boater activity, as well as boat ramp closures, particularly during the peak water level conditions throughout the system. Further investigation is needed by the GLAM Committee to understand how adaptive responses impacted recreational boating opportunities and allowed for continued functioning in some areas despite extreme conditions, for example making temporary or longer-term facility modifications to allow continued access. One area not included in the willingness-to-pay performance indicator is direct impact damages to shoreline facilities such as docks, storage buildings, etc. There is some crossover with the coastal performance indicators (e.g. flooding of residential buildings) but there were a number of examples where marina facilities appeared more sensitive to the high water conditions (i.e. they started flooding at lower water levels) due to their proximity to the shoreline and further investigation of these thresholds is required. It is also important for the GLAM Committee to establish a performance indicator that can be maintained and monitored into the future and there is some concern that willingness-to-pay may not lend itself well to such updates. This will need to be further explored to determine if a simpler proxy can be found.

There were no broader tourism related performance indicators used during the LOSLRS. Given anecdotal information from 2017, there may be opportunities for the GLAM Committee to develop or revisit relevant performance indicators in this area. For example, loss of beach use had local impacts at a number of state, provincial, and municipal locations. While the LOSLRS coastal technical working group tested a preliminary performance indicator related to beach impacts, it was not included in the overall evaluation based on advice of the economic advisors at the time and may need to be revisited. Also not captured by existing performance indicators was the significant impact to tourism caused by the closure of parks and particularly Toronto Island and other state and provincial parks which may have negatively affected the local economy. As has been mentioned earlier, while the performance indicators are not expected to capture all impacts, they are expected to be measurable representatives of the key impacts that are sensitive to water levels and significant to the interest category (i.e. they represent what people care about).

Key Findings and Next Steps: Recreational boating and tourism activities were negatively impacted throughout the Lake Ontario – St. Lawrence River in 2017. As with the coastal impacts, recreational boating impacts varied based on site specific conditions with some locations appearing to be more vulnerable than others. A priority is the initiation of a marina and yacht club owner survey to gather direct information on thresholds and impacts during 2017.

Due to the inability to assess the current performance indicator, it is necessary to reassess the current indicators for recreational boating. Assessing total possible boating days lost and net economic value lost or willingness-to-pay is not possible with the information available following the 2017 event. Additionally, GLAM intends to pursue the following activities:

- Investigate developing a performance indicator to track tourism, perhaps through reported numbers of visitors to beaches and shore adjacent parks;
- Better define regional high water thresholds throughout the system (some sites are very sensitive to high water conditions while others are less sensitive and GLAM does not yet have enough information from 2017 to assess any overall reductions in recreational boating activities);

- Look at how the timing and duration of flooding events impact overall recreational boating activity on Lake Ontario and the St. Lawrence River (e.g. how significant is a delay in the start of the season to overall recreational boating activity?) and how that compares to the LOSLRS performance indicator;
- Revisit how certain positive and negative impacts spanning multiple impact categories are captured by existing performance indicators. For example, potential overlaps or gaps between the coastal indicators and the recreational boating and tourism indicators related to flooding of non-residential buildings (e.g. marina buildings) or loss of use impacts (e.g. closure of park facilities); and
- Assess how fishing activity may be influenced by water levels as part of a performance indicator review.

6.0 Plan Review and Evaluation

What can be learned from the application of the regulation plans for the outflows from lakes Superior and Ontario in 2017 that could inform plan improvements? This section addresses that question for both lakes, with heavy emphasis on the Lake Ontario-St. Lawrence River plan because of the record high water levels and flows in that basin. The analysis is based on water levels, not economic or environmental impacts because the GLAM Committee is still in the process of gathering and documenting those impacts. In the future, the GLAM Committee will present an analysis using economic and environmental performance indicators informed by impacts in 2017, but for now, this section highlights areas where the impact analysis is expected to add essential insights into the on-going plan review.

6.1 Introduction

The IJC requires the GLAM Committee to support the ILSBC and the ILOSLRB in the on-going assessment of the regulation plans to "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 has developed the evaluation process used in this chapter to provide an immediate retrospective and to generate one year of information for 2017 that can be added to future assessments to support a long-term plan assessment.

The GLAM Committee is working to establish an annual plan evaluation that contributes to the long-term evaluation strategy by:

1. Analyzing how water levels and flows in the Great Lakes-St. Lawrence River system are influenced by particular hydrologic conditions in any given year (e.g. 2017);
2. Using net changes from a baseline regulation setting to clarify the impact of a regulation decision. In this report, GLAM uses the former regulation plan, pre-project conditions

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[1] IJC 2015 Directive to the GLAM Committee

(the unregulated hydraulic conditions) and, in the case of Plan 2014, even compares simulated variations from Plan 2014 to the actual Plan 2014 results;

3. Assessing not only water levels but the impacts, such as flood damage, shipping efficiency or power production. GLAM is in the process of acquiring impact data from 2017, so will not be able to include impact assessments in this report. This analysis will continue into the future; and
4. Supporting a multi-year analysis using a wide range of hydrologic and other conditions. There are several reasons for using multi-year evaluations:
    a. One year influences the next. Water levels do not return to the same level at the end of every year, so the ending level from the previous year can be an important input influencing the outcomes from the next year;
    b. Regulation rules that work well in some years and supply conditions may not work as well as they could in others. For example, because no one can predict the supply of water into the Great Lakes, regulation plans must hedge for the possibility of dry or wet futures. Rules that are best at avoiding drought levels might exacerbate flooding in wet years, and vice versa; and
    c. Many of the expected positive outcomes of the regulation plans, especially environmental ones, are only expected to be realized after several years, or possibly even decades, as they too depend on water supply conditions.

Based on the above, simulations of flows out of Lake Superior and out of Lake Ontario were conducted under a variety of scenarios to assess the influence of a number of factors related to the extreme water levels event of 2017. Again, this represents a very preliminary analysis of water levels and flows only. It does not include an assessment of negative or positive environmental or economic impacts which will be part of the longer-term, on-going review of the regulation plans.

6.2 Lake Superior: review of Plan 2012 performance based on conditions in 2017

In 2017, some of the water that normally would have been released from Lake Superior through the hydropower plants could not be because some of the turbines were shut down for maintenance at different times. Consequently, under strict application of Plan 2012 rules, the St. Mary’s Rapids would have borne much more of the impact from month to month flow changes and this may have damaged the fishery and caused flooding impacts on Whitefish Island. The ILSBC, with the approval of the IJC, attempted to reduce the risk of these impacts by deviating from Plan 2012. The deviation strategy was based on a projection of how much hydropower flow capacity would be lost between April and November (and updated monthly) due to scheduled hydropower maintenance, and then rather than releasing all surplus flow through the St. Marys Rapids each month, deviations were employed to allow the deficit to be spread more evenly and gradually across the period affected by the maintenance of the plants. The deviations were relatively small in terms of the total release of water through the St. Marys River, and in fact the ILSBC strategy was designed to ensure that approximately the same amount of water was released in total in order to minimize any effects on Lake Superior and Lake Michigan-Huron levels.

Nonetheless, should different releases have produced better outcomes? GLAM compared flows and levels simulated under several alternative regulation strategies to the actual flows and levels that occurred in 2017. Including the actual flows and water levels, seven release scenarios were compared:

> **Scenario 1: Recorded levels and flows ("Actual"):** This represents the actual water levels and flows that were recorded during 2017 and were the result of the actual weather and water supply conditions that occurred within the upper Great Lakes as well as the executed regulation strategy employed by the ILSBC.
>
> **Scenario 2: Simulated ("actual") levels and flows ("Simulated Actual")**: This scenario represents a model simulation of the water levels and flows that occurred in 2017. The bi-nationally coordinated water supply conditions recorded in 2017 were used as model inputs and the actual deviation strategy employed by the ILSBC was simulated using the Coordinated Great Lakes Regulation and Routing Model (CGLRRM). Calibration parameters within the model were adjusted with the objective of simulating as closely as possible the actual flow and water level conditions that occurred in 2017. As a result, differences between this scenario and Scenario 1 represent the residual model error, which would include both inaccuracies in recorded water supplies and in model calibration parameters. The same coordinated water supply conditions and calibrated model parameters from this scenario were then used to simulate all other alternative scenarios (described below) in order to provide a fair and consistent comparison of the effects of different regulation strategies alone.
>
> **Scenario 3: Plan 2012 with Operationally Expected Side Channel Capacity ("P2012_OpExpectedSC"):** This simulation was run to most closely reflect the conditions that would have occurred had the ILSBC not deviated from Plan 2012 during 2017. It uses the recorded 2017 water supplies and assumed Plan 2012 was followed without any deviations. This scenario used expected side channel capacities (i.e. hydro-power capacities that were expected at the time regulation calculations were performed each month) to set the Compensating Works gate setting at the start of each month (consistent with how gates are actually set operationally) and then the actual side-channel capacity (which can at times vary from that expected at the start of the month) was used to simulate the total St. Marys River outflow, the St. Marys Rapids flow, and the resulting water levels. This simulation captures the impacts that scheduled hydro-power outages would have had on Plan 2012 performance.
>
> **Scenario 4: Plan 2012 with Actual Side Channel Capacity ("P2012_ActualSC")**: This simulation is similar to Scenario 3 above, the only difference being that the expected side-channel capacity was not used to set the Compensating Works gates at the start of each month. Instead, the actual side-channel capacity was used both to set the gates and to

simulate flows and water levels. This scenario provides a slightly less accurate reflection of operations that would have occurred under Plan 2012, since under actual operations the ILSBC must estimate expected side-channel capacity when setting gates each month and does not know with exact certainty what the actual side channel capacity will be. However, this scenario was necessary to allow for a consistent comparison to simulations using the old regulation Plan 1977A (described below), as the currently available model for the old plan does not have the same flexibility as the Plan 2012 model used to simulate the more complex operational expected side channel scenario.

Scenario 5: Plan 2012 with Max Side Channel Capacity ("P2012_MaxSC"): This simulation is also similar to Scenario 3 in that it uses the recorded 2017 water supplies and assumes Plan 2012 was followed without any deviations, but in this case no limitations to the maximum side channel flow were applied. As a result, this simulation best represents how Plan 2012 would have performed if there was no hydropower maintenance in 2017 and the actual side channel capacity was at the full maximum values estimated during the IUGLS.

Scenario 6: Plan 1977A with Actual Side Channel Capacity ("P77A_ActualSC"): Similar to the previously described Plan 2012 simulations, the recorded 2017 water supplies were used, but in this case the regulation rules from Plan1977A were used without any deviations to simulate how the previous regulation plan would have performed during the same conditions experienced in 2017. Similar to Scenario 4 for Plan 2012, this simulation used the actual side channel capacity both to set the Compensating Works gate setting and to simulate water levels and flows. When compared to Scenario 4, this analysis provides a check to determine if the performance of Plan 2012 that was expected during the IUGLS is being realized under actual conditions, including any benefits expected from Plan 2012 in comparison to Plan 1977A.

Scenario 7: Plan 1977A with Max Side Channel Capacity ("P77A_MaxSC"): This simulation is similar to Scenario 5 for Plan 2012 in that it uses the recorded 2017 water supplies, but in this case it assumes Plan 1977A was followed without any deviations (as in Scenario 6) but with no limitations to the maximum side channel flow applied. This simulation was added to better compare with the Plan 2012 maximum side channel simulation as this most closely represents how performance of the different regulation plans were compared and assessed during the IUGLS. Note that during the IUGLS the differences between Plan 1977A and Plan 2012 were found to be relatively small, and it is to be expected that there will be many years where these scenarios show very similar results.

Figure 6-1, Figure 6-2 and Figure 6-3 show the water levels on Lake Superior, Lake Michigan-Huron, and the flows through the St. Marys River and St. Mary Rapids resulting from each of the different release scenarios listed above.

An important consideration when evaluating the difference between these plans is the flow through the St. Marys Rapids and the gate setting at the compensating works associated with that flow. The St. Marys Rapids is an important spawning location and overall fishery and is directly impacted by the amount of flow released from the compensating works gates. Another important consideration when evaluating plan performance is the impact the decisions have on Whitefish Island. Whitefish Island is Batchewana First Nations land, and is primarily recreational with hiking trails, small pavilions and visitor information booths. The island is located immediately downstream of the Compensating Works gates adjacent to the rapids, and substantial portions of the island flood as more gates are opened. While flooding of the island is unavoidable and expected under higher gate openings, the ILSBC attempts to minimize impacts to the island when possible. Figure 6-3 shows what the St. Marys Rapids flow would have been for each scenario to better evaluate the impacts of regulation decisions on the rapids themselves and Whitefish Island.

Actual vs Simulated "Actual" Conditions (Scenarios 1 and 2)

As noted above, differences between actual recorded water levels and flows and those simulated using the recorded water supplies and the ILSBC's regulation strategy in 2017 represents the residual model error. As shown in Figure 6-1, the actual recorded conditions that occurred in 2017 are closely replicated by the simulated conditions, with small differences observed in lake levels (max of 1 cm (0.4 in.)) and flows (less than 100 m^3/s (3,500 cfs)). To ensure that the differences observed in the other scenarios were attributed only to the differences in regulation strategies and not caused by these residual model errors, the same coordinated water supply conditions and calibrated model parameters from this scenario were then used to simulate all other alternative scenarios (described below).

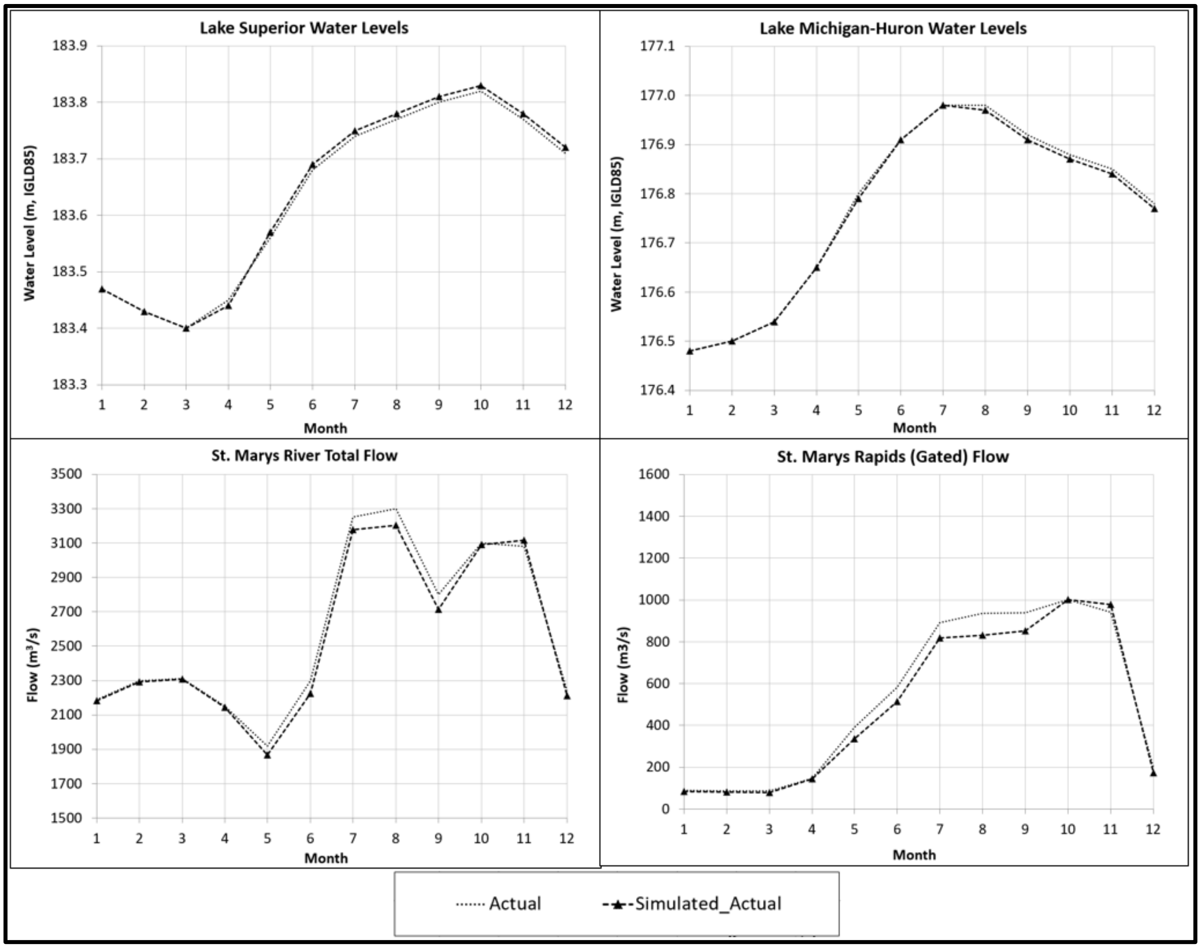


Figure 6-1: Actual water level and flow conditions (Scenario 1) compared to model simulated "actual" conditions (Scenario 2). Both scenarios include effects of ILSBC deviation strategy.

Simulated "Actual" vs. Plan 2012 Conditions (Scenarios 2 – 5)

These scenarios, shown in Figure 6-2, illustrate the impacts of the deviation strategy that the ILSBC executed in 2017 in comparison to what would have occurred following Plan 2012. As shown, the water levels on lakes Superior and Michigan-Huron show very little differences between any of the different scenarios. This is not surprising as the deviation strategy executed by the ILSBC was intended to release roughly the same total flow during the year, just spread differently across the spring, summer, and fall months. The largest water level differences among any of the scenarios for Lake Superior occurred in June where the difference was a maximum of 4 cm (1.6 in.) when comparing the simulated actual level and Plan 2012 assuming maximum side-channel capacity was available. The differences during all other months and scenarios were less than this. Comparing the simulated actual level with the Plan 2012 simulation that used the operationally expected side-channel flow (i.e., Scenario 3, which is the closest representation of what would have occurred in 2017 had Plan 2012 been followed while the hydropower outage occurred) shows that Lake Superior levels were at most 3 cm (0.8 in.) higher in June, but only 2 cm (0.8 in.) higher in the summer of 2017 as a result of the ILSBC regulation strategy. On Lake Michigan-Huron, the simulated water levels from the various scenarios are even more similar, with a maximum difference of 2 cm (0.8 in.) between any scenarios, and levels were at most only 1 cm (0.4 in.) lower due to the ILSBC deviation strategy. These water level differences are extremely small and would not be expected to result in any measureable positive or negative stakeholder impacts.

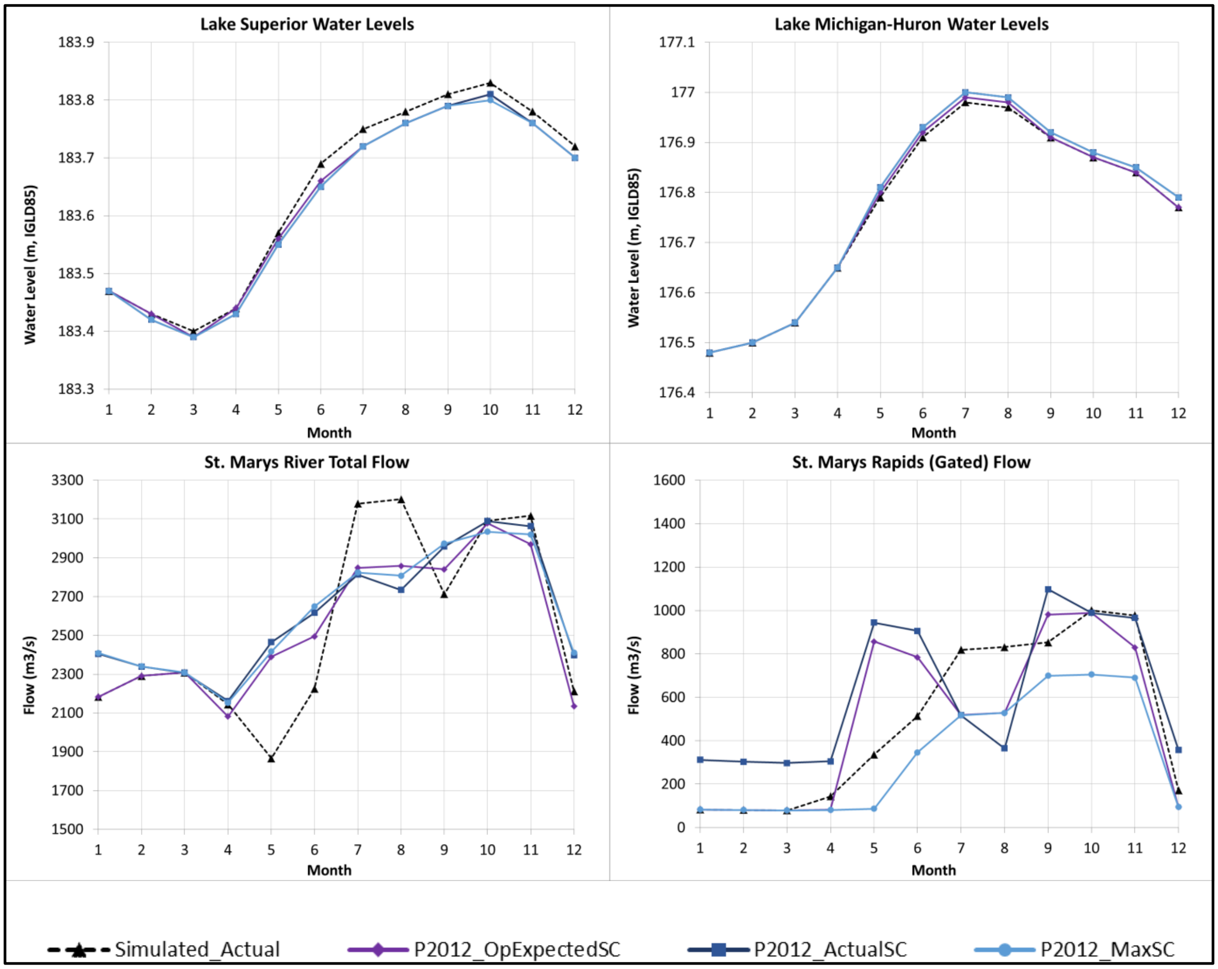


Figure 6-2: Simulated "actual" conditions (including effects of ILSBC deviation strategy) compared to simulated Plan 2012 conditions with and without side-channel capacity limitations.

When comparing the total flow of the St. Marys River, actual flows were lower than those specified by Plan 2012 in May, June and September, higher than those specified by Plan 2012 in July and August, and approximately the same in other months. These fluctuations in total flow allowed for much smoother flow changes in the St. Marys Rapids, where hydraulic conditions are much more sensitive to fluctuating flows. The highest total St. Marys River flows that occurred in July and August under the 2017 deviation strategy were more than would have been prescribed by Plan 2012. As was noted during the IUGLS, higher flows in the river can result in flooding of Soo Harbor just downstream of the Soo Locks and can result in navigation concerns. However, this total flow increase was relatively small and did not cause water levels to rise enough to cause flooding in Soo Harbor. Also, the increase did not generate any known problems for the commercial navigation industry.

St. Marys Rapids flows show large variations between the two regulation strategies, with the simulated actual flows showing much less variation than the flows that would have occurred under Plan 2012 with actual side-channel flow limitations in 2017. This was expected as this was the primary reason for deviating from Plan 2012 flow in 2017. Due to the scheduled and unscheduled hydropower outages, large month-to-month variations would have been necessary in the St. Marys Rapids flow in order to pass the total St. Marys River flow that Plan 2012 prescribed. Interestingly, the simulated actual flows show a similar pattern to the Plan 2012 flows with maximum side-channel capacity available, suggesting that, given the hydropower maintenance that occurred, the ILSBC's deviation strategy resulted in actual flows that more closely resembled the expected performance of Plan 2012 from the IUGLS in the St. Marys Rapids. Also notable is that the smaller peak flow resulted in less flooding on Whitefish Island than would have occurred had Plan 2012 been strictly followed, while the smoother transitions are expected to benefit the environmental health of the rapids.

Based on these observations, it appears the deviation strategy did achieve the intended objective of reducing high and fluctuating flows through the St. Marys Rapids while producing no measureable negative impacts. GLAM is currently developing tools and indicators that can be used to perform this analysis using a more quantitative approach in future reports.

Simulated "Actual" vs. Plan 2012 vs Plan 1977A Conditions (Scenarios 2 – 7)

A comparison of simulated actual and Plan 2012 conditions was also made to the former regulation Plan 1977A, which was the benchmark plan that the performance of all other regulation plans were compared against during the IUGLS. When comparing these simulations, observations can be made to determine if the anticipated benefits of switching to the new plan would have been realized under the conditions the plan was originally evaluated against.

Similar to the previous analysis, water level differences on Lake Superior and Lake Michigan-Huron between the two plans are minimal, but interesting observations can be made in the total St. Marys River and St. Marys Rapids flow differences. An anticipated benefit of switching from Plan 1977A to Plan 2012 was that Plan 2012 would produce more gradual flow changes from month to month and provide slightly lower peak flows. As shown in Figure 6-3, in the bottom left total river flow graph, Plan 2012 would have indeed provided a more gradual increase in flows during the spring and summer season than Plan 1977A, which would have seen flows fluctuate more widely during this time, including much higher flows in May and June 2017. However, Plan 2012 would have resulted in a more abrupt reduction in flows in the fall ahead of the winter minimum gate setting.

Perhaps most notable are the differences in St. Marys Rapids flows between the two regulation plans, shown in the bottom right of Figure 6-3. In particular, the higher flows prescribed by Plan 1977A during May 2017 combined with the hydropower maintenance activities would have resulted in much higher St. Marys Rapids flows during this month; in fact, all 16 gates would have been opened had the old regulation Plan 1977A been strictly followed. Plan 2012 also would have seen large fluctuations due to hydropower maintenance, though less so than those that would have occurred under Plan 1977A. In contrast and as noted previously, the ILSBC's deviation strategy provided much more gradual flow changes and smoother flow fluctuations overall.

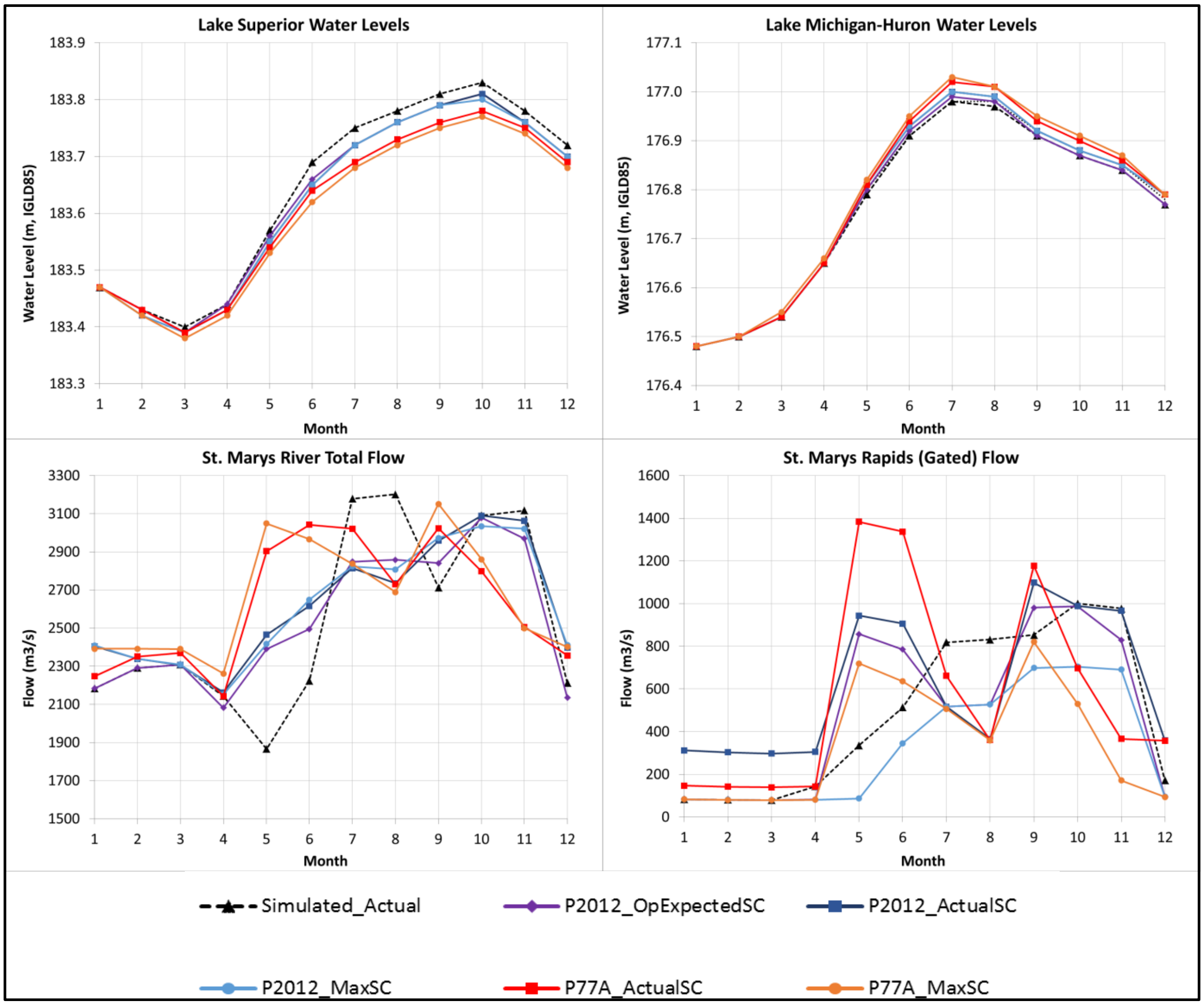


Figure 6-3: Simulated "actual" conditions (including effects of ILSBC deviation strategy) compared to simulated Plan 2012 and Plan 1977A conditions, both with and without side-channel capacity limitations.

6.3 Lake Ontario: review of Plan 2014 performance based on conditions in 2017

This section provides some preliminary analysis of Plan 2014 performance based on water level and flow simulations. It does not include an assessment of negative or positive environmental or economic impacts which will be part of the longer-term, ongoing review of the regulation plans. The year 2017 provided a unique opportunity to look at various aspects of plan performance under extreme conditions, but it must be noted that plan performance must ultimately be assessed under a range of conditions to determine whether overall objectives are being met. This section is meant to provide an immediate retrospective review of how Plan 2014 performed during the extreme conditions of 2017, allowing the GLAM Committee 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. This section presents an abbreviated version of what is included in Annex 2 – Plan Review. For a more detailed discussion of this analysis, please refer to that Annex.

Section 6.3 covers three areas of investigation. The first is an assessment of how the hydrological conditions in 2017 impacted the regulation of outflow and how Plan 2014 would have performed if conditions had been different, including had there been more or less challenging ice conditions, fewer spring storm events, or a different starting water level in January 2017. The second analysis focusses on the effects of modified outflow regulation strategies on water levels and flows in 2017, including the effects of modified Plan 2014 rules and maximum flow limitations, alternative criterion H14 thresholds for determining when the ILOSLRB could deviate, alternative ILOSLRB deviation strategies and comparisons between observed Plan 2014 conditions and simulations of the old regulation plan 1958-DD and pre-project outlet conditions. The final analysis focusses on a specific question from the GLAM Committee directive to assess whether future water supplies might be different than those used to evaluate regulation plans. This analysis 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.

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 which will also include the assessment of environmental and economic performance indicators to support a long-term plan assessment.

6.3.1 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 in 2017. The modifications represent minor changes or “perturbations” of the uncontrolled natural factors, external to regulation, 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. These simulations can be considered sensitivity analyses of the factors considered.

The simulations include analyses of the effects of:

a) St. Lawrence River ice conditions. This is covered in section0, immediately below;

b) spring water supplies (in this case April and May), including the multiple heavy precipitation events in April and May that occurred across the basin and resulted in record NTS to Lake Ontario and record Ottawa River flows into the St. Lawrence River. This is covered in section 6.3.1.2; and
c) a higher Lake Ontario level at the start of 2017 (Section 6.3.1.3).

The rules of Plan 2014 are followed throughout Section 6.3.1 only; the hydrologic inputs are varied. A longer discussion of these simulations is described in detail in Annex 2-Plan Review. The following provides the key elements and findings.

SIMULATING WEEKLY REGULATION DECISIONS

The analysis of hydrologic inflows and plan rules assessed within this section use a “Weekly Operational Simulation” method which closely aligns with the actual process of regulating outflows. 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, including actual water supplies and ice conditions, as well as operational considerations (such as hydropower outages, ship requests, boat haul-outs, Seaway ship transits, downstream flooding concerns, etc.) to determine if operational adjustments or deviations from the plan might have been necessary. The effects of these 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 if necessary (e.g.,

6.3.1.1 The impact of ice conditions on levels and flows

St. Lawrence River ice conditions during the period of January to March 2017 were very unusual because of highly variable winter temperatures. The ice conditions over this three month period are described in detail in the ILOSLRB report "Observed Conditions and Regulated Outflows in 2017" (ILOSLRB, 2018). Punctuated by a record five freeze-thaw cycles of the river ice cover, highly variable temperatures, and a relatively warm period followed by colder unprecedented ice forming conditions in March, ice conditions were very unusual in 2017 and a challenge from an operational perspective for managing outflows over this three month period.

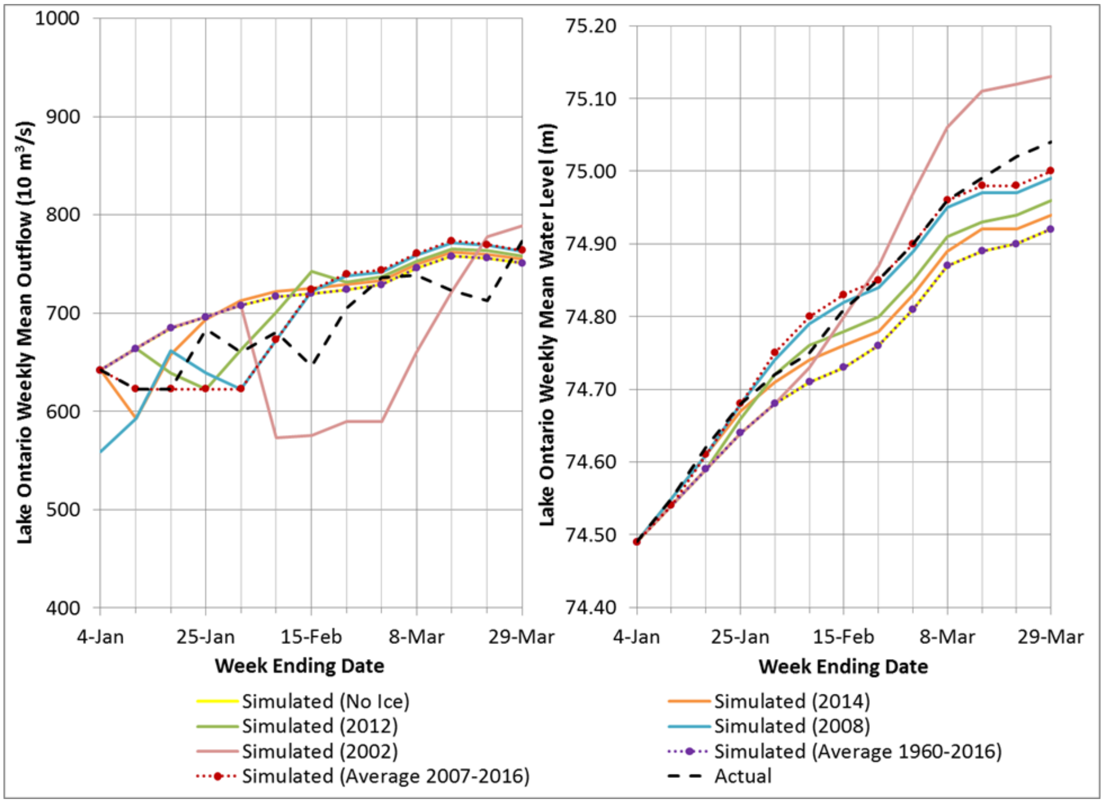


Figure 6-4: January-March 2017 outflows and water levels under various ice formation sequences

Simulations of various ice scenarios were completed and compared to actual water levels and flows from January to March 2017. The completed analysis (Figure 6-4**Error! Reference source not found.**) shows that, in comparison to other hydrologic factors, the unusual ice formation sequence played a relatively small part in raising water levels in 2017, having only contributed about 4 cm (1.6 in) more to water levels rising than what would have occurred under average ice conditions seen over the past decade. Had ice conditions been minimal and posed no restrictions on outflows, water levels would have been at most 12 cm (4.7 in) lower by March 31, 2017. 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.

Moreover, the 12 cm (4.7 in) maximum difference in water levels from actual conditions would have occurred in the highly unlikely scenario that ice conditions imposed no restrictions on outflows. This is not to say that ice conditions are not important. For example, in the 2002 scenario, which was the most challenging scenario reviewed in terms of ice conditions and the effects on regulated outflows, the ice conditions could have contributed as much as a 9 cm (8.3 in) difference in water levels compared to 2017, and as much as 21 cm (8.3 in) in comparison to the scenario where ice posed no limitations on outflows. Yet in 2017, the effects on water levels from variable ice conditions were far less of a contributor than other hydrologic factors during the winter months January through March. Further details of this analysis can be found in Annex 2-Plan Review (2.2.1).

6.3.1.2 The relative impact of water supplies in different time periods

April and May were extremely wet across the Lake Ontario and Ottawa River basins as was demonstrated in the ILOSLRB's report ("Observed Conditions and Regulated Outflows in 2017") and in Section 4 of this report. Figure 6-5 shows five notable storms that occurred during this period and the impacts they had on cumulative precipitation totals at five weather stations around the Lake Ontario – St. Lawrence River basin. The heavy precipitation resulted in significant increases in the net inflows to Lake Ontario and the St. Lawrence River, including the inflows from Lake Erie and the Ottawa River. To better understand the effects of these different factors, individually and collectively, the GLAM Committee simulated water levels and flows under seven alternative inflow scenarios (depicted in Figure 6-6) and compared the results to what actually occurred in 2017 (Figure 6-7).

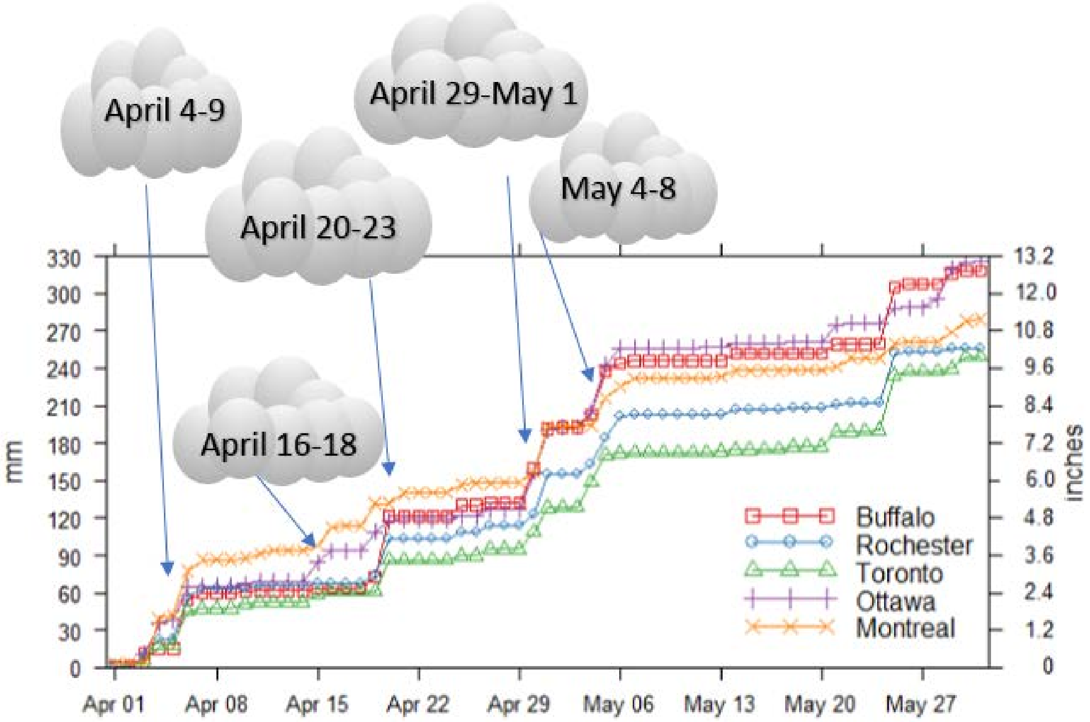
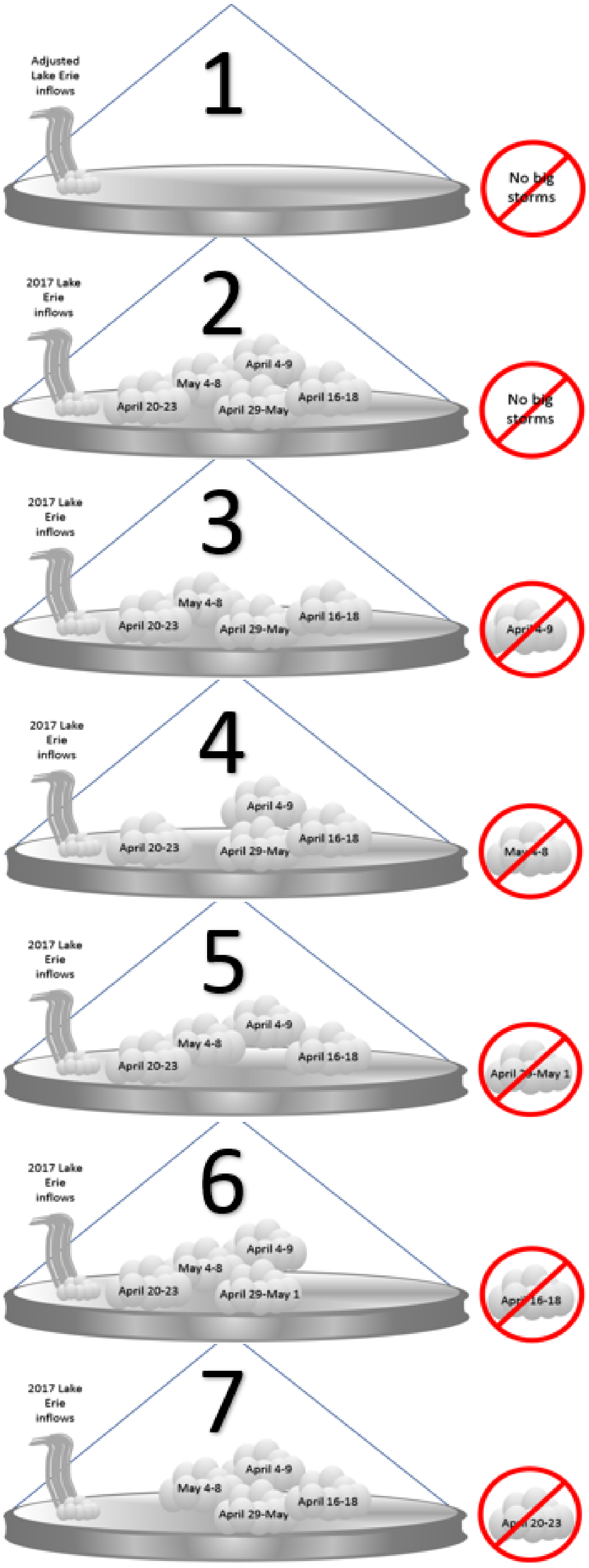


Figure 6-5: Cumulative April-May precipitation at five stations with five storms used in alternative hydrology simulations



1. Lake Ontario peak reduced by 42 cm (17 inches); Lake St. Louis peak reduced by 21 cm (8.3 inches).

2. Lake Ontario peak reduced by 39 cm (15 inches); Lake St. Louis peak reduced by 19 cm (7.5 inches)

3. Lake Ontario peak reduced by 25 cm (9.8 inches); Lake St. Louis peak unchanged.

4. Lake Ontario peak reduced by 16 cm (6.3 inches); Lake St. Louis peak unchanged.

5. Lake Ontario peak reduced by 14 cm (5.5 inches); Lake St. Louis peak unchanged.

6. Lake Ontario peak reduced by 5 cm (2 inches); Lake St. Louis peak unchanged.

7. Lake Ontario peak reduced by 3 cm (1.2 inches); Lake St. Louis peak unchanged.

Figure 6-6: Depiction of seven alternative inflow scenarios used for simulations

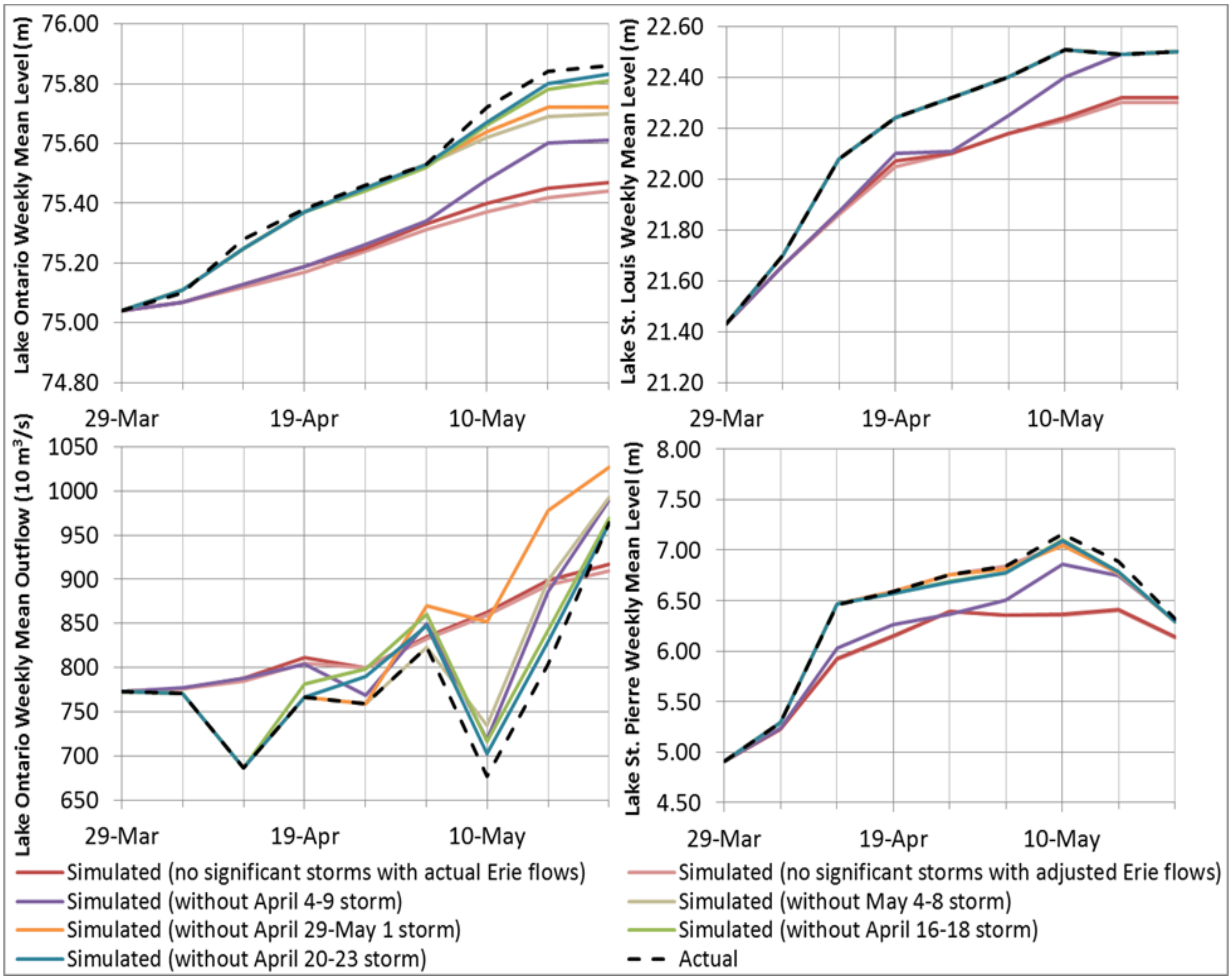


Figure 6-7 - Lake Ontario outflows, Lake Ontario water levels, Lake Saint-Louis water levels and Lake Saint-Pierre water levels under various alternative spring water supply scenarios.

The simulations allowed the GLAM Committee to 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. This analysis may help the GLAM Committee develop better NBS datasets to use for testing or even refining Plan 2014 in the future.

Alternative inflow sequences to Lake Ontario and the St. Lawrence River (including NBS, Lake Erie inflows and Ottawa River flows) were created by reducing those portions of the actual 2017 sequences to remove the increases that occurred as a result of the most significant storm events in April and early May. Further details are provided in the Annex 2-Plan Review. Based on this analysis, and as demonstrated in Figures 6-6 and 6-7, removal of the April 4-9 storm (Scenario 3) had the greatest impact on peak Lake Ontario and Lake Saint-Louis levels in the simulation. When only the April 4-9 storm was eliminated from the simulation and NBS 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. Lake Saint-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 ft) by mid-May. At levels above 75.60 m (248 ft), outflows would have been adjusted to maintain levels at 22.48 m (73.8 ft) on Lake Saint-Louis, the highest tier of the F-limit.

Removal of each of the May 4-8 (Storm Scenario 4) and April 29-May 1 (Storm Scenario 5) storms also significantly reduced peak Lake Ontario water levels in the simulations. The removal of the May 4-8 storm resulted in Lake Ontario water levels that were 16 cm (6.3 in) lower than actual peak levels, while the removal of the April 29-May 1 storm resulted in peak Lake Ontario water levels 14 cm (5.5 in) below actual peak levels. When either of the April 29-May 1 or May 4-8 storm events are removed, Lake Saint-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 had little impact on peak Lake Ontario or Lake Saint-Louis water levels. This analysis shows the additive effect of a series of moderately rare precipitation anomalies in one year tracking over the same basin one after another. Further details of this analysis can be found in Annex 2-Plan Review (2.2.2).

6.3.1.3 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-D; how would the water levels that occurred later in 2017 have been affected had Plan 2014 been in effect previously? Plan 2014 was implemented operationally on January 7, 2017, but prior to its implementation, water levels and flows under Plan 2014 had been simulated continuously from 2001 to the end of 2016. At the end of the simulation, Lake Ontario levels were 10 cm (4 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 with Lake Ontario levels starting 10 cm (3.9 in) higher to determine how much effect that would have had on peak 2017 water levels. The results are shown in Figure 6-8.

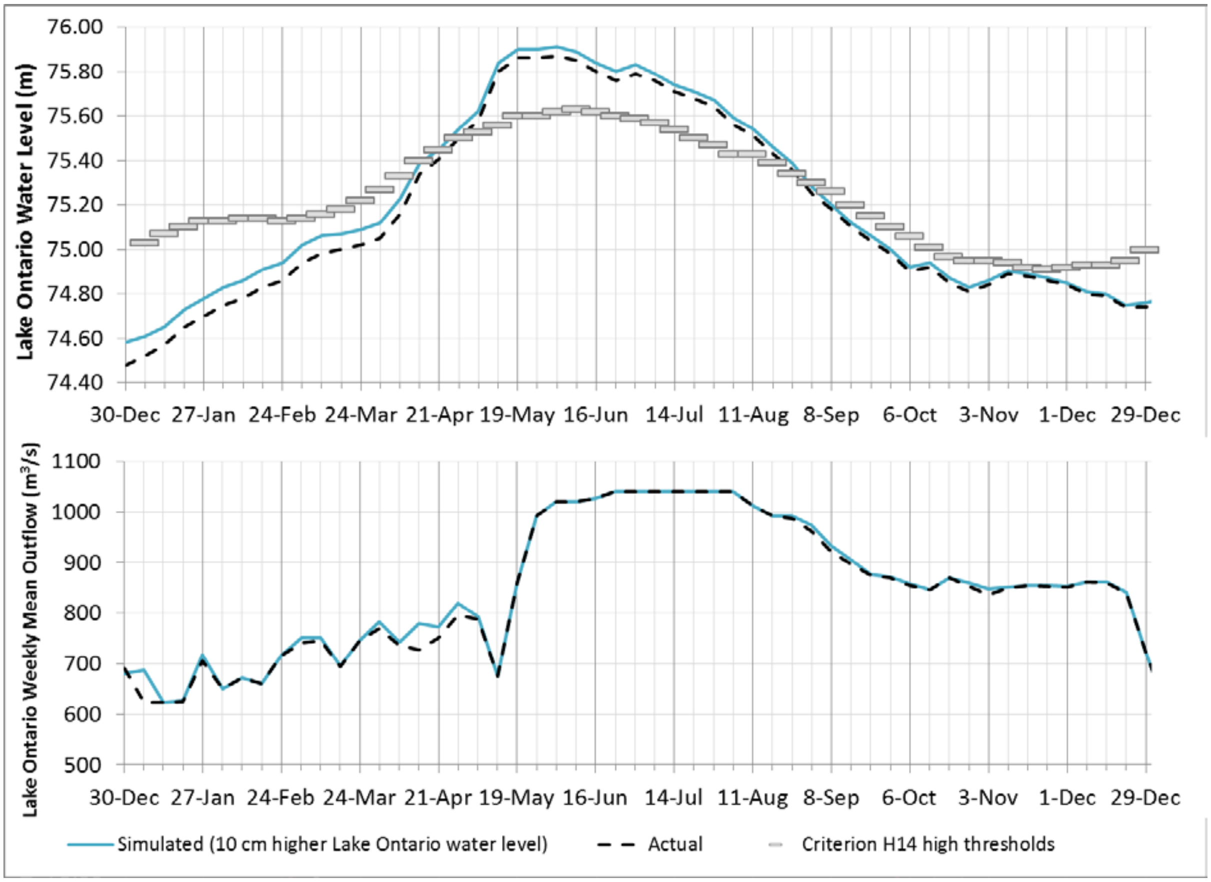


Figure 6-8: Lake Ontario levels and releases in 2017 simulated based on actual and 10 cm higher January 1st Lake Ontario elevation

The simulation shows that the initial 10 cm (4 in) difference at the beginning of the year is 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 (less than an inch) 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. Had Lake Ontario started at higher levels, higher rule curve flows would have been prescribed and could have been released during a handful of days in the winter that outflows were not limited by ice conditions, and this would have had a small effect on lowering water levels. Second, because the simulated Lake Ontario level was higher when Lake Saint-Louis started to rise and the F-limit was first imposed, the initial Lake Saint-Louis level that was maintained and the corresponding F-limit outflows that were released were also higher (see Annex 2-Plan Review for F-limit thresholds). The peak level would have been 4 cm (1.6 in) higher at this time. These higher levels continued later into the simulation and this would have also caused slightly higher releases in accordance with the L-limit beginning in the fall, again causing levels to converge towards the end of the year.

Higher starting levels on Lake Ontario would not have increased the peak level of 22.48 m (73.75 ft) maintained at Lake Saint-Louis since this is the highest tier of the F-limit.

6.3.2 Effects of modified outflow regulation strategies in 2017

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 these alternative outflow strategies. These scenarios were used to test the implications of modified rules and maximum flow limitations within the plan; alternative criterion H14 thresholds for when the ILOSLRB could deviate; alternative ILOSLRB deviation strategies; and comparisons between observed Plan 2014 conditions and simulations of the old regulation plan 1958-DD and pre-project outlet conditions. Further details of these analyses are presented in Annex 2-Plan Review (2.3).

6.3.2.1 Modifying the rules balancing flooding above and below the dam

The F-limit rules of Plan 2014 prescribe maximum outflow limits to balance high water impacts on Lake Ontario and the upper river with those on Lake Saint-Louis and downstream. A number of scenarios based on modifications to the Plan 2014 F-limit rules were tested for their impacts on water levels. The two most significant changes to the F-limit that were evaluated result in the greatest impacts on water levels upstream and downstream: one of these maintained Lake Saint-Louis at a maximum of only the 22.33 m (73.26 ft), which would have provided the most significant protection to Lake Saint-Louis and more than the F-limit currently provides; while the other, which involved a modified F-limit with Lake Saint-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 the first of these scenarios, lower outflows from Lake Ontario would have been required beginning on May 5 to maintain Lake Saint-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. Under the second 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 Saint-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 Saint-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.

In summary, 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. While changes to the F-limit could have lowered Lake Ontario levels without raising peak Lake Saint-Louis levels, they would have prolonged downstream flooding for weeks as is demonstrated by Figure 6-9 below showing water levels at Lake Saint-Louis and downstream at Sorel just above Lake Saint-Pierre. Furthermore, it is important to note that 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 Saint-Louis and further downstream in the St. Lawrence 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.

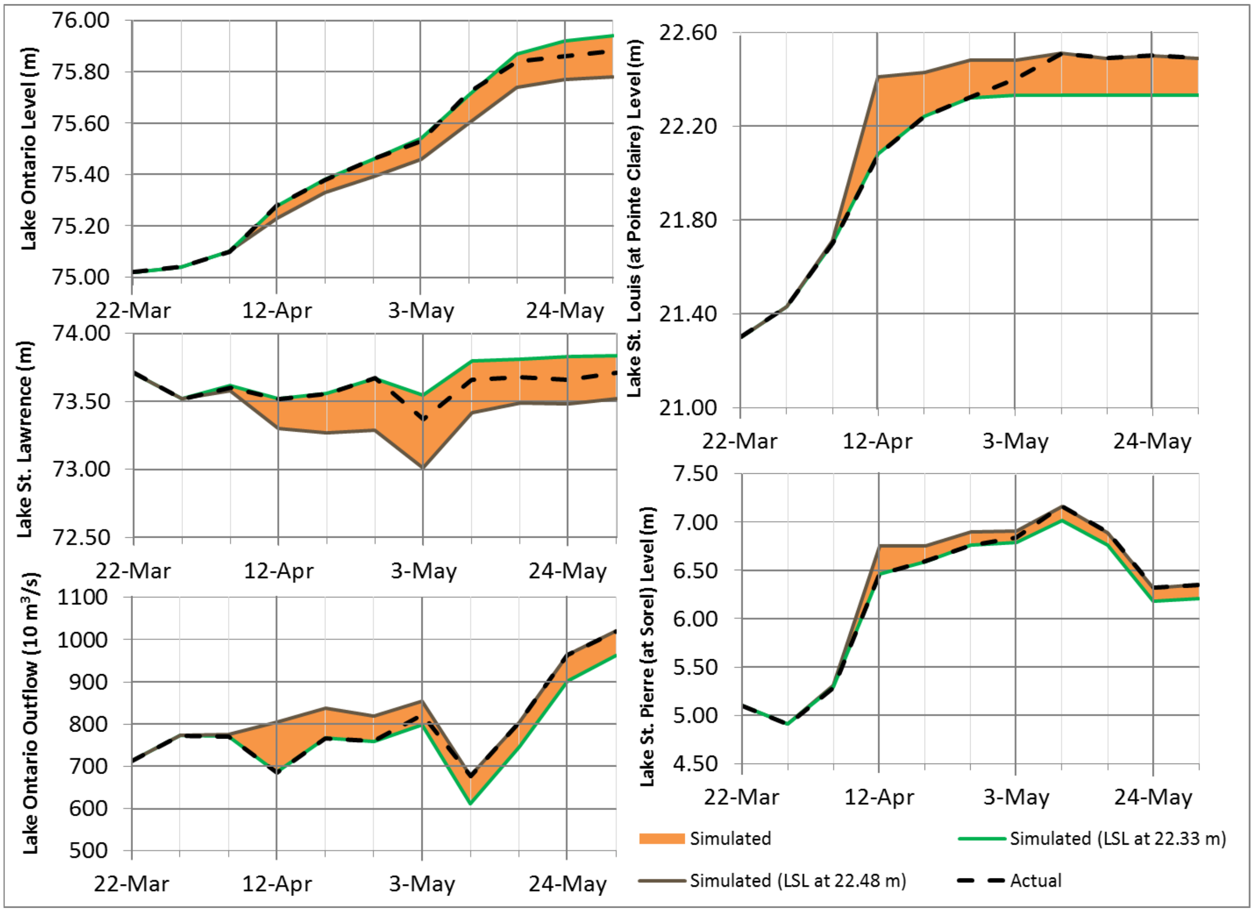


Figure 6-9: Simulated Lake Ontario outflows, Lake Ontario water levels, Lake St. Lawrence water levels, Lake Saint-Louis water levels and Lake Saint-Pierre water levels based on modified F-limit rules compared to actual outflows and water levels in 2017.

6.3.2.2 Modified criterion H14 high trigger levels

Under the H14 criterion of the December 8, 2016 Order of Approval, the ILOSLRB is given the authority to deviate from the rules set in Plan 2014 when Lake Ontario levels reach or exceed high and low water level trigger levels specified in a directive to the ILOSLRB. The high-water triggers for each quarter-month are set at levels that are expected to be exceeded only 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.

To determine the effects of lowering the high triggers on Lake Ontario and St. Lawrence River levels, the GLAM Committee simulated Plan 2014 with five and ten percent exceedance level triggers (levels that are expected to be exceeded five and ten percent of the time, respectively). Results indicated that these changes made no difference in outflows or water levels in 2017 because in either scenario, when water levels crossed the trigger levels the ILOSLRB would have been operating under the Plan 2014 F-limit. This is assuming that the ILOSLRB would have made similar decisions in either of these scenarios as it did in 2017, given the ILOSLRB chose to follow the F-limit to continue balancing high water impacts upstream and downstream, even after levels crossed the actual H14 thresholds.

To determine how low the trigger levels would have to be in order for there to be a meaningful effect on Lake Ontario levels, the GLAM Committee simulated 2017 conditions using trigger levels lowered by as much as one foot as a sensitivity test (refer to Annex 2 – Plan Review (2.3.2) for more details). As Figure 6-10 shows, even one-foot lower triggers had a relatively small effect, lowering peak Lake Ontario levels by 6 cm (about 2 in) at the most.

There are several reasons why lowering the triggers has so little effect in 2017, as explained in Annex 2-Plan Review, but, for example, as 2017 operations showed, outflows may be limited by ice conditions, or downstream flooding. Furthermore, this effect is only possible because 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.

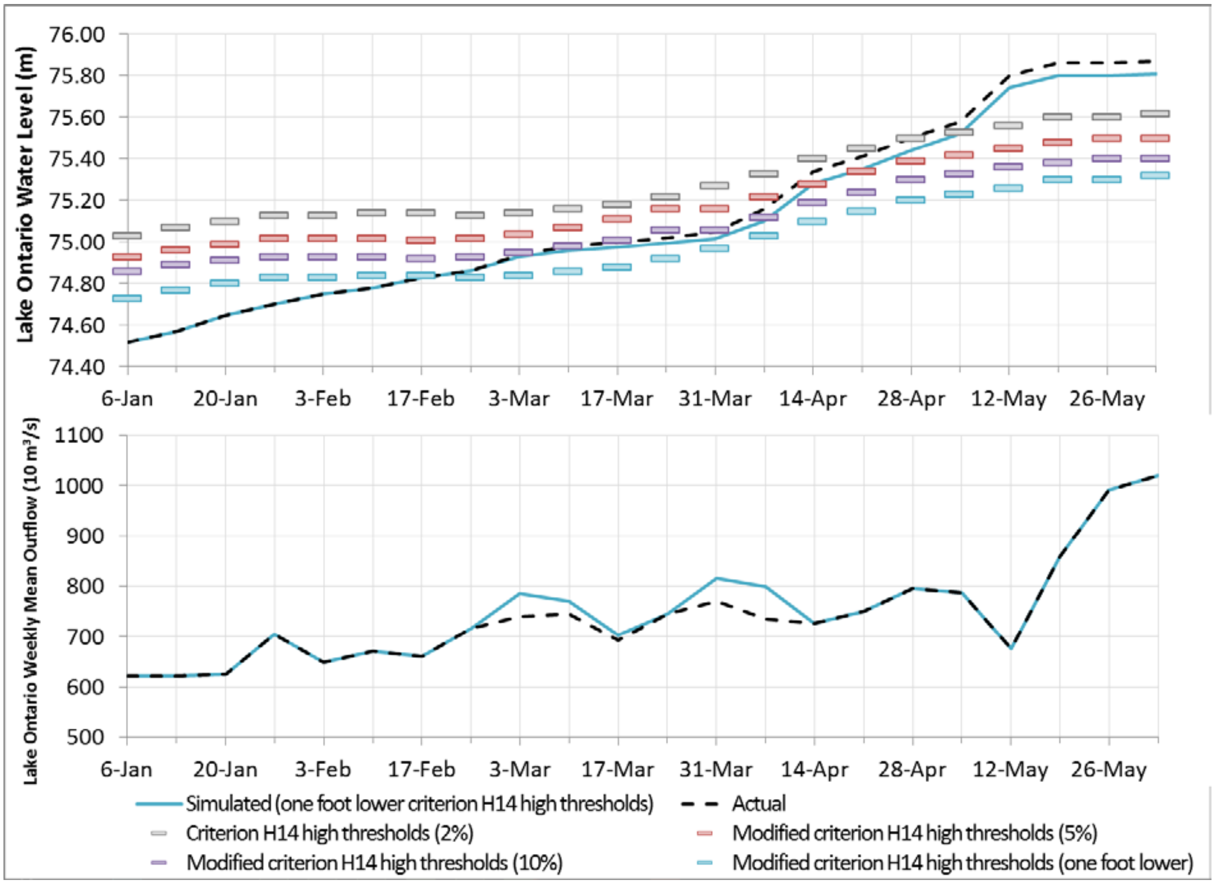


Figure 6-10: Lake Ontario levels and releases based on alternative deviation triggers

6.3.2.3 Modified rules for navigation safety

The L-limit of Plan 2014 sets flows to maintain safe water velocities and river levels for ships in the St. Lawrence Seaway. 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. This included the release of maximum L-limit flows starting on August 8. After Lake Ontario levels fell back below the criterion H14 high threshold levels in September 2017, outflows remained high and were largely constrained by the Plan 2014 maximum L-limit to the end of the year.

Two sets of modified L-limit applications are tested here to estimate how much more rapidly the reduction in the Lake Ontario levels might have been during this time of declining water levels, had slightly higher flows been released. This would have provided coastal landowners along Lake Ontario with somewhat more rapid relief from the higher levels that occurred earlier in the year, but absent of new evidence to the effects on commercial navigation, the risks such a strategy would impose to shipping are unknown.

Two scenarios were tested by increasing the plan-prescribed L-limit flows by up to an additional i) 200 m^3/s and ii) 300 m^3/s. The impacts to water levels and outflows of these scenarios are illustrated in Figure 6-11. Had up to 200 m^3/s more than the plan-prescribed L-limits been released, Lake Ontario levels would have been 8 cm (3 inches) lower by the end of December. Had up to 300 m^3/s more flow been released, this would have caused a 10 cm (3.9 in) reduction over the same time period.

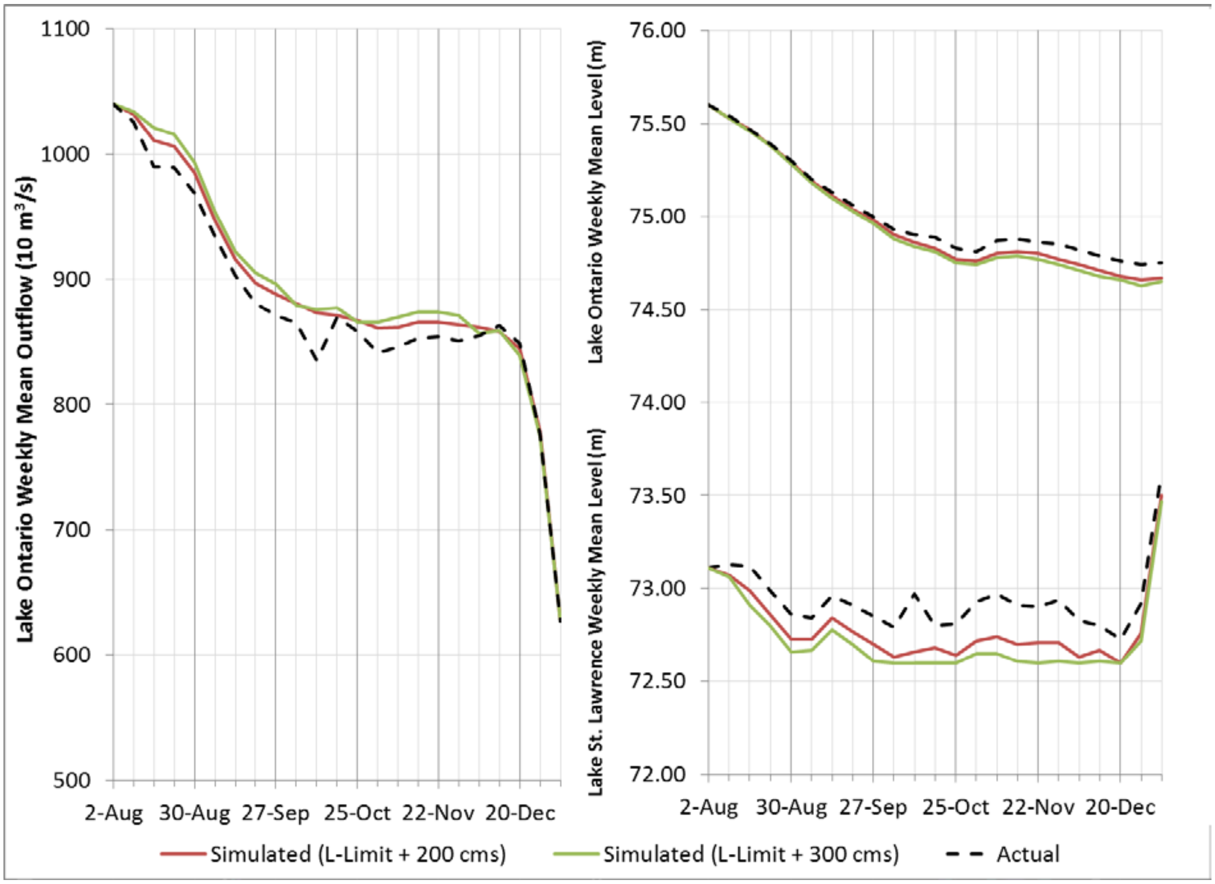


Figure 6-11: Simulations of Lake Ontario outflows, Lake Ontario water levels and Lake St. Lawrence water levels based on modified L-limit flows compared to actual outflows and water levels in 2017.

6.3.2.4 Modified major deviation scenarios

From June 14 to August 8, 2017 outflows were maintained at 10,400 m^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.

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) in mid-

June (instead of 10,400 m^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 Saint-Louis levels were maintained at or below 22.48 m (73.8 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).

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 dam on Lake St. Lawrence, where levels would have been reduced significantly had releases exceeded 10,400 m^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. These simulations are simply meant to illustrate potential impacts to water levels if alternative major deviations were conducted in 2017.

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.

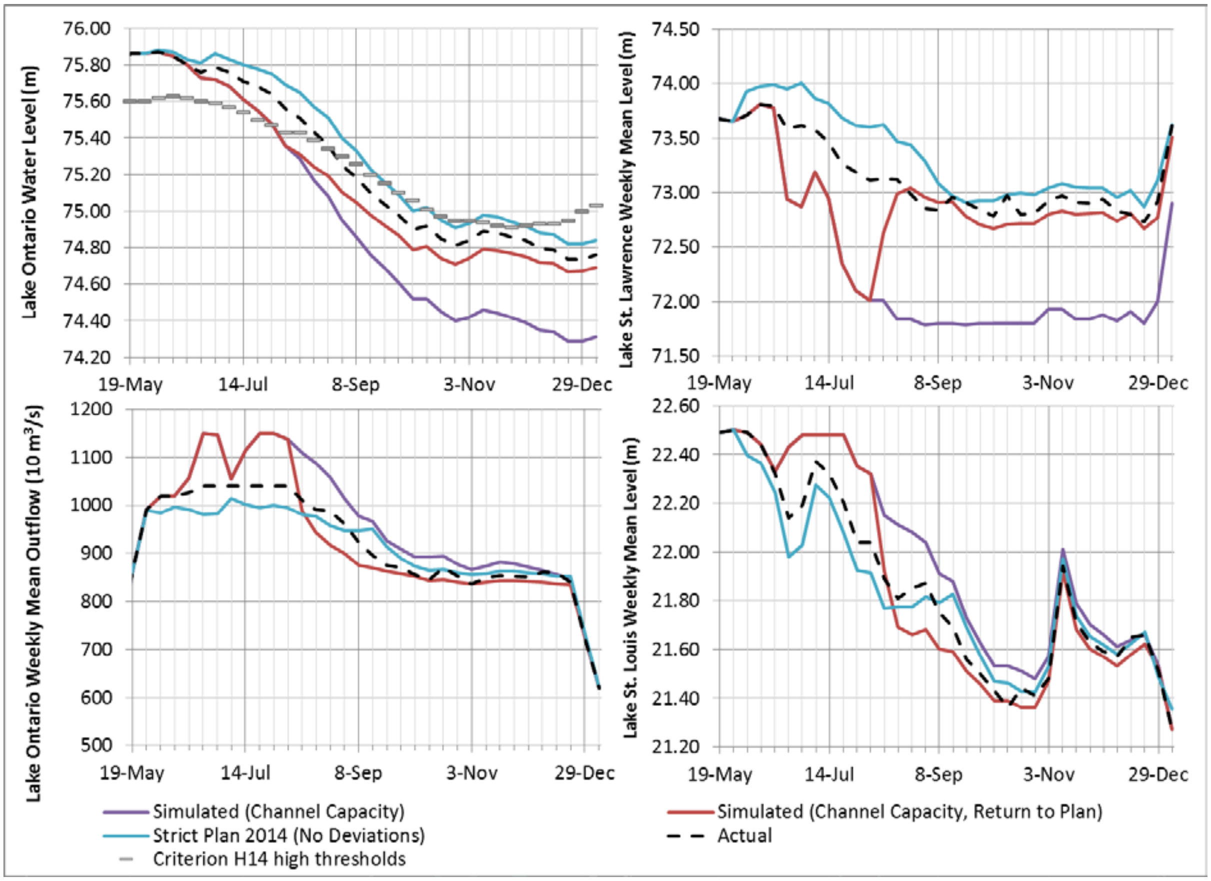


Figure 6-12: Simulated Lake Ontario outflows, Lake Ontario water levels, Lake St. Lawrence water levels and Lake Saint-Louis water levels based on modified major deviation scenarios

As Figure 6-12 shows, the 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. The extreme flows (if feasible on a sustained basis) would have maintained Lake Saint-Louis at flood stage longer 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 (ILOSLRB, 2017).

The alternative major deviation scenario that was simulated (applying outflows of up to 11,500 m^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 as well as lower outflows at that time because the L-limit is a function of lake levels.

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 peaked 1 cm (0.4 in) higher and would have been 15 cm (5.9 in) higher at the beginning of September. Those higher levels would have allowed higher than actual flows (while maintaining safe navigation) after September, and as a result, Lake Ontario levels would have been 8 cm (3.2 in) higher than actual levels by the end of December (see section 2.3.4 of Annex 2-Plan Review for further details).

6.3.2.5 Plan 2014 compared with pre-project channel water levels and outflows

A simulation was conducted to compare actual levels and outflows in 2017 to pre-project conditions. Pre-project represents what outflows would have occurred under the channel capacity just before the project was built, that is, with no regulation. The results are shown in Figure 6-13.

Under the pre-project simulation, Lake Ontario water levels would have been higher at the beginning of the year and would have been higher than actual 2017 levels throughout the year. Actual Lake Ontario levels dropped because of higher outflows possible with regulation in June; the pre-project peak would have occurred in the first week of July, reaching a level about 18 cm (7.1 in) higher than the actual 2017 peak. Levels at the end of 2017 would have been about 76 cm (2.5 ft) higher than actual Plan 2014 levels. On the lower river on Lake Saint-Louis, water levels would have peaked about 53 cm (1.7 ft.) higher with unregulated, pre-project outflows.

The regulation plans include outflow management to create a stable ice cover to avoid the ice-jam floods that were common before the dam was built. The pre-project levels and flows do not account for the potential for ice jams under pre-project conditions which would have the potential to cause extreme flooding on the upper St. Lawrence River above the dam and in the St. Lawrence River above the Beauharnois dam. Ice jam flooding can happen very quickly with extreme and devastating results.

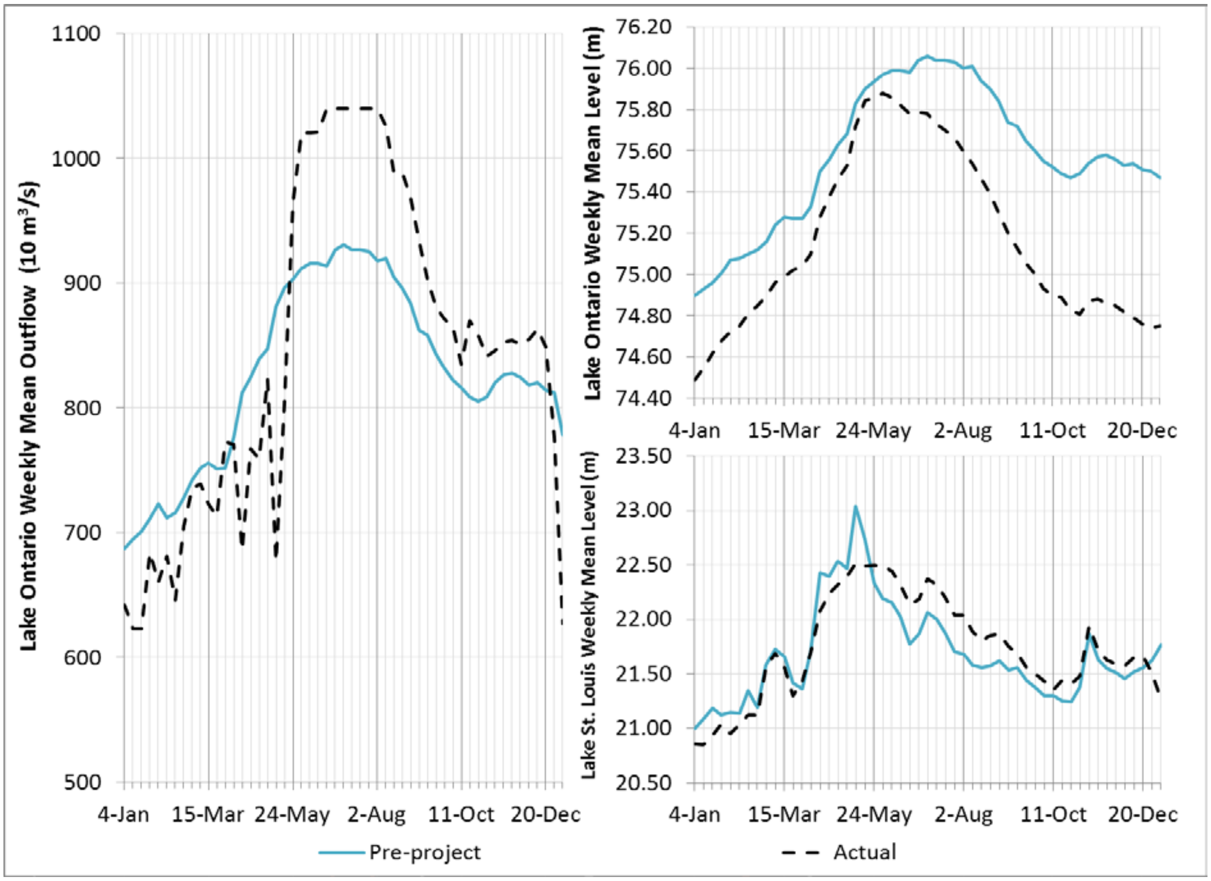


Figure 6-13: Simulated pre-project Lake Ontario outflows, Lake Ontario water levels and Lake Saint-Louis water levels compared to actual water levels and outflows in 2017.

6.3.2.6 Plan 2014 compared with Regulation Plan 1958-D with deviations

Plan 2014 was implemented January 7, 2017. This alternative scenario replaces the Plan 2014 releases that occurred in 2017 with estimates of the releases that would have occurred had the previous regulation Plan 1958-D with deviations (1958-DD) remained in operation.

A discussion of the way flows were simulated is included in section 2.3.5 of t Annex 2-Plan Review. Figure 6-14 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.

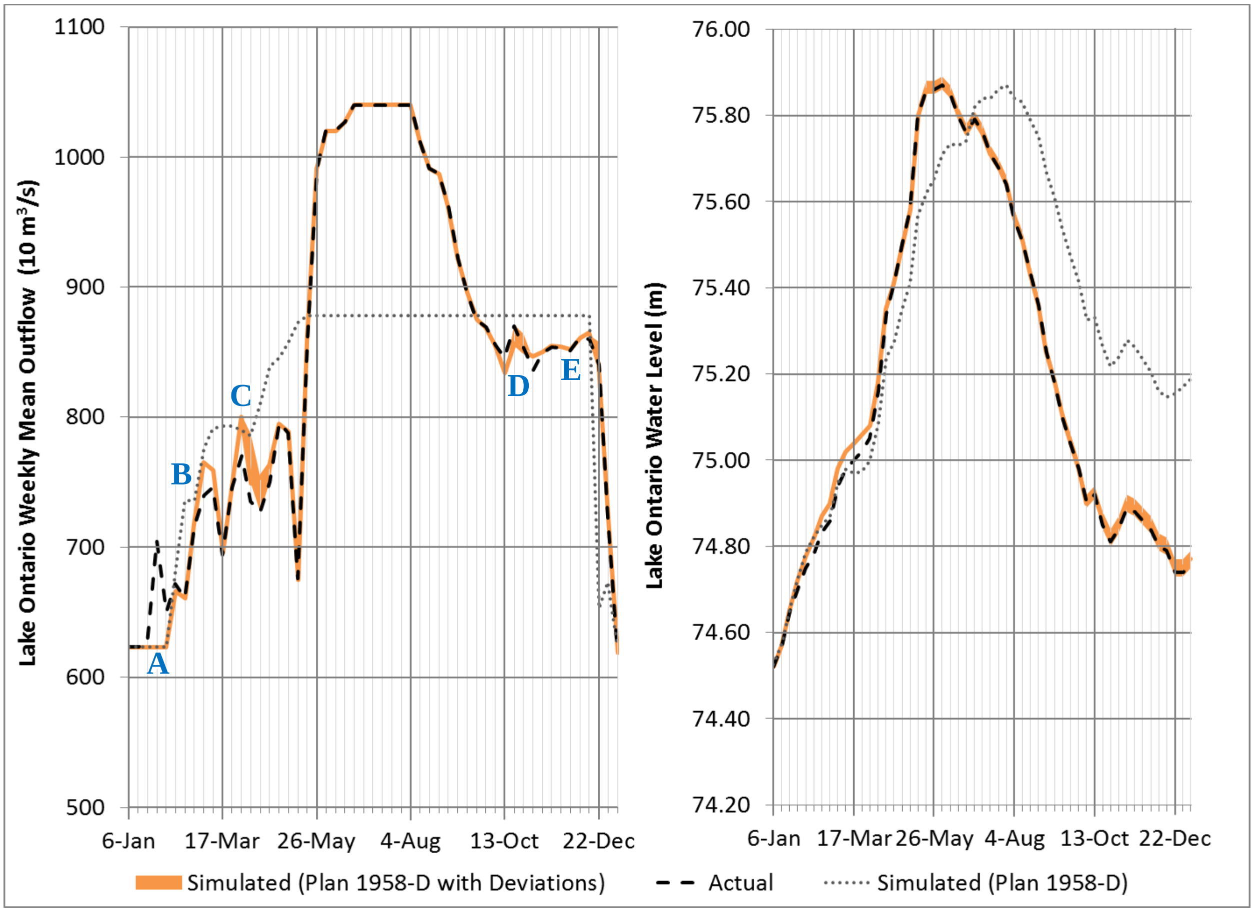


Figure 6-14: Simulated Plan 1958-D with deviations (shaded orange series) and simulated Plan 1958-D prescribed outflows and water levels (dotted grey series) compared to actual outflows and water levels in 2017

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 6-14 and described below.

In January, Plan 1958-D typically specified a maximum flow of 6230 m^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 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 allow boat haul-out 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.

6.3.3 Observed 2017 Water Levels and Hydroclimate Conditions Compared to Those Used in Plan Evaluation

Part of the charge to the GLAM Committee is to help the IJC boards 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 LOSLRS Board 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 LOSLRS Board 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 quarter-month to quarter-month 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.

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.

Annex 2-Plan Review provides a preliminary 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. Annex 2-Plan Review includes the following assessments:

1. **Ice Conditions (Annex 2 - 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 Saint-Louis Water Levels (Annex 2 - 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 Saint-Louis levels is required.
3. **Simulation of Lake Ontario Levels (covered here and in Annex 2 – 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 (Annex 2 - 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 (Annex 2 - 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?

Only the second and third simulations are discussed briefly here as their findings seemed particularly pertinent.

6.3.3.1 Differences between simulated and operational Plan 2014 Lake Saint-Louis (Pt. Claire) levels

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

In previous Plan 2014 simulations, it was found that the quarter-monthly F-limit calculation was not applied correctly in the model code for Plan 2014 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 Saint-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 Saint-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 Saint-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 Saint-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 Saint-Louis level is reduced from 23.33 m (76.54 ft) to 22.81m (74.84 ft) (decrease of 52 cm (20.5 in)).

6.3.3.2 Observed 2017 Conditions Compared with the Stochastic Supply Sequence

Lake Ontario levels are the cumulative result of the timing and magnitude of different inflows and the releases from the Moses-Saunders Dam. The relationship between input and outcome is not simple. Plan 2014 was designed and tested using both historical water supplies and a broad range of potential future water supply conditions and a primary source for these water supplies was the statistically generated times series of 50,000 years of water supplies and tributary flows. The highest lake level reached in the stochastic simulation using Plan 2014 was 76.66 m 251.5 ft), which came during an extreme water supply sequence, but while the quarter-monthly NTS (flows from Lake Erie plus local inflows to Lake Ontario) were very high in that sequence, they were not the highest in the 50,000-year stochastic test data.

The 2017 conditions were extreme, exceeding conditions that occurred historically, and while similar conditions are captured within the stochastic series used to evaluate regulation plan performance, such occurrences are rare (see Figure 6-15). Continued research as to whether such conditions will continue to be rare, or whether they will occur more frequently, is necessary for the purposes of developing regulation plans and ensuring robust performance over time.

More information on this analysis is provided in Annex 2-Plan Review.

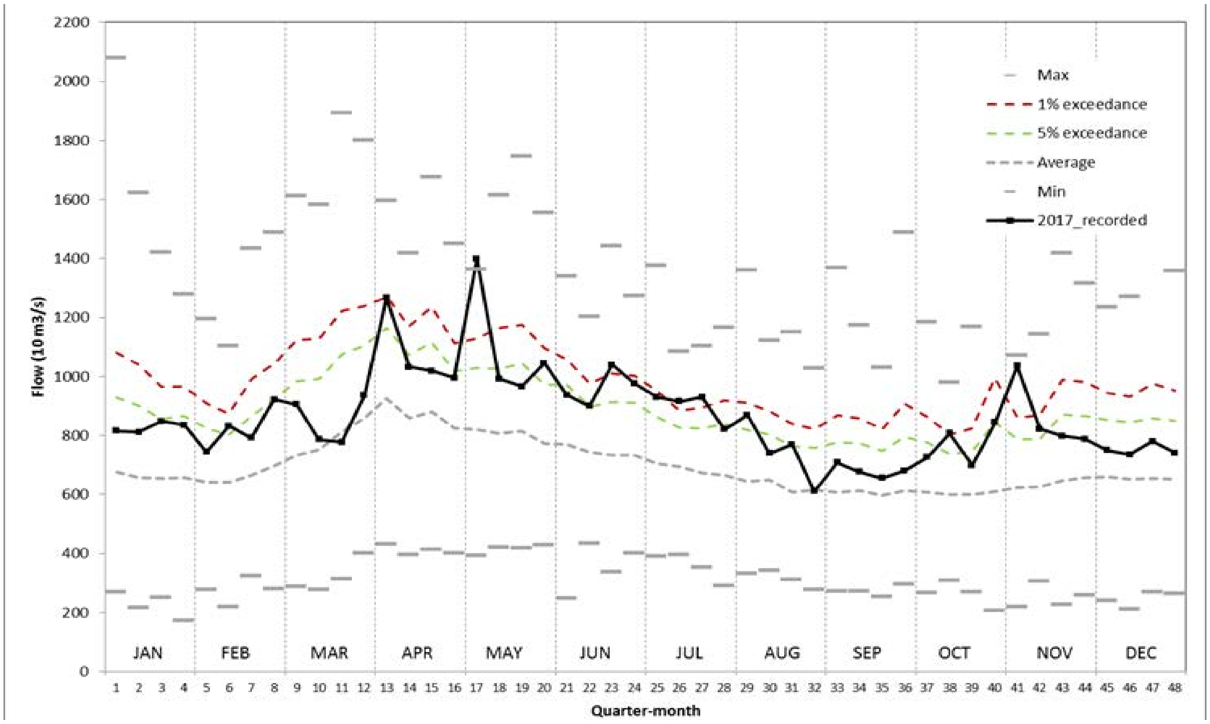


Figure 6-15: 2017 NTS versus NTS range for the entire stochastic series

6.4 Findings and suggested next steps for on-going plan evaluation analyses

The Orders of Approval for both Lake Superior and Lake Ontario require the IJC to review the results of applying the Plan 2012 and Plan 2014 rules. This includes an assessment of how well the observed impacts of water levels compare to those predicted by the research and models used to develop and select the plans. This review can be used to re-evaluate performance and trade-offs which may lead to changes to the regulation plans. Ideas for improvements can come from the particular conditions in any one year or more general observations, for example, that there might be advantages for using a navigation model that covers the entire Great Lakes - St. Lawrence River system. In this report, the focus is on the former, ideas that arise from conditions in 2017, with suggestions for more general assessments where it makes sense.

6.4.1 Plan review findings - Upper Great Lakes

On Lake Superior, the ILSBC deviated from Plan 2012 releases in 2015 and 2016 based, in large part, on a revised and lower estimate of how much flow could be passed through the side channels to hydropower turbines. Greater deviations were required in 2017 when the closure of some turbines for maintenance reduced side channel capacity even more. As discussed in6.2 Lake Superior: review of Plan 2012 performance based on conditions in 2017, the 2017 deviation strategy allowed for much smoother flow changes in the St. Marys Rapids without causing problems for the commercial navigation industry. Smaller peak flows in the rapids resulted in less flooding on Whitefish Island, while the smoother transitions were consistent with objectives of Plan 2012 which, based on qualitative research, are expected to benefit the environmental health of the rapids (IUGLS, 2012).

The 2017 operations suggest that the GLAM Committee should investigate modifications to Plan 2012 to produce these sorts of benefits routinely, perhaps using predictions of available turbine capacity as an input. Because the benefits for the St. Marys fishery and the reduction in high water damages to Whitefish Island are now qualitative, research to quantify the relationship between flows over the rapids and the environmental and coastal benefits could help produce more beneficial rules.

6.4.2 Plan review findings - Lake Ontario-St. Lawrence River system

The hydrologic events of 2017 provided an extreme challenge to the regulation of Lake Ontario and the St. Lawrence River and regulation Plan 2014. The results show that Plan 2014 generally performed as it was expected to under extreme weather and water supply conditions in that it provided greater flexibility to manage difficult ice conditions through the winter of 2017 and, to the extent that this was possible, it attempted to minimize and balance the flood risks during the extreme spring weather conditions, which would have occurred regardless of the regulation plan in place. Nonetheless, the analysis in Section 6 revealed some opportunities for improving the way regulation plans are tested and evaluated in the future. The findings can be classified into three categories:

1. Reconsideration of historical and stochastic modelling inputs
2. Re-evaluation of the plan model processes and algorithms
3. Reconsideration of plan evaluation and ranking process

Each is discussed in separate sub-sections below.

6.4.2.1 Reconsideration of historical and stochastic modelling inputs

The evaluation and ranking of Lake Ontario regulation plans since the LOSLRS have depended in large part on the assumption that a stochastically generated set of simulation model inputs including net basin and total water supplies, tributary flows and ice conditions accurately represents the range of future hydrologic conditions that could be expected. No one can be sure of the degree to which weather conditions in 2017 were caused by climate change, but the analysis in Section 6.3.1 shows that high water levels in 2017 were caused by the sequence and simultaneous occurrence of significant events, some apparently independent from one another (warm February followed by a cold March, extremely wet April and May). While some of these events may be captured in the stochastic series to some degree, they raise questions about how frequently such events may occur in the future, and whether the stochastic datasets provide an accurate characterization of the conditions under which plans will be operated.

In 2017, there were record net basin and total supplies and Ottawa River discharges. In most, but not all cases, the 2017 inflows fell within the maximum stochastic inflows, but the extraordinary severity of spring precipitation aligns with expectations of severe storms under climate change. The influence of climate change is difficult to prove or disprove, so no one can be sure whether 2017 was an extraordinarily rare event for the climate in this region, or a moderately rare event in a climate that is shifting. The use of the existing LOSLRS stochastic hydrology is logically consistent with the former interpretation. If the latter is true, the existing stochastic hydrology could be misrepresenting the risk of high inflows and should be updated to reflect a changing climate.

Air and surface water temperature trends over the past decades support climate change projections for warmer temperatures in the future, which could change ice formation and winter runoff patterns and evaporation from the lake surface. The ice formation cycles that occurred in 2017 are unprecedented in the historical record and un-represented in the stochastic ice condition indicator dataset. Section 6.3.1.1 shows that this year's ice formation raised water levels several centimeters given the conditions in 2016-2017. The current ice data applied along with the stochastic water supply set is simply a sampling from the approximately 40 years of ice record available at the time of the LOSLRS. These ice data include a time series of ice status indicators so that the impacts of ice formation and roughness are included in plan testing, but there are no indicator strings in those data matching what happened in 2017, so the stochastic simulations cannot reveal the impact 2017 ice formation patterns would have in combination with different water supply sequences and antecedent water levels.

Climate change projections for warmer temperatures could also affect the timing and rates of runoff from winter rains and snowmelt. It may be that there will be more winter rain and snowmelt events with less snow accumulation and/or the time between snowmelt and heavy spring rains will increase under climate change to a degree not well represented in the current stochastic data (Notaro, 2015; Whitfield and Cannon, 2000; Barnett et al., 2005). Evaporation and precipitation may each increase under climate change, but the timing of the two may also change in ways not well represented in the current stochastic data (Music et al., 2015, Notaro, 2015; GLISA, 2018). However, the significant uncertainties in how these factors will change with a changing climate remains a challenge in developing a new stochastic dataset as well as changing the rules of regulation plans to respond to this uncertainty.

This section also makes evident that high Lake Ontario levels can be caused by the sequence and simultaneous occurrence of climate factors, so forecasting research that predicts simple parameters like the amount of spring precipitation may not forecast high water levels. The GLAM Committee concludes that to be useful, fall forecasts should be tested according to their ability to predict high spring Lake Ontario levels, not simply high NBS or NTS. Even with such research, it could be many years or decades until the skill of such forecasts is to a level that might influence regulation plan decisions.

6.4.2.2 Re-evaluation of the model processes and algorithms

Section 6.3.2 shows that Lake Ontario levels could have been reduced somewhat in 2017 by modifying the F and L limits, although modifications may alter the balance of impacts upstream and downstream. These current limits are part of Plan 2014 rules and 1958-DD practice that were based on long standing perceptions about protecting navigation safety and balancing flooding above and below the dam. There is no evidence to date that suggests that changing those practices would improve outcomes in any significant way. Changing these limits would shift impacts or risks from one area or interest to another. Any future analysis should focus the assessment on a broad range of extreme and difficult water supply conditions as well as socio-economic and environmental performance indicators.

Section 6.3.2.2 shows no water level reduction would have resulted from any realistic adjustment of the H14 high trigger levels based on 2017 conditions. The reductions in 2017 that could have been caused by one-foot lower trigger levels would, if acted upon by the ILOSLRB, cause deviations from Plan 2014 rules about 20% of the time, eviscerating the nature of the plan. People who suffered through the high levels often expressed the belief that lower trigger levels would have helped. Based on the 2017 analysis, the GLAM Committee does not believe that examining changes to the triggers provides much promise in terms of looking for plan improvements during extreme water supply conditions. However, as with the limits, any future analysis of the H14 high trigger should include attention on a broader range of extreme water supply conditions as well as socio-economic and environmental performance indicators.

The simulation of water levels in the river is based on regression equations using past levels, tributary flows and releases from Lake Ontario. Given extreme water levels in 2017, it was determined that re-examining the regressions used to simulate Lake Saint-Louis and further downstream levels could produce meaningful improvements in the validity of the simulation model under extreme flow conditions.

Section 6.3.2.7 summarized the discovery of a coding issue in the simulation of Plan 2014 that, when Lake Ontario is above 75.75 m, can underestimate Lake Ontario levels and overestimate levels at Pointe Claire. The GLAM Committee concludes that the implications of the quarter-monthly simulation of Pointe Claire levels for Plan 2014 be investigated to determine the effects it may have on plan evaluations and inherent upstream and downstream tradeoffs. This may include re-running the full stochastic evaluations to determine the implications for the calculation of the performance indicator results.

6.4.3 Next steps: reconsideration of plan evaluation process

6.4.3.1 Upper Great Lakes: The development of new shorter-term plan evaluation tools

Computer models were developed during the IUGLS (2007-2012) to analyze and compare the performance of differing regulation plans. The plans had to be tested under many different hydrologic conditions, so they used century long time series data. These models are not designed for the comparison of different water level regulation rules over only one or two years. The GLAM Committee is currently developing short term evaluation tools. Once these tools are developed, the GLAM Committee will produce quantitative reviews of Plan 2012 performance in the current and recent years.

6.4.3.2 Lake Ontario – St. Lawrence River: extensive scenario testing

The LOSLRS Board based much of their plan ranking on expected values of economic benefits calculated as averages from stochastic simulations and environmental performance indicators simulated using the historic record. Expected values are averages of the impacts times the probability of the impact, and ranking based on those averages suggests how the plans are most likely to perform. Scenario analysis can be used in addition to expected value calculations to test a plan's robustness in the face of unusual combinations of conditions. An additional approach that can be used to complement the average annual impacts based on stochastic hydrology, is scenario analysis, where plan rules are tested with many short-term input data sets. This approach was used by the IUGLS Board (IUGLS, 2007-2012) and to a lesser degree during and after the LOSLRS. Section 6.3.3 and Annex 2-Plan Review revealed that there is some evidence that suggests the stochastic inputs do not fully represent the future conditions Plan 2014 will be applied under and this leads the GLAM Committee to conclude that more extensive scenario analysis would be beneficial in testing Plan 2014:

- In some cases, such as in ice formation, there is no doubt that the stochastic data do not represent what happened in 2017 and the implications of this should be fully reviewed and evaluated;
- The use of average benefits of regulation plan performance is useful because it incorporates the results from all events weighted by their probability of occurrence, but it takes attention away from rare events that have the greatest impact on stakeholders (or

interests) and which (if possible) may be the most important for regulation plans to attempt to better address, particularly if the probability of such rare events is expected to increase in the future; and

- There is some evidence that the probability, magnitude and timing of temperature, precipitation, evaporation and runoff may be changing. Section 6.3.1 shows that the coincidence and sequencing of these factors can raise water levels. Presumably, the stochastic simulation includes the correlations among these parameters found in the historic record. Scenario analysis would allow the creation of uncharacteristic but plausible combinations of these parameters.

7.0 Key Findings and Next Steps

The GLAM Committee has developed this special report of conditions in 2017 as a component of its long-term adaptive management process to review and improve outflow regulation on the Great Lakes. The year 2017 was impactful and challenging, particularly for the interests of the Lake Ontario-St. Lawrence River system. It offered a critical test of both Plan 2012 and Plan 2014 and a challenge for the GLAM Committee in initiating a reporting process for event-based data and information. Information learned in 2017 will be used to guide GLAM Committee activities in the coming year and beyond, as resources become available. The following sections highlight critical findings and potential next steps.

7.1 The year 2017 had extraordinary conditions across Lake Ontario and the St. Lawrence River basin, but Plan 2014 did not contribute to record high water levels

Finding: 2017 was unusually wet across the entire Great Lakes with record-breaking precipitation and water levels on the Lake Ontario-St. Lawrence River system. These conditions caused widespread damages to coastal communities and other interest categories upstream and downstream of the Moses-Saunders dam. The GLAM Committee analyses of conditions and plan performance in 2017 supports the ILOSLRB finding that Plan 2014 did not cause, or meaningfully exacerbate, the flooding and associated damages that occurred in 2017. The analysis showed that the outflows released in 2017 under the new regulation plan were very similar to those that would have been released had the board still been operating under the old regulation plan with previous operating and deviation authorities.

Next Steps: The GLAM Committee will continue to analyze data gathered from 2017 and future years to support the on-going evaluation of the regulation plans and search for improvements.

7.2 Great Lakes Basin: Quantitative data on impacts from the high water levels in 2017 is not widely available and is required for performance indicator model validation

Finding: Performance indicators generally captured critical sectors in 2017, but conditions raised questions about model details and on-going monitoring required for validation. While the GLAM Committee pursued various potential data sources, much of the data was not available for public distribution and in many cases, quantitative economic and environmental impact data was not being actively collected nor consolidated. In most cases, it was difficult (if not impossible) to get the appropriate quantitative data required to validate existing economic and environmental performance indicators used in the existing models. This raises the question about revisiting performance indicators to support long-term plan evaluation. Some areas seem more critical than others and the GLAM Committee will need to prioritize performance indicator validation efforts to efficiently guide its collection of critical data. There were some impacts that could not be compared with existing performance indicators, either because the information was not available to support the comparison, or because the impacts observed were not directly captured by the existing performance indicators. The impacts experienced in 2017 not captured by existing performance indicators may or may not reflect important issues affecting relative comparisons of plan performance. Either way, it does highlight the need for regular review and updating of the performance indicators as part of the adaptive management process.

Next Steps: Once the studies of 2017 impacts are completed, the GLAM Committee should compare the results to model predictions, report on the accuracy of performance indicator model predictions and modify the performance indicator functions, if necessary. The GLAM Committee should continue to pursue on-going monitoring needs to validate models and update performance indicators as required to support the ongoing review of the regulation plans. As well, the GLAM Committee should revisit the significance, sensitivity and certainty of all of the performance indicators to ensure they can effectively be used in future plan reviews and evaluations.

7.3 Great Lakes Basin: Simulation models will continue to be improved

Finding: The simulations of water levels and flows under Plan 2012 and Plan 2014, as well as alternative regulation strategies, should be continually tested and improved as appropriate to minimize inherent uncertainties. For example, on Lake Ontario and the St. Lawrence River system, the simulation of Lake Saint-Louis levels is uncertain under very high water supply conditions, as are the effects that such conditions may have throughout the lower St. Lawrence River. On the upper Great Lakes, the maximum combined capacity of the side channels, which carry flow to the hydropower plants on the St. Marys River, is reduced at times of hydropower maintenance activities, but the effects of these reductions in capacity were not considered when

Plan 2012 was evaluated. To reduce the impacts on the St. Marys Rapids during periods of high flows and reduced capacity, the ILSBC has had to deviate annually since the plan was implemented in 2015.

Next Steps: The simulation and evaluation models will be improved, and the new models used during subsequent evaluations will be periodically reviewed and updated as appropriate.

7.4. Upper Great Lakes: New performance indicators need to be developed for the St. Marys River

Finding: Lake Superior outflow regulation has the greatest effect on the St. Marys River. While the ILSBC has tried to minimize the potential negative impacts of high and fluctuating flows in the St. Marys Rapids by deviating from Plan 2012 during recent years, there is insufficient monitoring data or metrics to validate the effects of the ILSBC's deviation strategies. The St. Marys Rapids ecosystem and the low-lying adjacent shoreline of Whitefish Island are particularly sensitive to high flows or changes in flows through the Compensating Works. Performance indicators need to be developed to quantify and better understand the impacts in the St. Marys Rapids, and these can be used to inform future evaluations of regulation plan performance as well as the effects of potential deviation strategies.

Next Steps: Continue efforts to develop ecosystem and flooding performance indicators and models for the St. Marys River.

7.5 Lake Ontario-St. Lawrence: The impacts of modifying the F and L limits should be studied

Finding: The GLAM Committee examined some of the rules of Plan 2014, including the maximum flow limits within the plan. Plan 2014's maximum limits were established over decades of board operation based on expert knowledge and experience in balancing coastal impacts above and below the dam (F-limit) and balancing those impacts with maintaining safe water velocities and river levels for ships in the St. Lawrence Seaway (L-limit). A review of how these limits applied during 2017 showed that altering them would not eliminate or significantly reduce the high flows and water levels that occurred, but it would shift the effects from one geographic location and/or interest to another. The impacts of such actions on various interests are uncertain. While the LOSLRS did investigate the effects of altering these limits, the performance indicators used to model the impacts of these limits must be reviewed and informed by 2017 conditions and the trade-offs associated with these limits re-evaluated to better understand and explain the implications of modifying these limits and other plan rules.

Next steps: The GLAM Committee will continue to design and implement studies to review and evaluate the socio-economic and environmental implications of modifications to the limits and other plan rules to better understand and explain the inherent tradeoffs and balances of the plan rules and limits under a broad range of extreme conditions.

7.6 Lake Ontario-St. Lawrence: Changes to trigger levels do not substantially influence water levels under the extreme conditions seen in 2017

Finding: The GLAM Committee examined the trigger levels for board deviations and whether lower trigger levels could have provided additional flood relief upstream and downstream in 2017. This analysis indicates that no significant reduction of 2017 water levels would have resulted from any realistic adjustment of the H14 high trigger levels. A full analysis beyond 2017 conditions has not yet been completed and is needed to assess the value of changes to trigger levels under other extreme conditions than what occurred in 2017.

Next Steps: Any future analysis of trigger levels will be done as part of a full review of all rules within Plan 2014. Such analysis builds on previous studies by the IJC and is supported by lessons learned in 2017 and future years. It should also include an assessment of a broad array of extreme water supply scenarios as well as socio-economic and environmental performance indicators.

7.7 Lake Ontario-St. Lawrence: 2017 hydroclimate conditions highlight the importance of using scenario analyses to test and evaluate plan performance

Finding: Two components of 2017 weather conditions promote consideration of *scenario testing* (comparing regulation plans using short, extreme inputs) to complement *expected value testing* (using the products of impacts of many different input sets times the probability of that input set occurring). The first condition was the unprecedented forming and melting of ice in the St. Lawrence River five times in 2017 and the effects this had on regulated outflows and the water levels that occurred. The stochastic data used in the evaluation of the current plan during and after the LOSLRS included many different starting dates and durations of ice cover formation, but did not include a scenario in which ice went through several cycles of forming and melting in one year. The second condition was the record precipitation measured at stations on the Lake Ontario basin and on the Ottawa River basin, each exceeding historical maximums.

Expected value analysis offers the best assessment of the overall performance of regulation rules under a wide variety of conditions, but the response in very unusual scenarios is dampened by the low probability associated with those events. Climate change challenges the assumption that those probabilities can be estimated well. Scenario testing using many different plausible but extreme conditions would allow the GLAM Committee to test how well plans perform under extreme conditions not thought likely, offering the chance to adjust plan rules to better accommodate very unusual conditions. It should be used in combination with expected value testing so that the adjusted plan continued to perform well over a wide variety of conditions while also performing about as well as any plan could in plausible but extreme conditions.

Next Steps: A new set of model inputs should be created expressly for continued scenario testing beyond what has previously been analyzed and a framework for evaluating plan performance on the basis of both scenario and expected value tests should continue to be devised to test a plan's robustness in the face of unusual combinations of conditions.

7.8 Lake Ontario-St. Lawrence: Continue to investigate the value of forecasting high Lake Ontario water levels to support plan improvements

Finding: Analyses of the 2017 conditions provided evidence that high Lake Ontario water levels can be caused by the sequence and simultaneous occurrence of different climate factors, so forecasting research that predicts simple parameters like the amount of Lake Ontario spring precipitation may not forecast high water levels. The GLAM Committee concludes that to be useful, fall forecasts should be tested according to their ability to predict high Lake Ontario water levels, not just high NBS or NTS.

No such forecast exists now, but there may be some potential for trying to produce one based on ocean conditions in the fall. Given that it may be years, even decades or perhaps never, before seasonal forecasts have the skill to inform regulation plan decisions, a first step is to test the hypothesis that forecasts could reduce flooding while balancing the needs of other interests.

Next Steps: The GLAM Committee should test perfect forecasts and evaluate the implications of using more realistic imperfect forecasts as a means to reduce flooding while balancing other interests. The Committee should also identify the risk of incorrect forecasts. If results are promising, the GLAM Committee should investigate methods to evaluate different relationships between ocean conditions and Lake Ontario levels to improve seasonal forecasts. This would be done recognizing effective seasonal forecasts as a long-term goal.

7.9 Lake Ontario - St. Lawrence: Some notable changes in percent coverage appeared to occur at specific elevations where vegetation communities were flooded by higher water levels in 2017

Finding: Shifts in wetland vegetation extent resulting from 2017 water level conditions will not be immediately evident as there is a lag time for response in some guilds. However, field data from the surveillance of the Canadian and U.S. wetlands done in the fall of 2017 show some notable changes in percent coverage at specific elevations where vegetation communities were flooded by higher water levels in 2017. The meadow marsh guild appears to have experienced the most change out of all guilds in 2017. Not surprisingly, the average cover for meadow marsh was lower in 2017, compared with previous data, as these species were stressed by flooding for a large portion of the growing season.

Next Steps: Additional years of monitoring the wetlands’ response to the 2017 high levels as well as response to lower water level conditions is needed to complete the validation of the meadow marsh algorithm.

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Appendix 1: Performance Indicators and Coping Zones

Performance Indicators used in LOSLRS, 2006

Key Environmental Performance Indicators

Lake Ontario

Vegetation:

1. *Wetland Meadow Marsh Community - Total surface area, supply-based (ha)

Fish:

2. Fish Guild (Low Vegetation, 18C) - Spawning habitat supply
3. *Fish Guild (High Vegetation, 24C) - Spawning habitat supply
4. Fish Guild (Low Vegetation, 24C) - Spawning habitat supply
5. *Northern Pike – Young-of-year recruitment (#ha)
6. Largemouth Bass – Young-of-year recruitment (#ha)

Birds

7. *Virginia Rail (RALI) - Median reproductive index (index)
8. Least Bittern (IXEX) - Median reproductive index (index) (Species at risk)
9. *Black Tern (CHNI) - Median reproductive index (index) (Species at risk)
10. Yellow Rail (CONO) - Preferred breeding habitat coverage (ha) (Species at risk)
11. King Rail (RAEL) - Preferred breeding habitat coverage (ha) (Species at risk)

Upper St. Lawrence River

Fish:

12. Fish Guild (Low Vegetation, 18C) - Spawning habitat supply from Thousand Islands to Lake St. Lawrence
13. *Fish Guild (High Vegetation, 24C) - Spawning habitat supply from Thousand Islands to Lake St. Lawrence
14. Fish Guild (Low Vegetation, 24C) - Spawning habitat supply from Thousand Islands to Lake St. Lawrence
15. *Northern Pike – Young-of-year (YOY) recruitment (#ha) from Thousand Islands to Lake St. Lawrence
16. Largemouth Bass – YOY recruitment (#ha) from Thousand Islands to Lake St. Lawrence
17. *Northern Pike – YOY net productivity (grams (wet wt.)/ha) in Thousand Islands area

Birds:

18. *Virginia Rail (RALI) - Median reproductive index (index) on Lake St. Lawrence

Mammals:

19. *Muskrat (ONZI) - House density in drowned river mouth wetlands (#ha) in Thousand Islands area

Lower St. Lawrence River

Fish:

20. *Golden Shiner (NOCR) - Suitable feeding habitat surface area (ha) from Lake St. Louis to Trois-Rivières
21. Wetland Fish - Abundance index (ha) in Lower St. Lawrence River
22. *Northern Pike (ESLU) - Suitable reproductive habitat surface area (ha) from Lake St. Louis to Trois-Rivières
23. Eastern Sand Darter (AMPE) - Reproductive habitat surface area (ha) from Lake St. Louis to Trois-Rivières (Species at risk)
24. *Bridle Shiner (NOBI) - Reproductive habitat surface area (ha) from Lake St. Louis to Trois-Rivières (Species at risk)

Birds:

25. Migratory Wildfowl - Floodplain habitat surface area (ha) from Lake St. Louis to Trois-Rivières
26. Least Bittern (IXEX) - Reproductive index (index) from Lake St. Louis to Trois-Rivières (Species at risk)
27. *Virginia Rail (RALI) - Reproductive index (index) from Lake St. Louis to Trois-Rivières
28. *Migratory Wildfowl - Productivity (# juveniles) from Lake St. Louis to Trois-Rivières
29. Black Tern (CHNI) - Reproductive index (index) from Lake St. Louis to Trois-Rivières

Herpetiles

30. Frog species - Reproductive habitat surface area (ha) from Lake St. Louis to Trois-Rivières
31. Spiny Softshell Turtle (APSP) - Reproductive habitat surface area (ha) from Lake St. Louis to Trois-Rivières (Species at risk)

Mammals

32. *Muskrat (ONZI) - Surviving houses (# of houses) from Lake St. Louis to Trois-Rivières

*Priority subsets of key environmental indicators

Economic Performance Indicators

Coastal Performance Indicators

Lake Ontario

1. Flood Damages - The economic damages to developed properties based on high water levels, calculated on a county basis.
2. Erosion of Developed Parcels - Damage based on the cost of adding shore protection once the shoreline is within a defined distance from the house, calculated on a county basis. The value of lost material is not determined.
3. Shore Protection Maintenance - The cost of replacing shore protection damaged by water levels, calculated on a county basis.

Upper St. Lawrence River

4. Flood Damages - The economic damages to developed properties based on high water levels, calculated on a county basis. Based on U.S. counties only due to lack of availability of Canadian parcel data for upper St. Lawrence River regional municipalities.

Lower St. Lawrence River

5. Flood Damages - Damages associated with high water levels in the St. Lawrence River below the dam on a municipality basis; based on water levels at the closest gauge location (eight used for the river).
6. St. Lawrence River Shore Protection - The cost of replacing shore protection damaged by water levels. Each structure was placed in one of 80 structure zones on the Lower St. Lawrence River. These zones were selected on the basis of location and similarity of hydrodynamic conditions (local wind, wave, river flow and level, and shipping climate).

Non-Economic Performance Indicators (Reported in Board Room and Contextual Narrative)

- St. Lawrence River Flooding Non-Economic Impacts - Number of expropriated homes; kilometres of roads flooded, and area of flooded land. Damages are determined on a municipality basis; based on water levels at the closest gauge location (eight used for the river).
- St. Lawrence River Erosion - Land lost due to erosion. Impacts are determined for 27 high-erosion sites along the lower St. Lawrence River. No measurable economic loss as a result of land lost.

Commercial Navigation

7. Transportation Costs on Lake Ontario - Based on tonne-km travel time. Costs rise as travel time increases and are a function of minimal available channel depth on the lake.
8. Transportation Costs on the Seaway - Based on tonne-km travel time. Costs rise as travel time increases and are a function of minimal available channel depth along the Seaway, Seaway low-level wait time, and Seaway gradient delays (fall between gauges) and associated delay costs due to high-flow velocities between Ogdensburg - Cardinal, Cardinal-Iroquois HW, Iroquois TW - Morrisburg, Morrisburg - Long Sault.
9. Transportation Costs below the Port of Montreal - Based on tonne-km travel time. Costs rise as travel time increases and are a function of minimal available channel depth at Sorel andTrois-Rivières.

Hydropower

10. Value of energy produced based on station head, flow, efficiency rate and price of electricity.
11. Cost of foregone peaking opportunities (NYPA and OPG only) based on weekly averaged regulated release and value of peaking opportunity.
12. Predictability/stability of flows to maximize efficiency based on changes in flow and foregone energy production.
13. Frequency and severity of spill at Long Sault Dam during spawning season.

Recreational Boating

14. Net economic benefits lost by recreational boaters and charter boat patrons as water level varies from ideal levels for boating for six reaches (Lake Ontario, Alexandria Bay, Ogdensburg, Lake St. Lawrence, Lake St. Louis, Montreal Harbour, and Lac St. Pierre)

Municipal and Industrial Water Uses

15. Water Quality Infrastructure Costs Avoided on the lower St. Lawrence River - based on cost of upgrading municipal drinking water treatment plants to treat taste and odor compounds.
16. Water Supply Infrastructure Costs Avoided on the lower St. Lawrence River - based on costs required to adapt plants to lower than critical levels.

Coping Zones for the Upper Great Lakes for Coastal, Recreational Boating, Municipal and Industrial Water Uses and Commercial Navigation used in IUGLS, 2012 (hydropower and ecosystem to follow)

Lake Superior Coping Zones (Water Levels) (from IUGLS, 2012)

			Month											
Interest	**Water Level (WL) Conditions**	**Zone**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Coastal	High WL	Zone C	183.59	183.53	183.51	183.57	183.66	183.71	183.78	183.83	183.84	183.85	183.82	183.74
		Zone B	183.51	183.45	183.44	183.46	183.56	183.66	183.73	183.76	183.77	183.71	183.66	183.60
	Acceptable WL	Zone A	183.51-183.15	183.45-183.08	183.44-183.07	183.46-183.09	183.56-183.18	183.66-183.25	183.73-183.33	183.76-183.36	183.77-183.33	183.71-183.30	183.66-183.27	183.60-183.20
	Low WL	Zone B	183.15	183.08	183.07	183.09	183.18	183.25	183.33	183.36	183.33	183.30	183.27	183.20
		Zone C	182.83	182.76	182.74	182.72	182.76	182.85	182.96	183.01	183.02	183.10	183.01	182.92
Recreational Boating	High WL	Zone C	Recreational Boating Off-Season			184.6	184.6	184.6	184.6	184.6	184.6	184.6	Recreational Boating Off-Season	
		Zone B				184.3	184.3	184.3	184.3	184.3	184.3	184.3		
	Acceptable WL	Zone A				184.3-182.8	184.3-182.8	184.3-182.8	184.3-182.8	184.3-182.8	184.3-182.8	184.3-182.8		
	Low WL	Zone B				182.8	182.8	182.8	182.8	182.8	182.8	182.8		
		Zone C				181.9	181.9	181.9	181.9	181.9	181.9	181.9		
Municipal and Industrial Water Users	High WL	Zone C	184.6	184.6	184.6	184.6	184.6	184.6	184.6	184.6	184.6	184.6	184.6	184.6
		Zone B	184.3	184.3	184.3	184.3	184.3	184.3	184.3	184.3	184.3	184.3	184.3	184.3
	Acceptable WL	Zone A	184.3-182.72	184.3-182.72	184.3-182.72	184.3-182.72	184.3-182.72	184.3-182.72	184.3-182.72	184.3-182.72	184.3-182.72	184.3-182.72	184.3-182.72	184.3-182.72
	Low WL	Zone B	182.72	182.72	182.72	182.72	182.72	182.72	182.72	182.72	182.72	182.72	182.72	182.72
		Zone C	181.6	181.6	181.6	181.6	181.6	181.6	181.6	181.6	181.6	181.6	181.6	181.6
Commercial Navigation	High WL	Zone C	184.7	184.7	184.7	184.7	184.7	184.7	184.7	184.7	184.7	184.7	184.7	184.7
		Zone B	184.4	184.4	184.4	184.4	184.4	184.4	184.4	184.4	184.4	184.4	184.4	184.4
	Acceptable WL	Zone A	184.4-183.2	184.4-183.2	184.4-183.2	184.4-183.2	184.4-183.2	184.4-183.2	184.4-183.2	184.4-183.2	184.4-183.2	184.4-183.2	184.4-183.2	184.4-183.2
	Low WL	Zone B	183.2	183.2	183.2	183.2	183.2	183.2	183.2	183.2	183.2	183.2	183.2	183.2
		Zone C	182.6	182.6	182.6	182.6	182.6	182.6	182.6	182.6	182.6	182.6	182.6	182.6

Location: Lake Superior (from IUGLS, 2012)

Interest	Water Level Regime Characteristic	Zone A	Zone B	Zone C
Coastal	**Frequency of extremes**	Some impacts possible near extremes of Zone A. Higher frequency of extremes would cause some problems to most sensitive stakeholders	Zone B levels are likely to cause problems for moderately sensitive stakeholders and a higher frequency of extremes will exacerbate problems	Zone C levels will cause problems for moderately sensitive stakeholders. A higher frequency of extremes are expected to lead to large changes in the coastal riparian stakeholder community
	Duration	On high end, can withstand this range with minimal damage, regardless of duration, except under extreme (>1% exceedance surge/storm event). On low end of Zone A, persistent conditions (multiple consecutive years) will be a problem for riparians.	Longer duration of Zone B high levels will increase potential for coincidence of large storm event. Persistence of two consecutive years (or more) with max levels within Zone B likely to be of concern to stakeholders and potential exists for damages ranging from moderate to substantial, depending on storm events. On low end, two consecutive years (or more) with Zone B low levels will be of concern to stakeholders	One year with water levels exceeding high Zone C transition is likely to cause moderate damages. Coincidence of a small to moderate storm event will increase damages considerably and an extreme event will cause substantial damages. On low end, conditions have not been experienced within historic record and are likely to be of concern, even for one year.
	Rate of Change	Rapid rising to Max. or lowering to Min. levels will reduce time to adapt and will cause concern but severity of consequences will be minimal	Physical modifications (protection, dredging, etc.) are likely as adaptation to Zone B levels. Rapid rising to Max. or lowering to Min. levels within Zone B may eliminate ability to undertake necessary modifications.	Rapid rising above Max. Zone C threshold or lowering below Zone C threshold will restrict ability to take adaptive measures (e.g. construct shore protection) and will likely lead to substantial damages
	Seasonality	Historically, Lake Superior levels peak in July-October period and reach minimum in Feb-Apr, on average. Peak return period surge events for Thunder Bay tend to be greatest in summer and fall based on Baird (2010) analysis and so coincide with peak levels limiting the consequence of changes in seasonality.		
Recreational Boating	**Frequency of extremes**	During 30 year snapshot of the boating season (April through November), 0% of months exceed Max. and 0% of months are less than Min.	0% of months exceed Max. and 0% of months are less than Min.	0% of months exceed Max. and 0% of months are less than Min.
	Duration	Can withstand this range with minimal damage	Can withstand this range with minimal damage	
	Rate of Change	Quite resilient	Quite resilient	Quite resilient
	Seasonality			
Commercial Navigation	**Frequency of extremes**	Max. - level outside of historic record Min. - levels lower than min. have generally occurred only once in past 6 decades.	Neither high/low levels have been experienced in the historic records	Neither high/low levels have been experienced in the historic records
	Duration		Shippers are typically able to cope via light loading, however, extended periods (2-3 yrs) increase likelihood of end users considering a shift in modes of transportation	
	Rate of Change	Stable levels are preferred over rapidly varying levels	Stable levels are preferred over rapidly varying levels	Stable levels are preferred over rapidly varying levels
	Seasonality	For Min: June to Oct. for first level; Apr, May, Nov., & Dec. for second level	For min: June to Oct. for first level; Apr., May, Nov., & Dec. for second level	For min: June to Oct. for first level; Apr., May, Nov., & Dec. for second level
Municipal and Industrial Water Uses	**Frequency of extremes**	The Max. is the historic monthly high plus 3 sd. The Min. is the historic monthly Min.	The Upper and Lower Levels are where operational problems begin and before the elevations where the first facility operations cease.	Levels are significantly outside historical record and pre-project levels simulation.
	Duration	Can withstand this range with minimal problems.	Short term duration can be tolerated; levels for weeks or months are expected to cause operational issues.	Short term duration (12 to 24 hours) can be tolerated by public water supplies; levels for weeks or months will cause operational issues in some facilities, require capital changes or shut down facilities. This is the elevation where operations begin to cease.
	Rate of Change	Quick drops or rises generally can be handled in this	A quick rate of change from A to B can be tolerated. May	The quicker Zone C is reached from Zone B, the greater the

Interest	Water Level Regime Characteristic	Zone A	Zone B	Zone C
		zone.	require some operational changes if levels remain	chance for disruption in water supply.
	Seasonality	Timing of seasonal peaks are not an issue.	Winter temperatures around freezing might cause frazzle ice in some intakes. Some intakes might be more vulnerable to operational issues in winter levels as they are the seasonal low.	Same as B

Lake Michigan-Huron Coping Zones (Water Levels) (from IUGLS, 2012)

			Month											
Interest	**Water Level (WL) Conditions**	**Zone**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Coastal	High WL	Zone C	177.01	176.99	177.05	177.19	177.26	177.29	177.31	177.29	177.29	177.33	177.29	177.33
		Zone B	176.79	176.77	176.82	176.91	177.05	177.07	177.11	177.07	177.02	176.95	176.89	176.82
	Acceptable WL	Zone A	176.79-175.94	176.77-175.92	176.82-175.93	176.91-176.0.	177.05-176.12	177.07-176.17	177.11-176.17	177.07-176.13	177.02-176.09	176.95-176.07	176.89-176.00	176.82-175.96
	Low WL	Zone B	175.94	175.92	175.93	176.03	176.12	176.17	176.17	176.13	176.09	176.07	176.00	175.96
		Zone C	175.62	175.61	175.63	175.69	175.84	175.88	175.91	175.90	175.87	175.80	175.73	175.67
Recreational Boating	High WL	Zone C	Recreational Boating Off-Season			177.6	177.6	177.6	177.6	177.6	177.6	177.6	Recreational Boating Off-Season	
		Zone B				177.3	177.3	177.3	177.3	177.3	177.3	177.3		
	Acceptable WL	Zone A				177.3-175.8	177.3-175.8	177.3-175.8	177.3-175.8	177.3-175.8	177.3-175.8	177.3-175.8		
	Low WL	Zone B				175.8	175.8	175.8	175.8	175.8	175.8	175.8		
		Zone C				175.5	175.5	175.5	175.5	175.5	175.5	175.5		
Municipal and Industrial Water Users	High WL	Zone C	178.6	178.6	178.6	178.6	178.6	178.6	178.6	178.6	178.6	178.6	178.6	178.6
		Zone B	177.21	177.21	177.21	177.21	177.21	177.21	177.21	177.21	177.21	177.21	177.21	177.21
	Acceptable WL	Zone A	177.21-175.58	177.21-175.58	177.21-175.58	177.21-175.58	177.21-175.58	177.21-175.58	177.21-175.58	177.21-175.58	177.21-175.58	177.21-175.58	177.21-175.58	177.21-175.58
	Low WL	Zone B	175.58	175.58	175.58	175.58	175.58	175.58	175.58	175.58	175.58	175.58	175.58	175.58
		Zone C	174.6	174.6	174.6	174.6	174.6	174.6	174.6	174.6	174.6	174.6	174.6	174.6
Commercial Navigation	High WL	Zone C	177.5	177.5	177.5	177.5	177.5	177.5	177.5	177.5	177.5	177.5	177.5	177.5
		Zone B	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2	177.2
	Acceptable WL	Zone A	177.2-175.75	177.2-175.75	177.2-175.75	177.2-175.75	177.2-175.75	177.2-175.75	177.2-175.75	177.2-175.75	177.2-175.75	177.2-175.75	177.2-175.75	177.2-175.75
	Low WL	Zone B	175.75	175.75	175.75	175.75	175.75	175.75	175.75	175.75	175.75	175.75	175.75	175.75
		Zone C	175.15	175.15	175.15	175.15	175.15	175.15	175.15	175.15	175.15	175.15	175.15	175.15

Location: Lake Michigan-Huron (from IUGLS, 2012)

Interest	Water Level Regime Characteristic	Zone A	Zone B	Zone C
Coastal	Frequency of extremes	On high end, can withstand this range with minimal damage, regardless of duration, except under extreme (> 10 year return period (10% exceedance) surge/storm event). On low end of Zone A, persistent conditions (multiple consecutive years) will be a problem for riparians.	Longer duration of Zone B high levels will increase potential for coincidence of large storm event. Persistence of two consecutive years (or more) with Max. levels within Zone B likely to be of concern to stakeholders and potential exists for damages ranging from moderate to substantial depending on storm events. On low end, two consecutive years (or more) with Zone B low levels will be of concern to stakeholders.	One year with water levels exceeding high Zone C threshold is likely to cause moderate damages. Coincidence of a small to moderate storm event will increase damages considerably and an extreme event will cause substantial damages. On low end, conditions have not been experienced within historic record and are likely to be of concern, even for one year.
	Duration	On high end, can withstand this range with minimal damage, regardless of duration, except under extreme (>10 year return period (10% exceedance) surge/storm event). On low end of Zone A, persistent conditions (multiple consecutive years) will be a problem for riparians.	Longer duration of Zone B high levels will increase potential for coincidence of large storm event. Persistence of two consecutive years (or more) with Max. levels within Zone B likely to be of concern to stakeholders and potential exists for damages ranging from moderate to substantial depending on storm events. On low end, two consecutive years (or more) with Zone B low levels will be of concern to stakeholders	One year with water levels exceeding high Zone C threshold is likely to cause moderate damages. Coincidence of a small to moderate storm event will increase damages considerably and an extreme event will cause substantial damages. On low end, conditions have not been experienced within historic record and are likely to be of concern, even for one year.
	Rate of Change	Rapid rising to Max. or lowering to Min. levels will reduce time to adapt and will cause concern but severity of consequences will be minimal	Physical modifications (protection, dredging, etc.) are likely as adaptation to Zone B levels. Rapid rising to Max. or lowering to Min. levels within Zone B may eliminate ability to undertake necessary modifications.	Rapid rising above Max. Zone C threshold or lowering below Zone C threshold will lead to substantial damages
	Seasonality	Historically, Lake Huron/ Georgian Bay levels peak in June-August period and reach minimum in January-March, on average. Peak return period surge events for Honey Harbour (based on nearby Collingwood gauge) tend to be greatest in winter/spring and fall based on Baird (2010) analysis. Moving peak annual levels into the fall (Sept-Nov) would increase potential for event damages.		
Recreational Boating	Frequency of extremes	During 30 year snapshot of the boating season (April through November), 3% of months exceed Max. and 19% of months are less than Min.	3% of months exceed Max. and 0% of months are less than Min.	0% of months exceed Max. and 0% of months are less than Min.
	Duration	Can withstand this range with minimal damage	Either extreme will cause significant damage until actions are taken to adapt. Many would not be able to survive through a season given either extreme. Many are especially vulnerable during Spring 'Launch' and Fall 'Haul-out'.	Many would not be able to survive through a season given either extreme. Many are especially vulnerable during Spring 'Launch' and Fall 'Haul-out'. Many would have difficulty surviving longer than one season.
	Rate of Change	Quick drops or rises are generally considered a negative as interest does not have time to adjust.	A quick return to zone A regime would be beneficial. A further drop/rise, or prolonged period at this elevation could push interest to Zone C	Any length of time in Zone C would make it difficult for many of the marinas to remain operational.
	Seasonality	Lows are worse in the fall, winter and spring	Lows are worse in the fall, winter and spring	Same as B
Commercial Navigation	Frequency of extremes	Max - has been exceeded in 1952, 1973-74 and 1985-56; Min. - levels lower than Min. have generally occurred only once in past six decades.	Levels have been within this range since 1918	
	Duration		Shippers are typically able to cope via light loading, however, extended periods (2-3 yrs) increase likelihood of end users considering a shift in modes of transportation	

Interest	Water Level Regime Characteristic	Zone A	Zone B	Zone C
	Rate of Change	Stable levels are preferred over rapidly varying levels	Stable levels are preferred over rapidly varying levels	Stable levels are preferred over rapidly varying levels
	Seasonality	For Min: May to Sep. for first level; Apr. & Oct. to Dec. for second level	For Min: May to Sep. for first level; Apr. & Oct. to Dec. for second level	For Min: May to Sep. for first level; Apr. & Oct. to Dec. for second level
Municipal and Industrial Water Uses	**Frequency of extremes**	The Max. is 0.9 foot (0.29 m) less than the historic record; the Min. is the historic record. The Max. and Min. pre-project simulation are outside of Zone A.	Max. is Max. historical record + 3 ft (0.9 m); Min. is Min. historical Min. - 3.2 ft (1 m). Contains some extreme levels of pre-project simulation and historic record levels.	Levels are outside historical record.
	Duration	Can withstand this range with minimal problems.	Short term duration can be tolerated; levels for weeks or months are expected to cause operational issues.	Short term duration (12 to 24 hours) might be tolerated by public water supplies; levels for weeks or months will cause operational issues in some facilities, require capital changes or shut down facilities. This is the elevation where operations begin to cease.
	Rate of Change	A quick rate of change within A can be tolerated.	A quick rate of change from A to B can be tolerated. May require some operational changes if levels remain.	The quicker Zone C is reached from Zone B, the greater the chance for disruption in water supply.
	Seasonality	Timing of seasonal peaks are not an issue.	Winter temperatures around freezing might cause frazzle ice in some intakes. Some intakes might be more vulnerable in winter levels as they are the seasonal low.	Same as in B.

Lake Erie Coping Zones (Water Levels) (from IUGLS, 2012)

			Month											
Interest	**Water Level (WL) Conditions**	**Zone**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Coastal	High WL	Zone C	174.57	174.63	174.84	174.97	174.95	174.97	174.93	174.84	174.75	174.75	174.78	174.83
		Zone B	174.45	174.47	174.59	174.70	174.70	174.73	174.70	174.65	174.56	174.46	174.40	174.43
	Acceptable WL	Zone A	174.45-173.74	174.47-173.69	174.59-173.74	174.70-173.88	174.70-173.99	174.73-174.05	174.70-174.04	174.65-173.99	174.56-173.90	174.46-173.82	174.40-173.71	174.43-173.74
	Low WL	Zone B	173.74	173.69	173.74	173.88	173.99	174.05	174.04	173.99	173.90	173.82	173.71	173.74
		Zone C	173.46	173.50	173.62	173.78	173.86	173.85	173.81	173.75	173.68	173.55	173.48	173.44
Recreational Boating	High WL	Zone C	Recreational Boating Off-Season			175.6	175.6	175.6	175.6	175.6	175.6	175.6	Recreational Boating Off-Season	
		Zone B				175.3	175.3	175.3	175.3	175.3	175.3	175.3		
	Acceptable WL	Zone A				175.3-173.8	175.3-173.8	175.3-173.8	175.3-173.8	175.3-173.8	175.3-173.8	175.3-173.8		
	Low WL	Zone B				173.8	173.8	173.8	173.8	173.8	173.8	173.8		
		Zone C				173.5	173.5	173.5	173.5	173.5	173.5	173.5		
Municipal and Industrial Water Users	High WL	Zone C	176.1	176.1	176.1	176.1	176.1	176.1	176.1	176.1	176.1	176.1	176.1	176.1
		Zone B	175.04	175.04	175.04	175.04	175.04	175.04	175.04	175.04	175.04	175.04	175.04	175.04
	Acceptable WL	Zone A	175.04-173.18	175.04-173.18	175.04-173.18	175.04-173.18	175.04-173.18	175.04-173.18	175.04-173.18	175.04-173.18	175.04-173.18	175.04-173.18	175.04-173.18	175.04-173.18
	Low WL	Zone B	173.18	173.18	173.18	173.18	173.18	173.18	173.18	173.18	173.18	173.18	173.18	173.18
		Zone C	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6	171.6
Commercial Navigation	High WL	Zone C	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3	175.3
		Zone B	175	175	175	175	175	175	175	175	175	175	175	175
	Acceptable WL	Zone A	175-173.5	175-173.5	175-173.5	175-173.5	175-173.5	175-173.5	175-173.5	175-173.5	175-173.5	175-173.5	175-173.5	175-173.5
	Low WL	Zone B	173.5	173.5	173.5	173.5	173.5	173.5	173.5	173.5	173.5	173.5	173.5	173.5
		Zone C	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9	172.9

Location: Lake Erie (from IUGLS, 2012)

Interest	Water Level Regime Characteristic	Zone A	Zone B	Zone C
Coastal	**Frequency of extremes**	On high end, can withstand this range with minimal damage, regardless of duration, except under extreme (> 10 year return period (10% exceedance) surge/storm event). On low end of Zone A, persistent conditions (multiple consecutive years) will be a problem for riparians.	Longer duration of Zone B high levels will increase potential for coincidence of large storm event. Persistence of two consecutive years (or more) with max levels within Zone B likely to be of concern to stakeholders and potential exists for damages ranging from moderate to substantial depending on storm events. On low end, two consecutive years (or more) will Zone B low levels will be of concern to stakeholders	One year with water levels exceeding high Zone C threshold is likely to cause moderate damages. Coincidence of a small to moderate storm event will increase damages considerably and an extreme event will cause substantial damages. On low end, conditions have not been experienced within historic record and are likely to be of concern, even for one year.
	Duration	On high end, can withstand this range with minimal damage, regardless of duration, except under extreme (>10 year return period (10% exceedance) surge/storm event). On low end of Zone A, persistent conditions (multiple consecutive years) will be a problem for riparians.	Longer duration of Zone B high levels will increase potential for coincidence of large storm event. Persistence of two consecutive years (or more) with max levels within Zone B likely to be of concern to stakeholders and potential exists for damages ranging from moderate to substantial depending on storm events. On low end, two consecutive years (or more) will Zone B low levels will be of concern to stakeholders	One year with water levels exceeding high Zone C threshold is likely to cause moderate damages. Coincidence of a small to moderate storm event will increase damages considerably and an extreme event will cause substantial damages. On low end, conditions have not been experienced within historic record and are likely to be of concern, even for one year.
	Rate of Change	Rapid rising to Max. or lowering to Min. levels will reduce time to adapt and will cause concern but severity of consequences will be minimal	Physical modifications (protection, dredging, etc.) are likely as adaptation to Zone B levels. Rapid rising to Max. or lowering to Min. levels within Zone B may eliminate ability to undertake necessary modifications.	Rapid rising above Max. Zone C threshold or lowering below Zone C threshold will lead to substantial damages
	Seasonality	Historically, Lake Erie levels peak in May-July period and reach minimum in November-February, on average. Peak return period surge events for Kingsville (further west) tend to be greatest in winter/spring and fall based on Baird (2010) analysis. Moving peak annual levels into the spring (April-May) or fall (Sept-Nov) would increase potential for event damages.		
Recreational Boating	**Frequency of extremes**	During 30 year snapshot of the boating season (April through November), 12% of months exceed Max. and 16% of months are less than Min.	0% of months exceed Max. and 0% of months are less than Min.	0% of months exceed Max. and 0% of months are less than Min.
	Duration	Can withstand this range with minimal damage	If prolonged: between zero and 30% of marinas go out of business, and slip loss between five and 30%	If prolonged: more than 30% of marinas go out of business, and slip loss greater than 30%
	Rate of Change	Quick drops or rises are generally considered a negative as interest may need to adapt (dock adjustments).	Quick drops or rises are generally considered a negative as interest does not have time to adjust.	The quicker Zone C is reached from Zone B, the greater the damage will be as there will be little time to prepare or react.
	Seasonality	Seiches (flooding and ice damage) are worse in the winter.	Seiches (flooding and ice damage) are worse in the off season	Same as B
Commercial Navigation	**Frequency of extremes**	Max - exceeded for 2 months in 1986; Min. - levels lower than Min. have generally occurred only once in past six decades.	Levels have been within this range since 1918	Levels have been within this range since 1918
	Duration		Shippers are typically able to cope via light loading, however, extended periods (2-3 yrs) increase likelihood of end users considering a shift in modes of transportation	
	Rate of Change	Stable levels are preferred over rapidly varying levels	Stable levels are preferred over rapidly varying levels	Stable levels are preferred over rapidly varying levels
	Seasonality	For min: Apr to Oct. for first level; Nov. & Dec. for second level	For min: Apr to Oct. for first level; Nov. & Dec. for second level	For min: Apr to Oct. for first level; Nov. & Dec. for second level

Interest	Water Level Regime Characteristic	Zone A	Zone B	Zone C
Municipal and Industrial Water Uses	**Frequency of extremes**	Max. is record high; Min. is historic low.	Levels are outside historic range. Based in part on where operational problems occur.	Levels are outside historical record. Based on reported levels where operations cease.
	Duration	Can withstand this range with minimal problems	Short term duration can be tolerated; levels for weeks or months are expect to cause operational issues.	Short term duration (12 to 24 hours) can be tolerated; levels for days or months will cause operational issues in some facilities, require capital changes or shut down facilities. This is the elevation where operations begin to cease.
	Rate of Change	A quick rate of change within A can be tolerated.	A quick rate of change from A to B can be tolerated. May require some operational changes if levels remain	The quicker Zone C is reached from Zone B, the greater the chance for disruption in water supply.
	Seasonality	Timing of seasonal peaks are not an issue.	Winter temperatures around freezing might cause frazzle ice in some intakes. Some intakes might be more vulnerable in winter levels as they are the seasonal low.	Same as B

Location: St. Marys River: Hydropower Coping Zones (from IUGLS, 2012)

Hydropower coping zones table for the Cloverland Plant in the St. Marys River. Levels in metres (IGLD 1985), flows in m^3/s (Rose and Yee, 2011)

Zone	L Superior Outflows	L Superior Levels	Others, m^3/s	Cloverland capacity 850	US Plant capacity 405	Brookfield capacity 1140	Comments
A ideal	2374	183.45	94	**735**	405	1140	Equal share of available hydro water without spills.
A ideal	2374	183.45	94	**850**	290	1140	Equal share of available hydro water without spills.
A	2036~2409	183.26~183.47	94	**566~770**	405	971~1140	Adequate water for peaking operations (Cloverland IS curve).
A/B	Below 1236	182.74	94	**311**	260	571	Limited to winter. Cloverland and US Plant minimum for ice management and heating. US Plant lockage needs 40 m^3/s.
B	Below 716	182.34	94	**311 minimum**	0	311	Limited to winter. Assuming US Plant not requiring water for ice management, lockage and heating.
B		184.25					Overtopping bulkheads causing water onto generator floor.
B		**Max Tailrace 177.77 m at U.S. Slip**					Maintain level below the top of tailrace tunnel to avoid water in generator pits.
High B	Below 1526	182.94	94	**311 minimum**	405	716	Limited to winter. 311 m^3/s minimum for ice management and heating.
B/low C	Above 1084	182.63	94	**90 minimum**	405	495	90 m^3/s minimum for energy market.
B/low C		**Min Tailrace 175.96 m at US Slip**					To prevent cavitation damage causing loss of generation.
C	Below 904	182.51	94	**0**	405	405	Cloverland Zone C situation due to zero water allocation.

Ecological Performance Indicators for Lake Superior and Lake Michigan-Huron

Summary table of the eight primary IUGLS ecological performance indicators (taken directly from IUGLS, 2012, pg. 70)

PI Code	Zone C Condition	Performance Indicators	Goal is to Avoid Zone C
SUP-01	SUP-01 measures the degree to which natural **peak water level** events on Lake Superior, which occur roughly on a 30-year cycle, are lowered by regulation		Prevent/minimize range compression for Lake Superior
SUP-02	SUP-02 measures the degree to which there is a **drawdown** of Lake Superior following a peak water level 'event'. SUP-01 and SUP-02 scores closer to pre-project (and larger than 1977A) are better		Prevent/minimize range compression for Lake Superior
SUP-04	Peak summertime water level rises above 184.0 m (603.7 ft) for **three or more** consecutive years	Wild rice abundance in Kakagon Slough, near Duluth, MN	Maintain viability of wild rice population
SUP-05	Mean spring (Apr-May) water level is more than 0.67 m (2.2 ft) below the mean level for the preceding 10-year period for **seven or more** consecutive years	Northern pike habitat and population in Black Bay on the north shore of Lake Superior	Prevent significant decline in northern pike abundance
SMQ-01	Mean flow rate during June maintained below 1,700 m3/s (60,035.5 ft3/s) for **five or more** consecutive years	Lake sturgeon spawning habitat	Provide suitable spawning area for lake sturgeon
SMQ-02	Mean flow rate during May-June maintained below 2,000 m3/s (70,600 ft3/s) for **seven or more** consecutive years	Maintenance of flushing flows in the channel into Lake George (A small lake near Sault Ste. Marie, ON)	Maintain substrate in Lake George channel
LMH-07	Mean growing season (Apr-Oct) water level is less than 176.00 m (577.4 ft) for a period of **four or more consecutive years**	Fish and wildlife community eastern Georgian Bay wetlands	Maintain fish access to eastern Georgian Bay wetlands (current conditions)
LMH-08	Mean growing season (Apr-Oct) water level is less than 176.12 m (577.8 ft) for a period of **four or more consecutive years**	Fish and wildlife community eastern Georgian Bay wetlands	Maintain fish access to eastern Georgian Bay wetlands (+100 yr conditions)

Appendix 2: List of Acronyms

AO – Arctic Oscillation

CGIP - Chippewa–Grass Island Pool

CWS – Canadian Wildlife Service

ECCC - Environment and Climate Change Canada

ENSO – El Niño-Southern Oscillation

FEPS - Flood and Erosion Prediction System

GLAM – Great Lakes – St. Lawrence River Adaptive Management

GLERL – Great Lakes Environmental Research Laboratory

IERM – Integrated Ecological Response Model

IGLD – International Great Lakes Datum

IJC – International Joint Commission

ILOSLRB – International Lake Ontario-St. Lawrence River Board

ILSBC - International Lake Superior Board of Control

IMPLAN - Impact Analysis and Planning model

INBC – International Niagara Board of Control

IWI - International Watersheds Initiative

IUGLS – International Upper Great Lakes Study

LOSLRS – Lake Ontario - St. Lawrence River Study

NAO – North Atlantic Oscillation

NASH – North Atlantic subtropical high

NMME – North American Multi-Model Ensemble

NOAA – National Oceanic and Atmospheric Administration

NYDEC - New York Department of Environmental Conservation

NYPA – New York Power Authority

NBS – Net Basin Supply

NTS – Net Total Supplies

OPG – Ontario Power Generation

PI – Performance Indicators

PNA – Pacific/North American pattern

SWE – Snow Water Equivalent

USACE – United States Army Corps of Engineers

USEPA – United States Environmental Protection Agency

USGS – United States Geological Survey

Appendix 3: Glossary of Terms

ADAPTIVE MANAGEMENT – A planning process that can provide a structured, iterative approach for improving actions through long-term monitoring, modeling and assessment. Through adaptive management, decisions can be reviewed, adjusted and revised as new information and knowledge becomes available or as conditions change.

ARTIC OSCILLATION (AO) – A pattern in which atmospheric pressure at polar and middle latitudes fluctuates between negative and positive phases. The North Atlantic Oscillation is often considered to be a regional manifestation of the AO.

AUTHORITY – The right to enforce laws and regulations or to create policy.

AVERAGE WATER LEVEL – The arithmetic average of all past observations (of water levels or flows) for that month. The period of record used in this Study commences January 1900. This term is used interchangeable with monthly-mean water level.

BASIN; WATERSHED – The region or area of which the surface waters and groundwater ultimately drain into a particular course or body of water.

BASIN (GREAT LAKES – ST. LAWRENCE RIVER) – The surface area contributing runoff to the Great Lakes and the St. Lawrence River downstream to Trois Rivières, QC.

BARRIER BEACH – An offshore ridge of unconsolidated material (sand, pebbles, etc.) that runs parallel to a coastline, is formed in part by high tides and acts as a natural barrier.

BLUFF – A steep bank or cliff or variable heights, composed of glacial tills and lacustrine deposits consisting of clay, silt, gravel and boulders.

***BOUNDARY WATERS TREATY OF 1909* –** The agreement between the United States and Canada that established principles and mechanisms for the resolution of disputes related to boundary waters shared by the two countries. The International Joint Commission was created as a result of this treaty.

CHART DATUM – The water level used to calculate the water depths that are shown on “navigation charts” and are a reference point for harbor and channel dredging. Also known as Low Water Datum.

CLIMATE – The prevalent weather conditions of a given region (temperature, precipitation, wind speed, atmospheric pressure, etc.) observed throughout the year and averaged over at least 30 years.

CLIMATE CHANGE – A non-random change of climate that is attributed directly or indirectly to human activity, that alters the composition of the global atmosphere, and which is in addition to natural climate variability observed over comparable time periods.

COAST – The land or zone adjoining a large body of water.

COASTAL EROSION – The wearing away of a shoreline as a result of the action of water current, wind and waves.

COMPENSATING WORKS – A set of gated dams located at the mouth of the St Marys rapids, which are part of a series of regulatory structures on the St. Marys River used in the management of the outflow of water from Lake Superior. The works consists of 16 gates, half of which are on the American side, and the other half on the Canadian side of the river.

COMPUTER MODELLING – The use of computers to develop mathematical models of complex systems or processes.

CONNECTING CHANNELS – A natural or artificial waterway of perceptible extent, which either periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. On the Great Lakes, the Detroit River, Lake St. Clair and the St. Clair River comprise the connecting channel between Lake Huron and Lake Erie. Between Lake Superior and Lake Huron, the connecting channel is the St. Marys River.

CONSERVATION AUTHORITY - Local watershed management agencies that deliver services and programs to protect and manage impacts on water and other natural resources in partnership with all levels of government, landowners and many other organizations.

CONSERVATION ONTARIO - Conservation Ontario is the umbrella organization which represents all of the conservation authorities in Ontario. This nonprofit organization was founded in 1980/81. Conservation Ontario is the network of 36 Conservation Authorities

COPING ZONE – A range of water level zones defined generally by the water level regime (level, range, rate of change, frequency), location and other factors that cause vulnerabilities for a particular interest and reflect an interest’s ability to “cope” with a given water level regime.

DEVIATIONS – Temporary changes to a regulation plan to provide beneficial effects or relief from adverse effects to an interest, without causing appreciable adverse effects to any of the other interests.

DIRECTIVE – An IJC instruction to a new or existing Board or Committee specifying their terms of reference, including tasks and responsibilities.

DRAINAGE BASIN – The area that contributes runoff to a stream, river, or lake.

DUNE – A mound or ridge of sand or other loose sediment formed by the action of wind or waves

DYKE – A wall or earth mound built around a low lying area to prevent flooding.

ECOHYDRAULIC – Models that integrate the physics and biotic response through algorithms relating water levels and other climate drivers to flora and faunal responses.

ECOSYSTEM – A biological community in interaction with its physical environment, and including the transfer and circulation of matter and energy.

EL NINO-SOUTHERN OSCILLATION (ENSO) - An irregularly periodic variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting climate of much of the tropics and subtropics.

ENVIRONMENT – Air, land or water; plant and animal life including humans; and the social, economic, cultural, physical, biological and other conditions that may act on an organism or community to influence its development or existence.

EROSION – The wearing away of land surfaces through the action of rainfall, running water, wind, waves and water current. Erosion results naturally from weather or runoff, but human activity such as the clearing of land for farming, logging, construction or road building can intensify the process.

FLOOD AND EROSION PROTECTION SYSTEM (FEPS) – A series of numerical models including COSMOS that compile and evaluate shoreline data to compute flood and erosion damages.

FLOODING – The inundation of low-lying areas by water.

FLOODPLAIN – The lowlands surrounding a watercourse (river or stream) or a standing body of water (lake), which are subject to flooding.

FRAZIL ICE – Stream ice with the consistency of slush, formed when small ice crystals develop in supercooled stream water as air temperatures drop below freezing. These ice crystals join and are pressed together by newer crystals as they form.

FRESHET – The sudden overflow or rise in level of a stream as a result of heavy rains or snowmelt.

GEOMORPHOLOGY – The field of earth science that studies the origin and distribution of landforms, with special emphasis on the nature of erosional processes.

GROUNDWATER – Underground water occurring in soils and in pervious rocks.

HABITAT – The particular environment or place where a plant or an animal naturally lives and grows.

HAZARD ZONES – An area of land that is susceptible to flooding, erosion, or wave impact.

HYDRAULICS – The study of the mechanical properties of liquids, including energy transmission and effects of the flow of water.

HYDRAULIC MODELING – The use of mathematical or physical techniques to simulate water systems and make projections relating to water levels, flows and velocities.

HYDROCLIMATE – The study of the influence of climate upon the waters of the land including the energy and moisture exchanges between the atmosphere and the Earth’s surface and energy and moisture transport by the atmosphere.

HYDROELECTRIC POWER – Electrical energy produced by the action of moving water.

HYDROLOGIC ATTRIBUTES – Statistics on water levels and stream flows.

HYDROLOGIC CYCLE – The natural circulation of water, from the evaporation of seawater into the atmosphere, the transfer of water to the air from plants (transpiration), precipitation in the form of rain or snow, and runoff and storage in rivers, lakes and oceans.

HYDROLOGIC MODELING – The use of physical or mathematical techniques to simulate the hydrologic cycle and its effects on a watershed.

HYDROLOGY – The study of the properties of water, its distribution and circulation on and below the earth's surface and in the atmosphere.

ICE JAM – An accumulation of river ice, in any form which obstructs the normal river flow.

INTEGRATED ECOLOGICAL RESPONSE MODEL (IERM) – Establishes the framework for evaluating, comparing, and integrating the responses for the environmental performance indicators.

INTERESTS – In the context of the report, the groups or sectors served by the waters of Lake Ontario and the St. Lawrence River, including municipal and industrial water uses, commercial navigation, hydroelectric power generation, coastal development, ecosystems, and recreational boating. Under the Boundary Waters Treaty of 1909, the interests of domestic and sanitary water uses, navigation and hydroelectric generation and irrigation are given order of precedence in water uses in the development of regulation plans.

INTERNATIONAL GREAT LAKES DATUM (IGLD) – The elevation reference system used to define water levels within the Great Lakes-St. Lawrence River system. Due to the movement of the earth’s crust, the “datum” must be adjusted every 30-40 years.

INTERNATIONAL JOINT COMMISSION (IJC) – International independent agency formed in 1909 by the United States and Canada under the *Boundary Waters Treaty* to prevent and resolve boundary waters disputes between the two countries. The IJC makes decisions on applications for projects such as dams in boundary waters, issues Orders of Approval and regulates the operations of many of those projects. It also has a permanent reference under the Great Lakes Water Quality Agreement to help the two national governments restore and maintain the chemical, physical, and biological integrity of those waters.

INTERNATIONAL REACH – The portion of the St. Lawrence River that is between Lake Ontario and the Moses-Saunders Dam.

INTERNATIONAL LAKE ONTARIO - ST. LAWRENCE RIVER BOARD – Board established by the International Joint Commission originally in its 1952 Order of Approval and renamed from the St. Lawrence River Board of Control in 2017 with the implementation of Plan 2014 and the revised Order of Approval. Its main duty is to ensure that outflows from Lake Ontario meet the requirements of the Commission’s Order.

LAKE ONTARIO - ST. LAWRENCE RIVER STUDY (LOSLRS) – A study, sponsored by the IJC and completed in 2006, to examine the effects of water level and flow variations on all users and interest groups and to determine if better regulation is possible at the existing installations controlling Lake Ontario outflows.

LA NINA - The positive phase of the El Niño Southern Oscillation and is associated with cooler-than-average sea surface temperatures in the central and eastern tropical Pacific Ocean

LIDAR – which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.

LIGHT LOAD – A load less than the ship capacity, required when a fully loaded ship would be too close to the channel bottom because of low water levels.

LOWER ST. LAWRENCE RIVER – The portion of the St. Lawrence River downstream of the Moses-Saunders Dam is called the lower St. Lawrence. It includes Lake St. Francis, Lake Saint-Louis, Montreal Harbour, Lake Saint-Pierre and the portions of the River connecting these lakes as far downstream as Trois-Rivieres, QC.

MARINA – A private or publicly-owned facility allowing recreational watercraft access to water and offering mooring and related services.

MARSH – An area of low, wet land, characterized by shallow, stagnant water and plant life dominated by grasses and cattails.

MEASURE, STRUCTURAL – Any measure that requires some form of construction. Commonly includes control works and shore protection devices.

MODEL, COMPUTER – A series of equations and mathematical terms based on physical laws and statistical theories that simulate natural processes.

MONTHLY MEAN WATER LEVEL – The arithmetic average of all past observations (of water levels or flows) for that month.

NET BASIN SUPPLY (NBS) – The net amount of water entering one of the Great Lakes, comprised as the precipitation onto the lake minus evaporation from the lake, plus groundwater and runoff from its local basin. The net basin supply does not include inflow from another Great Lake.

NET TOTAL SUPPLY (NTS) – The Net Basin Supply plus the inflow from another Great Lake

NORTH ATLANTIC OSCILLATION (NAO) - A weather phenomenon in the North Atlantic Ocean of fluctuations in the difference of atmospheric pressure at sea level between the Icelandic low and the Azores high (also known as the North Atlantic subtropical high). The NAO controls the strength and direction of westerly winds and location of storm tracks across the North Atlantic and varies over time with no particular periodicity.

NORTH ATLANTIC SUBTROPICAL HIGH (NASH) – Also known at the "Azores High" is a large subtropical semi-permanent centre of high atmospheric pressure typically found south of the Azores in the Atlantic Ocean, situated around the latitudes of 30°N. It forms one pole of the

North Atlantic oscillation, the other being the Icelandic Low. The system influences the weather and climatic patterns of vast areas of North Africa and southern Europe, and to a lesser extent, eastern North America.

OBLIQUE IMAGERY - aerial photography that is captured at approximately a 45 degree angle with the ground.

ORDERS OF APPROVAL – In ruling upon applications for approval of projects affecting boundary or transboundary waters, such as dams and hydroelectric power stations, the IJC can regulate the terms and conditions of such projects through Orders of Approval to maintain specific targets with respect to water levels and flows in the lakes and connecting channels.

PACIFIC/NORTH AMERICAN (PNA) PATTERN - A climatological term for a large-scale weather pattern with two modes, denoted positive and negative, and which relates the atmospheric circulation pattern over the North Pacific Ocean with the one over the North American continent.

PEAKING – The variation of hourly water flows above and below the daily average flow (for instance, midday flow higher than evening and night flows), primarily due to hydroelectric generating operations during which water is stocked during periods of off-peak demand in order to increase hydroelectric power generation at peak periods.

PERFORMANCE INDICATOR – A measure of economic, social or environmental health. In the context of the Study, performance indicators relate to impacts of different water levels in Lake Ontario and the St. Lawrence River.

PLAN FORMULATION METHOD – A particular way of searching for a better regulation plan; mathematical optimization based on economic benefits, for example.

PONDING – The variation of daily water flows above and below the weekly average flow (for instance, average weekday flow higher than average weekend flow), primarily due to hydroelectric generating operations.

PUBLIC INTEREST ADVISORY GROUP (PIAG) – The group of volunteers from the United States and Canada that worked to ensure effective communication between the public and the 2006 International Lake Ontario-St. Lawrence River Study Board.

REFERENCE – A request from government for the IJC to study and recommend solutions to transboundary issue. The word is derived from Article IX of 1909 *Boundary Waters Treaty*, which stipulates that such issues "shall be referred from time to time to the International Joint Commission for examination and report, whenever either the Government of the United States or the Government of the Dominion of Canada shall request that such questions or matters of difference be so referred."

REGULATION PLANS – In the context of the report, the control of waterflows through regulatory structures to meet the needs of various water-using interests in a basin. These plans have incorporated the specific objectives established in the IJC's Orders of Approval, established monthly or weekly outflow levels, and allocated flows to various water-using interests, such as hydroelectric generation.

REGULATORY STRUCTURES – Adjustable structures, such as a gated dam that can be raised or lowered to adjust water levels and flows both upstream and downstream.

REVETMENT – A natural (e.g., grass, aquatic plants) or artificial (*e.g.*, concrete, stone, asphalt, earth, sand bag) covering to protect an embankment or other structure from erosion.

RIPARIAN – Of, relating to or found along a shoreline.

RIPARIANS – Persons residing on the banks of a body of water. Typically associated with private owners of shoreline property.

RUNOFF – The portion of precipitation on the land that ultimately reaches streams and lakes.

SHORE WELL – A well close to a lake in which the well water levels are directly influenced by lake levels.

SHORELINE – Intersection of a specified plane of water with the shore.

SIDE CHANNEL FLOW - Considered the sum of hydropower, navigation, municipal and industrial and all other flow that does not go through the Compensating Works on the St. Marys River.

SNOW WATER EQUIVALENT (SWE) - Is the amount of water contained within the snowpack. It can be thought of as the depth of water that would theoretically result if you melted the entire snowpack instantaneously.

STAKEHOLDER – An individual, group, or institution with an interest or concern, either economic, societal or environmental, that is affected by fluctuating water levels or by measures proposed to respond to fluctuating water levels within the Lake Ontario–St. Lawrence River Basin.

STOCHASTIC SUPPLIES – Statistically generated simulated sequences of water supply conditions based on historical climate variability.

TROPOPAUSE - The tropopause is the transitional area between the troposphere (the lowest atmospheric layer) and the stratosphere (the second layer of the earth's atmosphere) and is about 6 to 11 miles above the surface of the earth, just below the start of the stratosphere.

UPPER ST. LAWRENCE RIVER – The portion of the St. Lawrence River upstream of the Moses-Saunders Dam is called the upper St. Lawrence River. It includes the entire river from Kingston/Cape Vincent to the power dam and locks at Cornwall-Massena, including Lake St. Lawrence.

WATER LEVEL – The elevation of the surface of the water of a lake or at a particular site on the river. The elevation is measured with respect to average sea level.

WATER SUPPLY – Water reaching the Great Lakes as a direct result of precipitation, less evaporation from land and lake surfaces.

WATERFOWL – Birds that are ecologically dependent on wetlands for their food, shelter and reproduction.

WAVE – An oscillatory movement in a body of water which results in an alternate rise and fall of the surfaces.

WAVE CREST – The highest part of a wave.

WETLANDS – An area characterized by wet soil and high biologically productivity, providing an important habitat for waterfowl, amphibians, reptiles and mammals.

WILLINGNESS TO PAY (WTP) – The maximum amount that a consumer will pay for a given item or service.