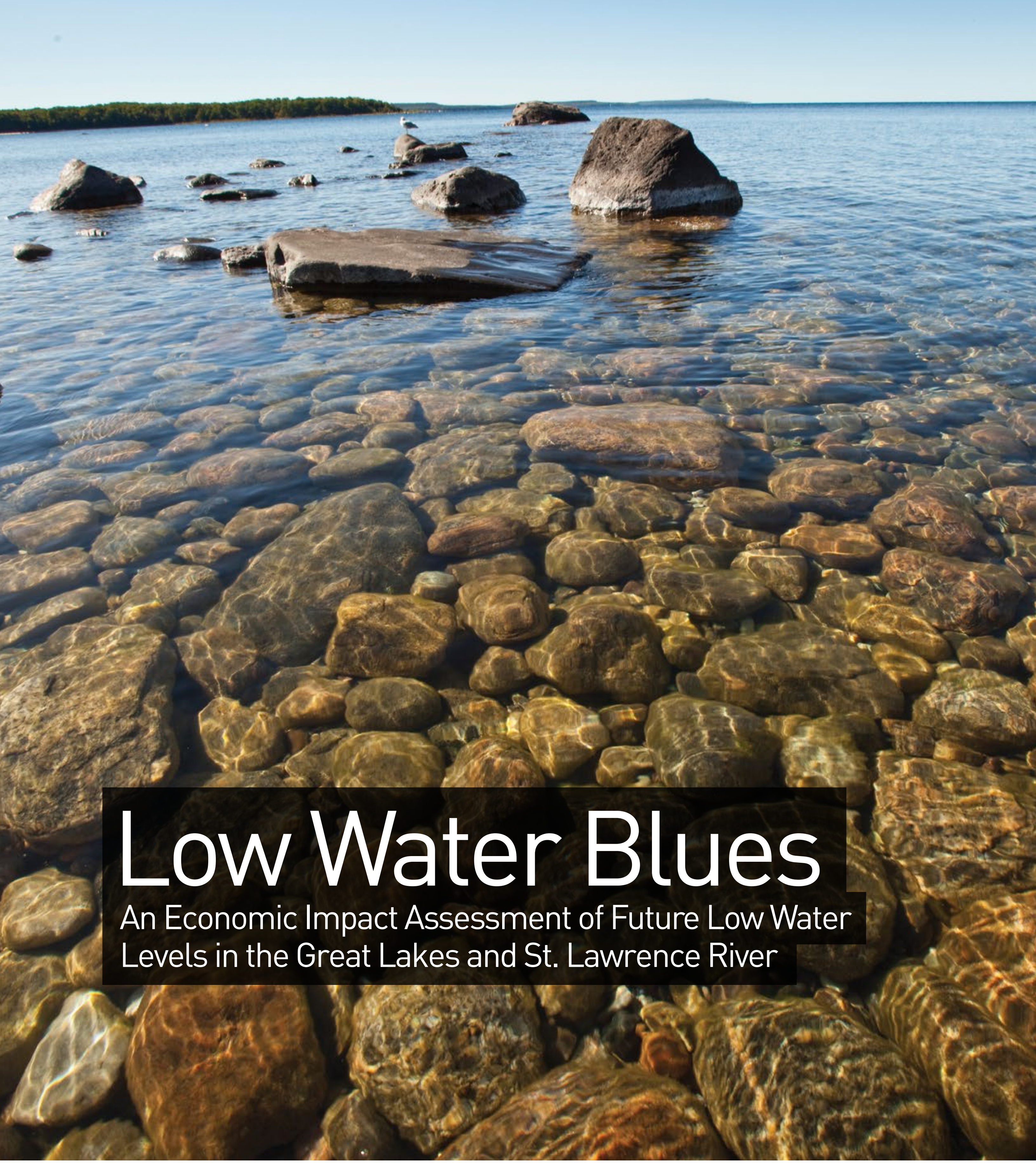

Low Water Blues

An Economic Impact Assessment of Future Low Water Levels in the Great Lakes and St. Lawrence River

CGLR
COUNCIL OF THE GREAT LAKES REGION

Mowat Centre
ONTARIO'S VOICE ON PUBLIC POLICY

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The authors would like to emphasize that the authors are solely responsible for the content of this report. An individual's or organization's Involvement in this project as a steering committee member, reviewer, consultant, or interviewee should not be taken as a sign of endorsement of the report's findings or of agreement with its conclusions.

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Executive Summary

Following nearly three decades of higher than historic average water levels throughout the Great Lakes and St. Lawrence (GLSL) basin, water levels fell dramatically across the region in 1997-8. During the period between 1997-8 and 2012-3, for example, water levels in Lakes Superior and Michigan-Huron were substantially below historic averages. In January 2013, Lake Michigan-Huron reached its lowest levels since the United States and Canada began coordinated measuring and tracking of water levels in 1918.

Though less dramatic, lower water levels were also experienced in the rest of the basin over the same period. Water levels in the St. Lawrence River were below historic averages for 78 per cent of the total months between 1998 and 2012. Water levels in Lake Erie dropped below historic averages between 1998 and 2004, and since then have remained around historic averages, markedly below the preceding higher water period. Even the closely regulated Lake Ontario saw some of its lowest levels since regulation began in the 1960s during this period.

Water levels have rebounded to some degree throughout the region since 2013, aided in large part by the extensive lake ice coverage and snowfall and cooler temperatures this past winter across the basin. But it is unclear whether or not this rebound will constitute an end of the low water trend, or if it represents an outlier event, as recently suggested by National Oceanic and Atmospheric Administration's (NOAA) Great Lakes Environmental Research Laboratory.

The continued health of the basin is crucial to the people of North America. The Great Lakes themselves contain about 20 per cent of the world's surface freshwater supply, providing drinking water to some 40 million households. More than 3,500 species of plants and animals inhabit the basin, making it a unique and diverse ecosystem.

The basin's ecosystem is obviously important to the entire continent, but the economic footprint of the region is also immense, with economic output of USD $4.9 trillion, accounting for 28 per cent of combined Canadian and US economic activity. Simply put, the lakes and their waterways bind together a complex economic, social and environmental system. We know, for example, that a prolonged and sustained decline in water levels would have significant impacts on the region's ecosystem. But what would the economic impact of low water levels be?

There is much debate in the scientific community about the causes of prolonged water levels decline and there is no consensus about the basin's likely near-term and medium-term water levels future. Our study recognizes this scientific uncertainty, and does not weigh in on these questions.

However, according to the Great Lakes Integrated Science and Assessment Centre, a consortium between Michigan State University and the University of Michigan, "most climate models project that evaporation from the Great Lakes will outpace increases in precipitation," and that "with more water leaving the basin than there is returning, the result could be less water remaining in the Great Lakes."

Using a plausible and realistic worst-case future water levels scenario that projects water levels mostly at the low end of the historic range, we quantify the likely economic impact for the region's key economic sectors. Our analysis suggests the economic impacts attributable to low water levels will be significant.

Our approach to economic analysis in this report is methodologically cautious, recognizing that data is unavailable in some sectors. However, given the variability and complexity of the basin, and given the data available and the uncertainty surrounding the state of hydro-climatic modelling, it is likely that our results underestimate the impacts of low water levels.

For instance, our study did not look at indirect impacts, nor could we include an economic analysis of how low water levels will impact manufacturing, commercial fishing, human health, ecological services, and other non-market goods, due to methodological reasons.

Nevertheless, the estimated direct economic impact of low water levels in the future in selected sectors is sobering: $9.61B over the period from the present through 2030 and $18.82B over the period from the present through 2050.[1] The sectors that would be most affected include:

» **Recreational boating and fishing**
$6.65B total through 2030 and $12.86B total through 2050.

» **Commercial shipping and harbours**
$1.18B total through 2030 and $1.92B total through 2050.

---

[1] All impact values expressed in USD 2012.

» **Hydroelectric generation**
$951M total through 2030 and $2.93B total through 2050.

» **Residential waterfront property values in Ontario municipalities adjacent to GLSL shores**
$794M total through 2030 and $976M total through 2050.

» **Rural groundwater users**
$28M total through 2030 and $35M total through 2050.

Although many of these impacts would be felt across the basin, different parts of the region would experience impacts in varying degrees in line with historical experience to date, depending on factors such as local climate and water conditions and the local economic mix. Towns, cities, and regions that rely more heavily on the shipping industry, on recreational boating and fishing activities or seasonal cottagers, and on hydroelectric generation, are the most vulnerable. For example:

» Jurisdictions relying on hydroelectric generation from the Niagara River, the Welland Canal, and Lake Ontario shores could face $951M through 2030 and $2.83B through 2050 in costs to replace lost hydroelectric production.

» Residential property owners in Ontario municipalities adjacent to the shores of Lake Huron could see property value losses of $403M through 2030 and $612M through 2050; those on the Ontario shores of Lake Erie could see losses of $340M through 2030.

» Lake Erie harbours could see $292M in added dredging and maintenance costs through 2030; Lake Michigan harbours could see $142M in similar added costs through 2030.

» Lake Huron marinas could experience $230M through 2030 and $690M through 2050, and Lake Michigan marinas could experience $180M through 2030 and $460M through 2050, in added dredging and maintenance costs.

» Iron ore shippers and producers, who have a strong presence around Lake Superior, could face losses to shipping capacity estimated at $220M through 2030 and $465M through 2050.

» Coal shippers and producers in the region could face losses to shipping capacity estimated at $190M through 2030 and $373M through 2050.

The prediction of water levels is inherently difficult, and the estimation of economic impacts necessarily contains assumptions and uncertainties. Nevertheless, policy makers, experts and stakeholders have begun weighing the potential policy and engineering responses to water levels fluctuations. The International Joint Commission (IJC) has already carried out significant work on this front, and we rely on the Commission's work in our report.

We hope our report will serve as a foundation for dialogue and future work on possible responses to fluctuating water levels. Given the high stakes to the regional economy and to many local economies, decision-makers, business leaders and residents of the basin need the best available guidance on the risks associated with different water futures so they can make prudent decisions about adapting to and/or mitigating the impacts of variable fluctuations in water levels.

Areas for Future Action

» Better scientific data collection and improved accessibility to this data.

» Significant investment in new equipment and technology to provide more extensive and sensitive monitoring of climate factors affecting GLSL water levels.

» Enhanced partnership, collaboration, and exchange between government, the scientific community, and the private sector in driving required data collection and monitoring as well as coordinated solutions.

» Deepening the GLSL's stock of economic impact data through new research that assesses impacts based on recent projections and especially of a realistic worst-case high water levels scenario, and through research into additional key sectors such as manufacturing or commercial fishing.

» Continued consultation and planning on the part of decision-makers that takes account of future water levels uncertainty by planning for increased adjustability and for worst-case scenarios.

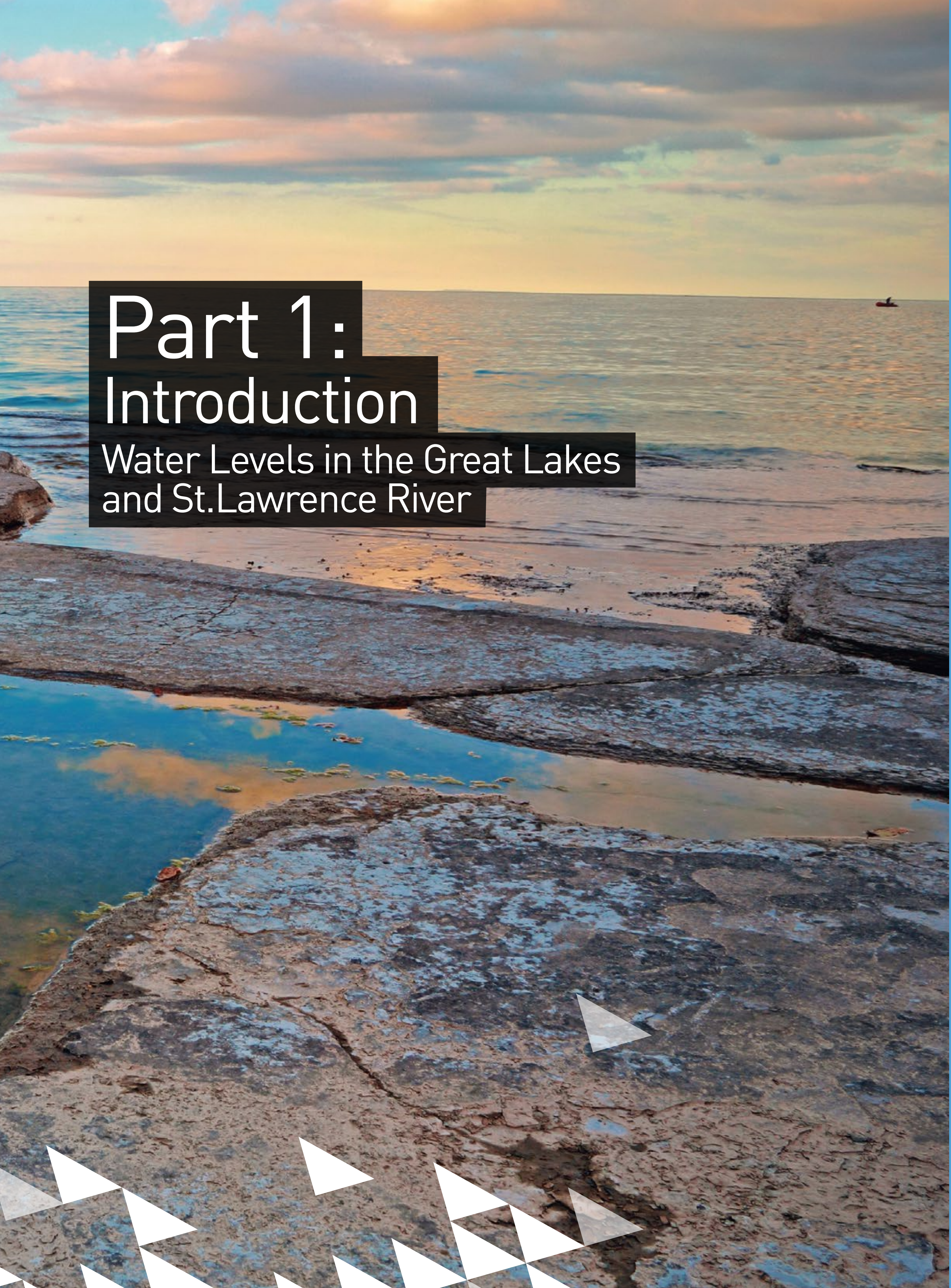
» Further analysis of potential responses to water levels fluctuations, and especially an analysis of the costs and benefits of different options for action.

» Private sector participation and leadership in robust contingency planning and in the implementation of adaptive behaviours in the various potentially affected sectors.

Part 1:

Introduction

Water Levels in the Great Lakes and St.Lawrence River



Recent Water Levels and the Challenge for Governments

In January 2013, Lake Michigan-Huron recorded its lowest mean monthly level in the official period of record (hydraulically and hydrologically, Lakes Michigan and Huron are one lake). This was the most dramatic instance in a 14-year period, since March 1999, in which the lake's mean monthly levels have been below long-term monthly means. This period represents Lake Michigan-Huron's longest stretch of consecutive months below long-term monthly means in the period of record (see Figure 1).

The 1997-1998 drop, which followed three decades of high water levels throughout the Great Lakes and St. Lawrence River (GLSL), was evidenced across the basin, albeit in varying degrees. Lake Superior mean monthly levels were below long-term monthly means from August 1998 and until March 2014, save for a brief period of fluctuations within 0.39 inches (1 cm) above and below long-term monthly means between November 2004 and April 2005. These have been the longest stretches of consecutive months below long-term monthly means in the period of record in Lake Superior as well (see Figure 2).

Lake Erie mean monthly levels dropped below long-term monthly means in May 1999, and remained so until May 2004, with the exception of one month (May 2002). Lake Erie has fluctuated below and above long-term monthly means since May 2004, with 59 mean monthly levels below long-term monthly means and 55 mean monthly levels above long-term monthly means.

During this period, Lake Erie mean monthly levels have not been above long-term monthly means for longer than 12 consecutive months, but have been below long-term monthly means for longer than 12 consecutive months on two occasions (January 2010 through April 2011 and May 2012 through June 2013). Winter 2012-2013 water levels were among Lake Erie's lowest since the winter of 1966-1967 (The lowest winter on Lake Erie in the 1999-2013 period was actually that of 2002-2003), though far higher than many winter water levels recorded pre-1967 (see Figure 3).

How are water levels measured and recorded in the Great Lakes-St. Lawrence basin?

While water levels in the GLSL basin have been measured and recorded since 1860, officially coordinated monthly lake-wide mean water level data has only been compiled since 1918, known as the official period of record for the GLSL.[2]

The official holders of mean monthly water levels data are the United States Army Corps of Engineers (USACE) and Environment Canada (EC), both working under the auspices of the Coordinating Committee on Basic Great Lakes Hydraulic and Hydrologic Data. They compile this data from verified daily mean water levels collected from a number of gauges operated by the United States National Oceanic and Atmospheric Administration (NOAA) and the Canadian Hydrographic Service.

These measurements are averaged out to produce a mean monthly level for each lake. Mean monthly levels for each calendar month since 1918 are in turn averaged out to produce a long-term monthly mean for that calendar month in each lake. The mean monthly levels for all months are also averaged out to produce annual means, as well as an overall historic mean for that lake. Notably, since long-term monthly means are recalibrated regularly to incorporate the months of each new year, past mean monthly observations close to the long-term monthly mean may oscillate between being above and below the long-term monthly mean as that mean is updated.

Using long-term monthly means as a benchmark to determine whether particular water levels observations are high or low has the advantage of accounting for seasonal fluctuations in water levels. However, because of the uncertainty inherent in projecting future GLSL water levels, such projections are typically expressed in annual means. For this reason, in this report we use long-term monthly means in our account of recent water levels trends in their historical context, and annual means when using or analyzing future water levels projections.

Water levels data for the Great Lakes is publicly available from NOAA through its Great Lakes Water Levels Dashboard (GLWLD) project at http://www.glerl.noaa.gov/data/now/wlevels/dbd/. Unless otherwise noted, the analysis of water level trends in this report draws on this data, extending to March 2014. As the GLWLD does not include water levels data for the St. Lawrence River, such data was obtained by the researchers from EC, extending to December 2012.

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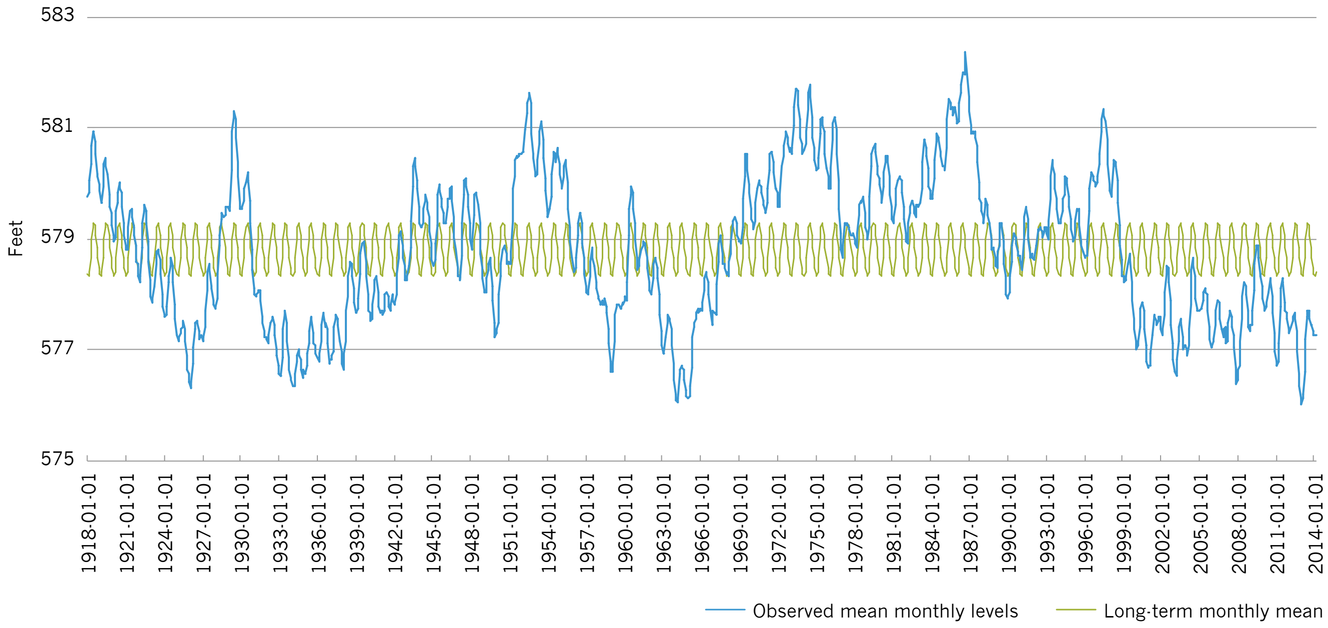
[2] IUGLS, 2009: 2.

FIGURE 1

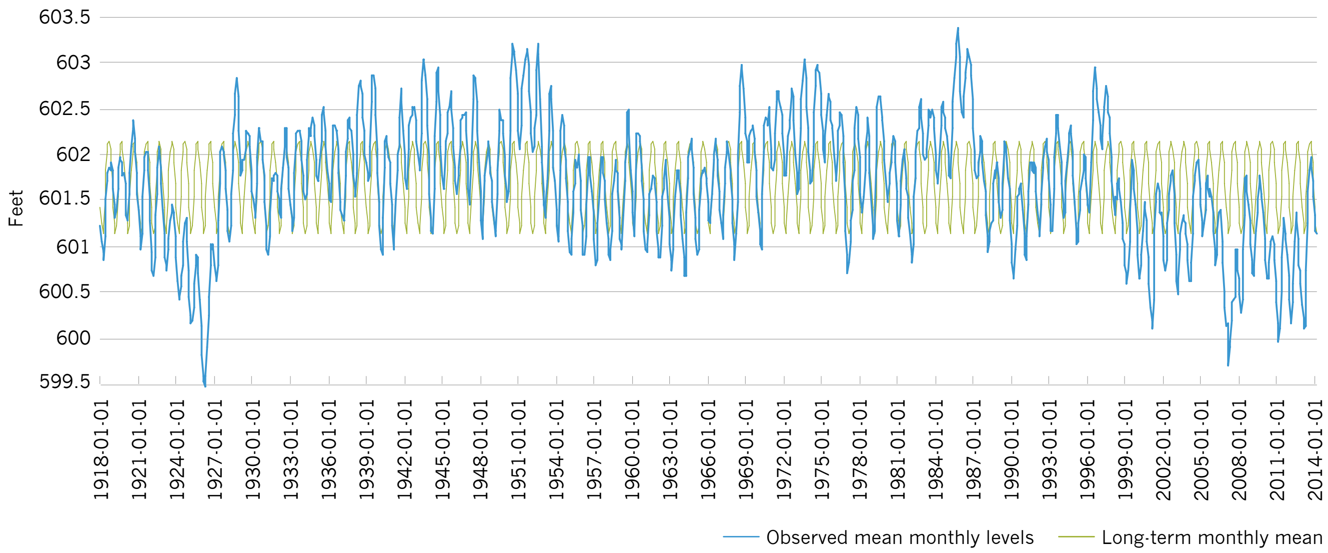
Lake Michigan-Huron mean monthly levels and long-term monthly means in the official period of record



Source: Data downloaded from GLWLD

FIGURE 2

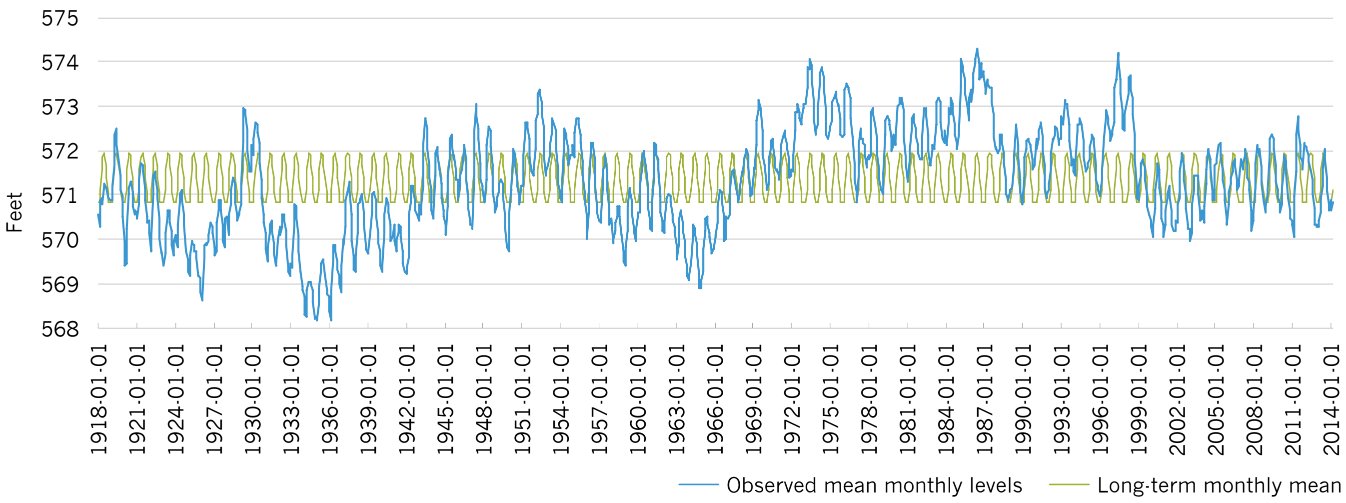
Lake Superior mean monthly levels and long-term monthly means in the official period of record



Source: Data downloaded from GLWLD

FIGURE 3

Lake Erie mean monthly levels and long-term monthly means in the official period of record



Source: Data downloaded from GLWLD

Water levels data for the lower St. Lawrence River

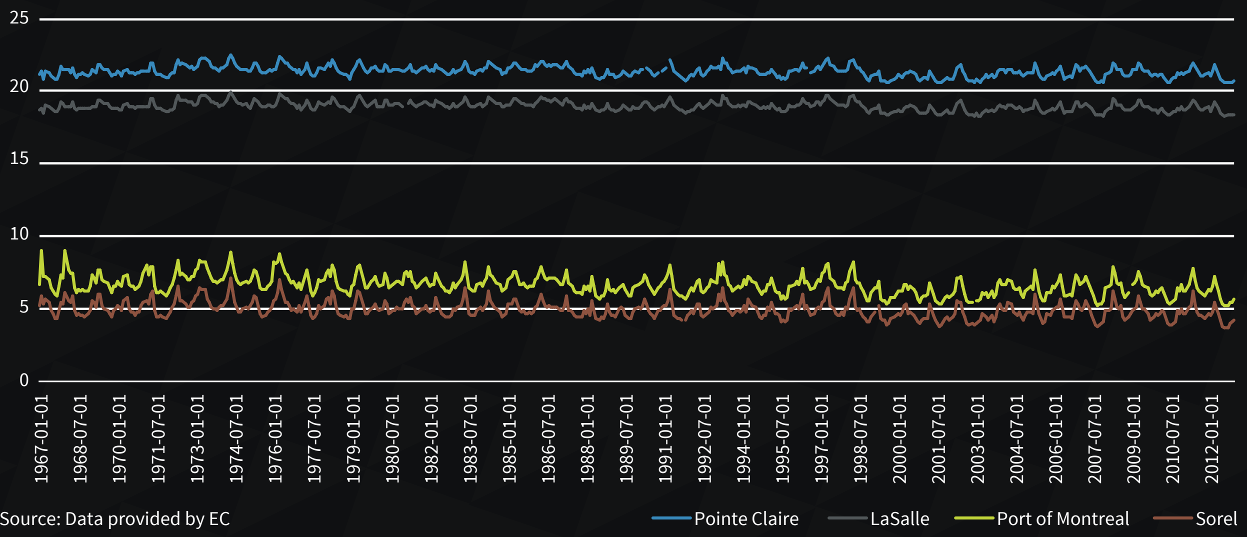
St. Lawrence River water levels data was not available from the GLWLD, and was directly obtained from EC. This data extended only to December 2012.

On advice from EC, we only analyze data from January 1967 onwards, because the building of the Moses-Saunders dam, the introduction of water levels management in the early 1960s, and the creation of the artificial Île Notre-Dame and the artificial expansion of Île Sainte-Hélène in the lead up to Expo 67, have so significantly altered water conditions on the St. Lawrence that comparison with earlier data is unreliable.

We focus on the lower St. Lawrence River as water levels in the upper St. Lawrence River upstream of the control structures at the Moses-Saunders dam are too interlinked to those of Lake Ontario. EC provided data for four lower St. Lawrence River gauges, but since over-time trends in all four gauges have been remarkably similar since 1967 (see Figure 4), we use one of them (Port of Montreal) as a proxy for water level trends in the lower St. Lawrence River.

FIGURE 4

Mean monthly levels at four Lower St. Lawrence River gauges, 1967-2012



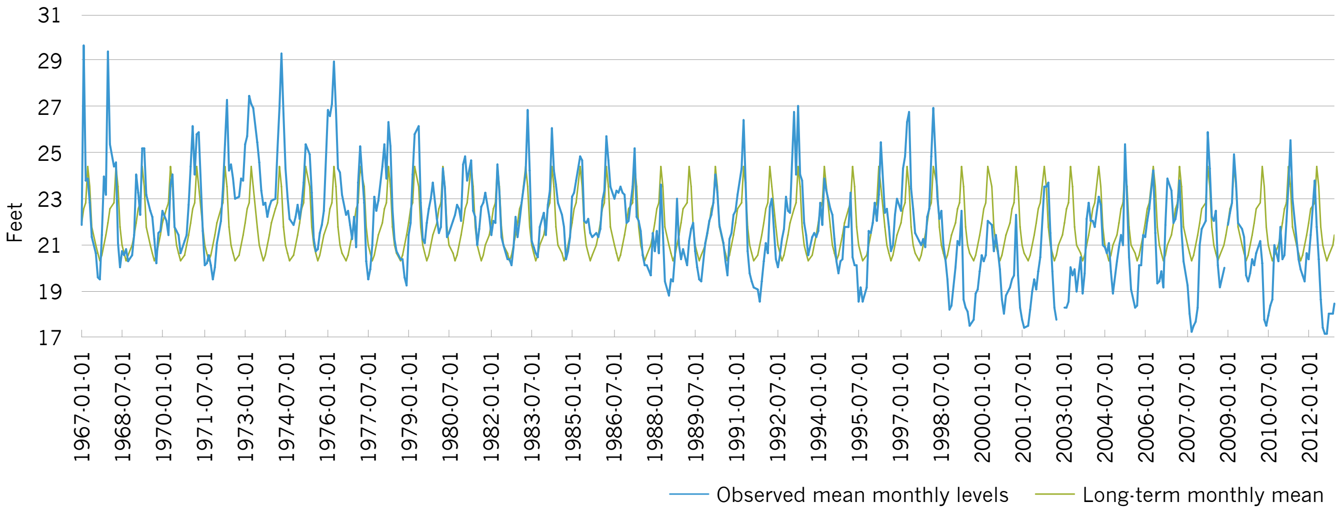
Source: Data provided by EC

Since early 1998, water levels on the lower St. Lawrence River, represented by Port of Montreal data (see Textbox, p. 7), have been mostly below, and sometimes well below, long-term monthly means (see Figure 5). In all, of the 180 months in the 1998-2012 period, Port of Montreal mean monthly water levels have been below long-term monthly means 141 times (78.33 per cent).

Port of Montreal's lowest and second lowest monthly means since 1967 for every calendar month have been set during the 1998-2012 period. At the same time, in 12 of the 15 years between 1998 and 2012 Port of Montreal mean monthly levels have spiked above long-term monthly means at least once. If one tracks the Port of Montreal's 1967-2012 five lowest mean monthly levels for each calendar month, the majority of these (54 out of 60) occurred between 1998 and 2012 (see Figure 6).

FIGURE 5

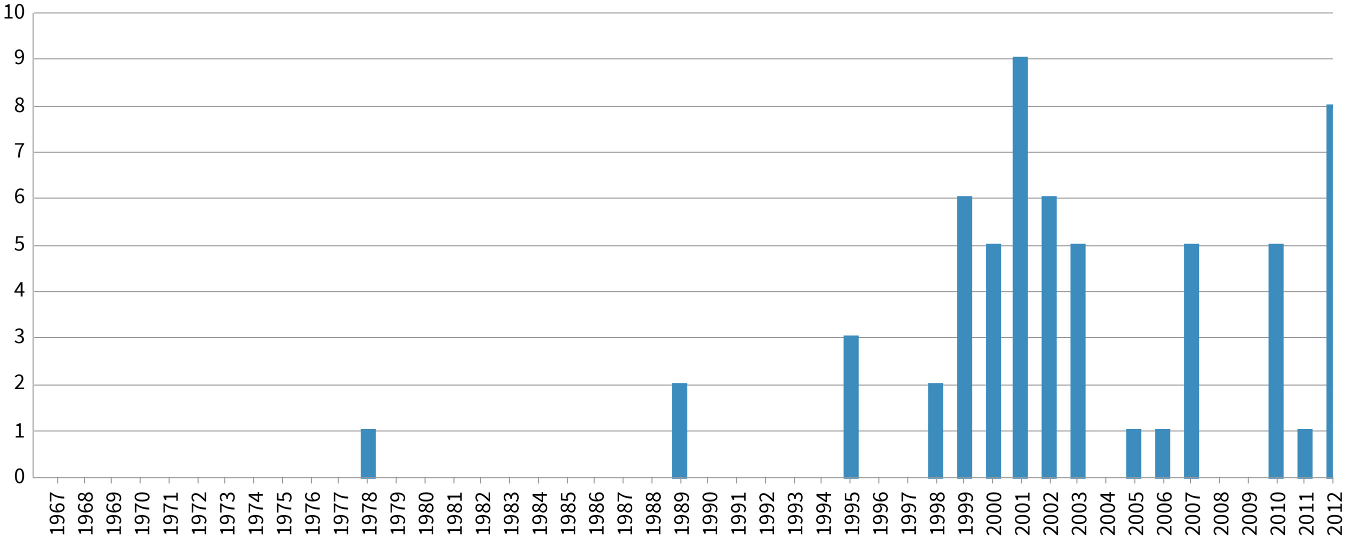
Port of Montreal mean monthly levels and long-term monthly means, 1967-2012



Source: Data provided by EC

FIGURE 6

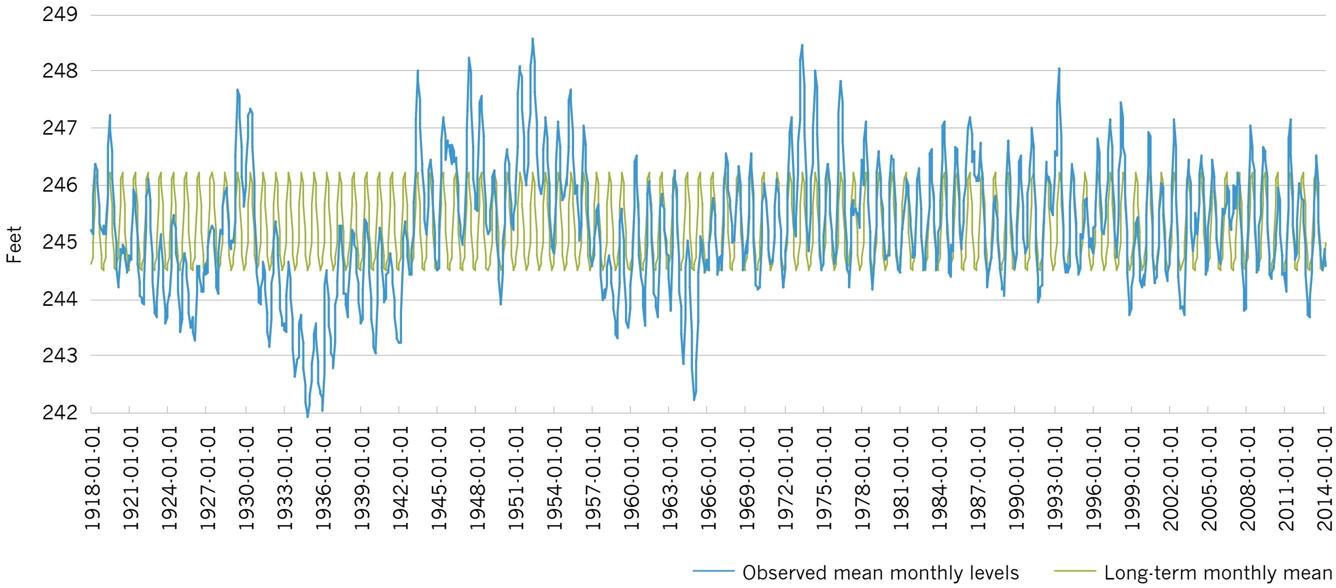
Number of calendar months per year between 1967 and 2012 in which one of the five lowest mean monthly levels for that month was registered at the Port of Montreal



Note: Based on 1967-2012 data provided by EC

FIGURE 7

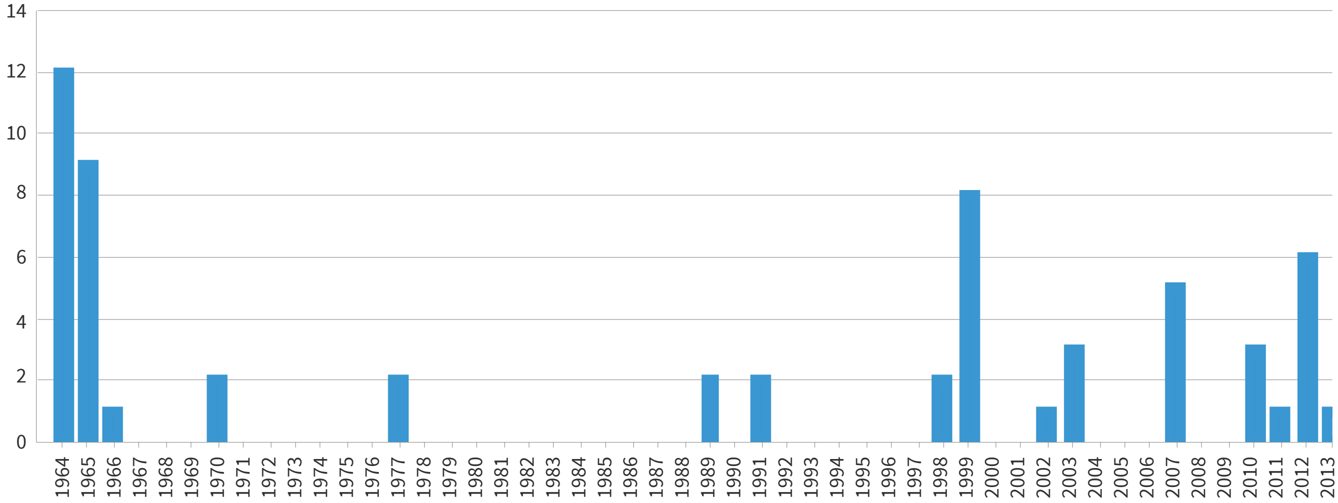
Lake Ontario mean monthly levels and long-term monthly means in the official period of record



Source: Data downloaded from GLWLD

FIGURE 8

Number of calendar months per year between 1964 and 2013 in which one of the five lowest mean monthly levels for that month was registered on Lake Ontario



Note: Based on 1964-2013 data downloaded from GLWLD

Lake Ontario water levels have been regulated by the International Joint Commission (IJC) since the early 1960s with the expressed purpose of mitigating extreme water level highs and lows (see Textbox, p. 10). Indeed, over the 192 months between 1998 and 2013, mean monthly levels on Lake Ontario have been above long-term monthly means 96 times (50 per cent), below long-term monthly means 89 times (46 per cent), and at the long-term monthly means seven times (4 per cent). For Lake Ontario mean monthly levels as compared to long-term monthly means, see Figure 7.

Since April 1965, Lake Ontario water levels have remained above the 243.29 ft (74.15 m) minimum targeted by the IJC (see Textbox, p. 10). Lake Ontario's 12 lowest mean monthly levels since April 1965 have all occurred between 1998 and 2013, with the lowest level registered in December 2012. For every calendar month, the lowest mean monthly level on record since September 1965 was recorded between 1998 and 2013. If one tracks Lake Ontario's 1964-2013 five lowest mean monthly levels for each calendar month, half of these (30 out of 60) have occurred between 1998 and 2013, while only nine of these have occurred between 1966 and 1997 (see Figure 8).

In sum, since dropping drastically across the region in 1997-1998 and until 2013, water levels have remained below long-term monthly means on Lakes Superior and Michigan-Huron, and for much of this period also on the St. Lawrence River. Low water levels have been particularly dramatic on Lake Michigan-Huron and at time on the St. Lawrence River. Water levels had been below long-term monthly means in Lake Erie until 2004, and have oscillated around long-term monthly means since. Only the more closely regulated waters of Lake Ontario have not shown a persistent low water levels pattern, but have nonetheless on several occasions been at their lowest since the early years of regulation.

Water level regulation in Lake Ontario and the St. Lawrence River

The IJC, through the International St. Lawrence River Board of Control (ISLRBC), has been managing water levels in Lake Ontario and both the upper and lower St. Lawrence River since 1960, with the current regulation plan, 1958D, in operation since October 1963.[3] The IJC regulates water flows mainly through the Moses-Saunders Dam, located between Messena, NY and Cornwall, ON, to keep Lake Ontario fluctuations between 243.29 ft (74.15 m) and 247.29 (75.37 m).[4]

Dams at Long-Sault and Iroquois can provide support management capacity if needed. For example, in May 2013 the Iroquois dam was used to ease a short-term rise in water levels on the St. Lawrence.[5] Water levels on Lake Saint-François, immediately downstream of Cornwall-Massena on the lower St. Lawrence River, are "highly stabilized downstream by the Beauharnois and Coteau dams."[6]

Under the Boundary Waters Treaty of 1909, the IJC is tasked with "ensuring that all affected interests are considered in decisions that change the levels and flows of boundary waters."[7] The Treaty establishes an order of precedence among affected interests that IJC decision-making must follow, with domestic and sanitary uses first, navigation second, and power and irrigation third.

Nonetheless, Lake Ontario and St. Lawrence River regulation was put in place in no small part to moderate extreme high water levels in response to flooding in Lake Ontario in the 1950s. It was then refined to ensure a minimal low water levels threshold for the lower St. Lawrence River.[8]

Criteria K of the current regulation plan (1958D), which applies when water levels are higher or lower than those experienced in 1860-1954, reduces high water levels "to provide all possible relief to both upstream and downstream property owners" and counteracts lower water levels "to provide all possible relief to navigation and power interests."[9]

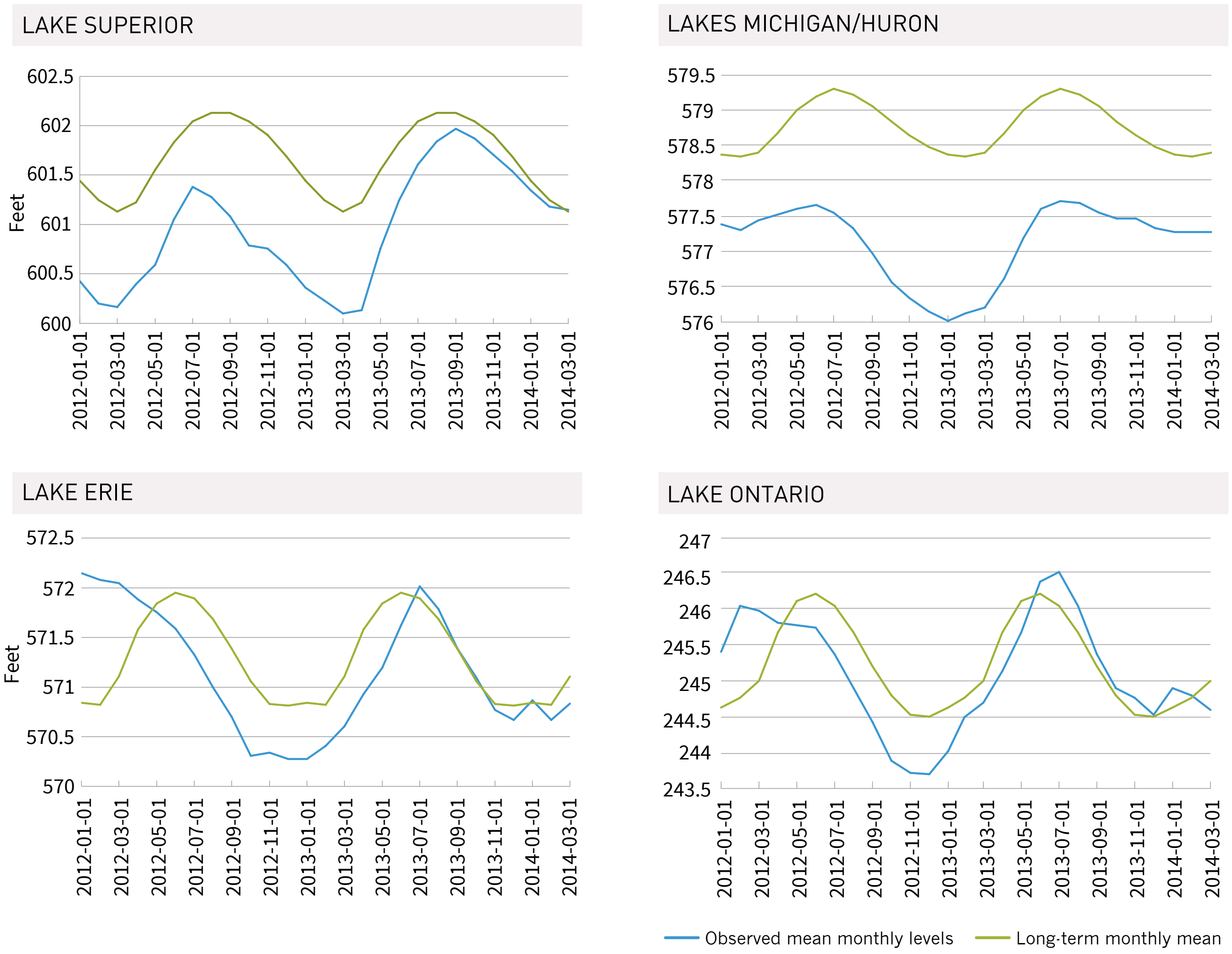
The Lake Ontario range of fluctuation targeted by the IJC is fairly broad, reducing only extreme water levels. In the 504 months between January 1918 and December 1959, Lake Ontario's actual water levels were higher than this range on 28 months (6 per cent) and lower than this range on 36 months (7 per cent). In the 600 months between January 1964 and December 2013, water levels have exceeded this range on 14 months (2 per cent, most recently in April 1998), and gone below this range on 7 months (1 per cent, all in 1964 and 1965).

Notably, mitigating high water levels on Lake Ontario entails releasing excess water into the St. Lawrence River, while mitigating low water levels on Lake Ontario entails keeping more water in the lake. This may exacerbate water level variations downstream of Beauharnois, although the ISLRBC is mandated to take St. Lawrence River interests into account in its decisions, as already noted.

[3] ILOSLRSB, 2006a: i.
[4] IJC, n.d.
[5] Sommerstein, 2013.
[6] Morin et al., 2000: 385.
[7] IJC, n.d.
[8] IJC, n.d.
[9] ILSBC, n.d.a.

FIGURE 9

Lakes Superior, Michigan-Huron, Erie, and Ontario mean monthly levels and long-term monthly means, 1/2012-3/2014



Source: Data downloaded from GLWLD

Note: Because Lake Erie's oscillation around long-term monthly averages since June 2013 has often been small, we use a different water levels scale for this lake than for the other lakes (0.1 m intervals as opposed to 0.2 m intervals).

Water levels throughout the basin have been rebounding since 2013 (Lakes Erie and Ontario) and 2014 (Lakes Superior and Michigan-Huron), as shown in Figure 9 (using data up to March 2014 for the Great Lakes; the St. Lawrence River is omitted as we did not have St. Lawrence River water levels data for 2013-2014 at the time of writing.

In July 2013, Lake Erie reached its highest mean monthly level since April 2012, and crossed above long-term monthly means for the first time since June 2012. It has continued to oscillate within 3.9 inches (10 cm) around long-term monthly means between June 2012 and March 2014.

In June 2013, Lake Ontario crossed above long-term monthly means for the first time since April 2012. It reached its highest mean monthly level since June 2011 a month later. It remained above long-term monthly means until dipping back below in March 2014.

In March 2014, Lake Superior mean monthly water levels rose above long-term monthly means for the first time since April 2005 and just the third time since August 1998.

In January-March 2014 Lake Michigan-Huron was the closest to long-term monthly means it had been since April 2012. However, it remained more than 11.8 inches (30 cm) below long-term monthly means at least up to March 2014.

Fluctuations in water levels are inherent to the GLSL water system (see Textbox, p. 12). The result is that "large variations in water supplies to the lakes are absorbed and modulated to maintain out flows that are remarkably steady. This essentially self-regulating feature helps keep lake levels within typical ranges over long periods."[10] Indeed, over the last 150 years, water levels have remained within a 6.56 ft (2m) range throughout the GLSL,[11] though extreme fluctuations within this 6.56 ft (2m) range can still have significant impacts on the human systems created in the GLSL.

Nonetheless, "the size of the Great Lakes and the limited discharge capacity of their out flow rivers mean that extremely high or low levels and flows can persist for a considerable time after the factors that caused them have changed."[12] Indeed, the International Upper Great Lakes Study Board (IUGLSB) found that in the upper Great Lakes "water supplies have been declining in general over the last 40 years, a finding consistent with the current understanding of the effects of climate change."[13]

This finding is particularly notable given that "on average less than 1 percent of the water of the Great Lakes is renewed annually by precipitation, surface water runoff, and inflow from groundwater sources."[14] In Lake Michigan-Huron, the top 3.28 ft (one meter) of water represents 1.39 per cent of the overall volume.[15]

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10 IUGLS, 2012: 3.
11 GLEAM, n.d.
12 IUGLS, 2012: 3.
13 IJC, 2013: 6.
14 IJC, 2000: 6.
15 Lake Michigan-Huron has a surface area of 45,300 miles^2 (117,400 km^2) with a volume of 2,029 cubic miles (8,460 cubic meters). (117400x0.001)/8460 = 1.39%.

The GLSL is a region whose quality of life, sustainability, and economic prosperity depend on its shared access to the largest freshwater system on earth. As such, extreme fluctuations in water levels could pose significant risks to ecosystems and species throughout the GLSL region, as well as to sectors at the heart of the region's economy.

In balancing these sometimes divergent vulnerabilities, government decision-makers face a complicated challenge. For reasons explained below, it is hard to predict with accuracy what water levels will be in a given part of the basin on a given month or year, let alone decades into the future.

Responses to fluctuating water levels can involve actions by governments and stakeholders that adapt or adjust human behaviour, actions that seek to manage or control water levels, and/or actions that target climate change stressors.

Some of these responses can be expensive, take long to implement, and not easily adaptable to changing water conditions.[16] As a result, it can be difficult to gain and maintain public support for them. For example, fixed physical structures to control water levels, such as dams or weirs, can be expensive, could take decades to implement, might pose risks to local ecosystems, and may take several years to adjust to fluctuations in water levels (exacerbating high or low water level risks should water levels turn from low to high or from high to low more rapidly).

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[16] In the present report we do not mean to imply any preference for certain responses over others. We are currently undertaking in a follow-up study a cost-benefit analysis of several adaptive and water management options for the GLSL.

Water level fluctuations in the GLSL

As explained by the Great Lakes Environmental Assessment and Mapping (GLEAM) project, "Great Lakes water levels fluctuate within a normal range of variation, and these fluctuations are essential for maintaining habitat diversity and critical ecological functions. Normal ranges of variation tend to cycle over daily, seasonal, and longer (multiyear) periods of time.

» Short-term fluctuations, lasting under one hour to several days, are caused by sustained winds resulting from differences in barometric pressure. These fluctuations are also a result of daily changes in the direction of winds caused by differences in the rates at which land and water heat during the day and cool at night.

» Seasonal fluctuations [sic] 0.3-0.45 m (12-18 inches) are common due to annual variation in evaporation, precipitation, and runoff.

» Longer-term fluctuations lasting years, decades, or longer, are visible in the historic record."[17]

According to the IJC, longer-term fluctuations "have resulted in monthly water levels that range from about 2-3 ft (60-90 cm) above or below the long-term averages for the month, depending on the particular lake."[18] As explained below, it is not certain from existing evidence whether or not there is discernible cyclicality to long-term fluctuations in GLSL water levels.

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17 GLEAM, n.d.
18 IJC, 2013: 5.

Other responses could avoid these risks. For example, more dynamic control structures, which are used in other watersheds (for example, the Thames Barrier downstream of London, England), could offer greater flexibility. Dynamic control structures have yet to be explored in the GLSL, though recent improvements in predictive modelling, instrumentation, and feedback mechanisms may increase their viability for the region.

Complicating this decision is the fact that "most of the key interests have demonstrated their capacity to adapt to changes in water level conditions that have been within historical upper or lower ranges. However, future water levels that are outside these ranges would require some interests to carry out more comprehensive and costly adaptive responses than any undertaken to date."[19] The full extent and long-term impact of this future adaptability is itself impossible to predict—or economically quantify.

The decision whether and what mitigative and/or adaptive action to take therefore entails three components:

1. An assessment of future water levels and relative likelihoods of low and high water levels given the reality of climate change.

2. An assessment of the environmental and economic risks various future water levels could pose for the GLSL and for sub-regions within the GLSL, and whether these risks warrant considering mitigative and/or adaptive action.

3. An assessment of the costs and benefits of different combinations of mitigative and adaptive options for the region.

This decision requires a thoughtful public conversation, guided by evidence. The present report aims to advance this public conversation by outlining the positive and negative economic impacts high and low water levels could have on key regional interests, and by assessing what the negative impacts for these interests might be under a plausible worst-case scenario of future low water levels.

In the remainder of this section we discuss the uncertainties related to projecting future GLSL water levels and present the purpose, scope, structure, and limitations of the present report. In the next section of the report we discuss the potential risks and benefits that both low and high water levels may pose to key GLSL sectors, and provide an assessment of the economic impact of a worst-case low water levels scenario on those sectors. We conclude by providing a regional and sub-regional overview of our findings and conclusions.

The present report does not assess the costs and benefits of various mitigative and adaptive responses to fluctuations in GLSL water levels. This is the focus of a separate report we are currently working on.

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[19] IUGLS, 2012: vi. While the IUGLSB was speaking of the upper Great Lakes, the statement also applies to the rest of the region.

The Uncertainty of Future Water Levels

In 2007, the Intergovernmental Panel on Climate Change (IPCC) noted, in the context of its discussion of climate change impacts on surface water in North America, that "[m]any, but not all, assessments project lower net basin supplies and water levels for the Great Lakes-St. Lawrence Basin."[20] This reflected the prevalent understanding at the time of the likely impact of climate change on GLSL water levels.[21] Available economic impact data regarding future GLSL water levels impacts derives from several particular projections from this group, based on models developed by the Canadian Centre for Climate Policy and Analysis.

In recent years, however, scientific, methodological, and physical developments have introduced significant uncertainty into this position. Indeed, the IUGLSB concluded following its five-year study that "changes in levels in the upper Great Lakes over the next 30 years may not be as extreme as previous studies have predicted. Lake levels are likely to continue to fluctuate, but still remain within the relatively narrow historical range. While lower levels are likely, the possibility of higher levels at times cannot be dismissed ... Beyond the next 30 years, some projections by climate models of more extreme water levels (both higher and lower) in the upper Great Lakes may have more validity, though there is still a great deal of uncertainty regarding those projections."[22]

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[20] IPCC, 2007: 627.

[21] See for exampleMortsch et al., 2000, and Lofgren et al., 2002; Croley, 2003. This position remained prevalent throughout the first decade of the 21st century—see for example Hall and Stantz, 2007; Millerd, 2008 and Lishawa et al., 2010. Even official context materials from the GLEAM project still reflect this position; see GLEAM, n.d.

[22] IUGLS, 2012: vi.

Climate projection and economic impact analyses

Economic impact analyses of changing future climate conditions typically apply future climate scenarios to a set of data indicating economic impact. The future climate scenario could be derived from actual climate projections based on available climate change models, or on a "what if" change scenario (e.g., what if water levels dropped by one foot). Economic impact data can either be extrapolated from existing data or generated from new fieldwork, surveys, or non-public sources. The present report extrapolated from existing data in all cases except for waterfront properties, where non-public data was acquired and analyzed.

Climate change models are updated with every successive IPCC assessment. Future climate scenarios based on these models, such as future GLSL water level projections, begin to be published a few years later. Economic impact analyses utilizing these projections while generating new impact data would take a few more years to be conducted and published. Economic impact analyses that draw on this new impact data would take a few years more. By that point, a new IPCC assessment with updated climate change models could already be publicly available.

This has been the case with economic impact analyses of low GLSL water levels. The major sources of available and relevant economic impact data were published in 2002-2005,[23] and are therefore based on pre-2002 water levels projection derived from climate change models developed for the IPCC's first two assessments.[24] Most of these projected markedly lower water levels than recently published projections derived from climate change models developed for the IPCC's fourth assessment. Lower projected water levels typically mean higher projected economic impacts.

Without access to the fieldwork data on which earlier economic impact assessments were based, which is not typically provided in published articles and reports, it is not economically credible to simply recalculate existing economic impact data while substituting earlier projections with newer ones. We were therefore forced to use projections that had been employed to generate available economic impact data.

We use the most moderate set of projections. We restrict ourselves to only the most moderate one,projecting water levels that are within historic lows across the region through 2030, and throughout the region except for Lake Michigan-Huron through 2050. This is the only scenario on which available economic impact data is based and which can still be considered plausible in light of more recent projections. We treat this as a worst-case low water levels scenario. There is marked need for more research and analysis to enrich the store of available GLSL economic impact data with up to date analysis based on more recent water levels projections and climate change models.

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[23] Quinn, 2002; Buttle et al., 2004; Millerd, 2005.

[24] Mortsch and Quinn, 1996; Boer et al., 2000; Flato et al., 2000; Mortsch et al., 2000; Lofgren et al., 2002.

Climate change could increase both high and low water levels risks. Increasing temperatures can result in increased evapotranspiration and overlake evaporation and, insofar as evapotranspiration and overlake evaporation exceed precipitation, decreased water levels. At the same time, increased snowmelt or storm occurrences can increase high water levels risks such as flood and erosion. Changes in precipitation patterns could change the quantity and timing of water inputs into the GLSL. Unpredictable effects, such as the North American cold wave of winter 2013-2014, could also lead to higher or lower GLSL water levels.

The main reason for the uncertainty around future water level fluctuations is that the GLSL is a highly dynamic and adaptive natural and human system, with multiple factors that are continually changing, including water supplies and outflows. There remains significant uncertainty regarding the interplay of hydroclimatic factors that affect GLSL water levels, the likely impacts of climate change on these factors, and the projection of future GLSL water levels.

Several recent developments that have brought this uncertainty and variability back to the fore include:

1. Uncertainties regarding factors affecting GLSL water levels

The IJC recently noted that, "understanding the water balance still continues to be a scientific challenge and requires ongoing analyses."[25] According to the Great Lakes Information Network, "the major influences on Great Lakes hydrology are weather and climate, which affect the balance of water in the Great Lakes and their connecting channels. Water enters the system as precipitation, runoff (including snowmelt) from the surrounding land, and groundwater inflow. Water leaving the system consists of evaporation from the water's surface, groundwater outflow, consumptive uses, and diversions."[26]

According to IJC data based on the period 1948-2006, 98.8 per cent of water entering the GLSL basin originates in precipitation. Of the water leaving the basin, 56.8 per cent flows downstream to the ocean, and 42.5 per cent evaporates into water vapour. Because most of the water withdrawn from the basin for human uses (power generation, industrial uses, public supplies, and irrigation) is returned to the basin, consumptive human use (withdrawn water that is not returned to the system) accounts for less than one per cent of outflows.[27]

As explained by the IUGLSB, calculating the water balance of each Great Lake, also known as the Net Basin Supply (NBS), entails estimating overlake precipitation, overland runoff (over-land precipitation and evapotranspiration), and lake evaporation, through a combination of observation and extrapolation.[28] Specifically, overlake precipitation is estimated through extrapolation from precipitation observed on land-based gauges, overland runoff is "computed using streamflow records at gauged streamflow stations, extrapolated to ungauged portions of the basin," and lake evaporation is estimated "from areal-average air temperature, wind-speed, humidity, precipitation and cloud-cover data".[29]

This methodology represents the conventional way researchers calculate the Great Lakes' NBS. Its reliance on estimation, extrapolation, and computation introduces uncertainty and risk of error (known scientifically as 'bias') into the water balance calculation, as explained in detail by IUGLSB.[30] Other experts consulted for this report suggest changes in a lake's inflow and outflow over time should also be factored into the calculation of a lake's water budget, though the data presented in the present report follows the conventional methodology.

While there are methodological and statistical means to reduce such bias or assess the statistical confidence of outcomes, the best means of bias reduction is improved and more robust measurement and data collection.[31] For example, new data based upon instrumentation installed over the past three years, especially overlake precipitation and evaporation gauges, is starting to provide a better understanding of these factors.[32]

The interactions between overlake precipitation, overland runoff, and lake evaporation can vary quite markedly between individual lake basins, across particular locations in a given lake basin, and also from season to season and year over year. Adding to this complexity, in different parts of the GLSL, non-hydroclimatic factors interact with hydroclimatic factors to further affect the water balance. The major non-hydroclimatic factors include alterations to hydraulic regimes, lake water management, and the effects of the Global Isostatic Adjustment (GIA).

The hydraulic regimes of many rivers and channels flowing into, or connecting, the GLSL, have been altered by capital and maintenance dredging, channeling, shoreline protection works, shipwrecks, and the building of dams, culverts, and bridges.[33]

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[25] IJC, 2013: 5.
[26] GLIN, n.d.a. This statement applies to the St. Lawrence River as well as to the Great Lakes and connector channels.
[27] IUGLS, 2012: 25.
[28] IUGLS, 2012: 41.
[29] IUGLS, 2012: 41-42.
[30] IUGLS, 2012: 41.
[31] For a detailed discussion see IUGLS, 2012: 41-48.
[32] For a recent example see Lenters et al., 2013.
[33] IUGLS, 2009: 4.

One of the most dramatic examples of such alterations is the St. Clair River. Successive channel dredging operations were carried out in the river, most recently in the early 1960s, to enable commercial vessels of increasing sizes to pass through it. Combined with ongoing sand mining earlier in the 20th century, this work has increased the river's conveyance capacity. Even after work ceased in the early 1960s (other than occasional maintenance dredging) the river's conveyance capacity continued to increase somewhat, at least until 2000, due primarily to erosion of the river's sand-and-gravel riverbed.[34]

The IJC accepted the finding of the IUGLSB that the increase in the St. Clair River's conveyance capacity contributed between 2.8-5.5 inches (7-14 cm) of the 9-inch (23 cm) decline in Lake Michigan-Huron water levels relative to those of Lake Erie between 1963 and 2007.[35]

According to analysis made for EC, successive excavation and widening of the navigation channel (until 2001) may have also contributed to drops in St. Lawrence River water levels since 1960.[36]

The IJC, through dedicated boards of control, manages the outflow of Lake Superior into the St. Marys River and water levels in Lake Ontario and the St. Lawrence River. As explained earlier, Lake Ontario and St. Lawrence River water levels management aims to maintain water levels within a desired range, mitigating against extreme highs and lows.

The main objective of the current Lake Superior regulation plan is to determine "a flow that will bring the levels of Lake Superior and Lakes Michigan and Huron to nearly the same relative position within their respective ranges of actual historic levels" while taking mandated interests into account.[37]

The GIA is the rebounding of the earth's crust in response to the melting of glaciers since the last ice age. It consists of an upward and downward motion of the earth's crust, reducing or increasing water levels respectively. Since the GLSL is located on one of the GIA faultlines, some areas in the GLSL are rising (and shallowing), while others are lowering (and deepening).

Specifically, the GIA contributes (to differing degrees) to a decline in water levels on the Ontario shores of Lake Superior, the north half of Lake Huron and Georgian Bay, and the north shore of Lake Ontario. For example, "the shoreline of Parry Sound, Ontario, in Georgian Bay, is rising at a rate of about 24 cm (9.4 inches) per century relative to the outlet of Lake Michigan-Huron."[38]

At the same time, the GIA contributes to increases in water levels and flood risks on the west and south shores of Lake Superior, most of Lakes Michigan and Erie, and the south shore of Lake Ontario (for the upper Great Lakes see Figure 10). For example, "the shoreline around Milwaukee, Wisconsin, is subsiding at a rate of about 14 cm (5.5 inches) per century relative to the lake outlet."[39]

The scientific knowledge of the processes that govern the GLSL water budget, as well as scientists' ability to model the GLSL water budget, are improving. For example, recent evidence has enhanced scientists' understanding of overlake evaporation and ice coverage,[40] lake-effect snowfall,[41] precipitation,[42] and runoff.[43]

2. Uncertainties regarding climate change modelling and future GLSL water levels projections

As already noted, earlier projections of future GLSL water levels have largely predicted significant drops in water levels across the GLSL. However, more recent projections have painted a more ambiguous picture (see Figure 10).

Earlier projections are represented in Figure 10 by the scenarios B, F, and G, used by Frank Millerd.[44] As explained more fully in Appendix 1, Millerd used two future water levels scenarios, for one of which he provided two variants, for 2030 (scenario B, averaging out projections for 2021-2040) and for 2050 (scenario F, averaging out projections for 2041-2060). These two variants (labeled *SC2030* and *SC2050*) are those employed in the present report as a worst-case low water levels scenario. Scenario G, which Millerd labels *CCC GCM1*, is an older one that yielded extreme water level drops, well outside both the historic range and more recent projections, and was therefore not used in the present report. It is only included in Figure 10 for comparison.

Of the more recent projections, the most comprehensive is the work of Angel and Kunkel (scenarios C and H). Angel and Kunkel performed 565 model runs on 23 IPCC fourth assessment models and considering three emissions variants (low, moderate, high). This resulted in a range of projections that largely falls within the historic range since 1918.[45] Notably, while Angel and Kunkel published results for all three emissions variants regarding Lake Michigan-Huron, their results for other Great Lakes, found on the GLWLD and reflected in Figure 10, are for the high emissions scenario only.

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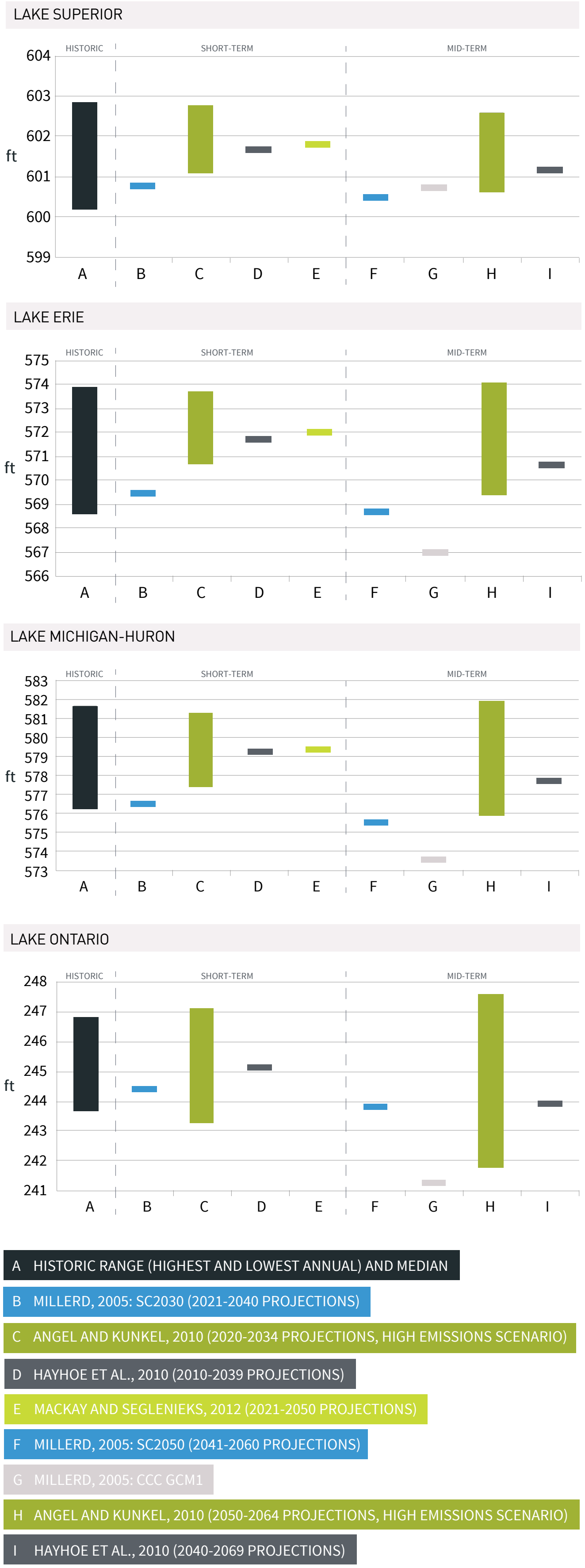
[34] The evidence before the IUGLSB suggested that the conveyance capacity of the St. Clair River had plateaued and perhaps even slightly decreased since 2000, indicating the riverbed was no longer eroding. However, the data on this is, by the IJC's own admission, incomplete. For a recent analysis suggesting erosion of the St. Clair River's riverbed is still ongoing, see Baird & Associates, 2012.
[35] IJC, 2013: 2.
[36] Cantin et al., 2006: 20-21.
[37] ILSBC, n.d.b.
[38] IUGLS, 2012: 6. For a detailed analysis of GIA effects on the region, see Bruxer and Southam, n.d.
[39] IUGLS, 2012: 6. For a detailed analysis of GIA effects on the region, see Bruxer and Southam, n.d.
[40] Lenters et al., 2013.
[41] Kunkel et al., 2008.
[42] Mahfouf et al., 2007.
[43] Deacu et al., 2012.
[44] Millerd, 2005.
[45] Angel and Kunkel, 2010.

FIGURE 10

Great Lakes water levels projections as compared to the historic range in the official period of record



Sources: GLWLD and Millerd, 2005

Hayhoe and her colleagues, performing less model runs but considering more emissions variants than Angel and Kunkel, projected higher water levels relatively close to the historic median (see scenarios D and I).[46] MacKay and Seglenieks, offering an alternative method of estimating future lake levels for Lakes Superior, Michigan-Huron, and Erie, projected water levels higher than the historic median for these lakes (see scenario E).[47] A fourth set of recent projections, from Lofgren and his colleagues, looked at a period later than those considered in the present report.[48]

These projections vary with time and emission scenario. As Cruce and Yurkovich noted in their analysis of the Angel and Kunkel results, “[f]or a lower emissions scenario, lake levels are projected to change very little from the historic average”. For a high emissions scenario, for 2080, “over 75% of all the model simulations showed steady or declining lake levels. Twenty-five percent of the models resulted in a decline of approximately three-quarters of a foot on Lake Superior, over one and three-quarters feet on Lake Erie, and approximately two and a quarter feet on Lakes Huron, Michigan, and Ontario” relative to the 1970-1999 average.[49]

Projections of future GLSL water levels are generated by applying climate change models (AOGCMs, short for Atmosphere-Ocean General Circulation Models) to GLSL data under different emissions variants (see Textbox, p. 18). These projections “are not predictions, but rather represent future conditions under particular assumptions.”[50] “The various scientic assumptions used in creating General Climate Models, as well as the technological, demographic and economic assumptions underlying the Greenhouse Gas (GHG) emission scenarios used in General Climate Models simulations are simplifications of a highly variable reality, hence the variability of long–term General Climate Models projections.”[51]

Climate change modelling is an evolving field. AOGCMs are developed or updated every five to seven years, in conjunction with each successive IPCC assessment, with new generation models incorporating ongoing methodological and data improvements. Projections of future regional climate conditions and variables, such as future GLSL water levels, can then be generated on the basis of these models. Such projections begin to be published several years after an IPCC assessment, and can be markedly different from projections made on the basis of earlier models.

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[46] Hayhoe et al., 2010.
[47] MacKay and Seglenieks, 2013.
[48] Lofgren et al., 2011.
[49] Cruce and Yurkovich, 2011: 14. Notably, the 1970-1999 average reflects a period of high water levels in the GLSL.
[50] Hayhoe et al., 2010: 9.
[51] Buttle et al., 2004: 102.

While methodological and data improvements are ongoing, significant uncertainty remains inherent in climate change modelling as well as in the projection of future GLSL water levels. This uncertainty can lead to both an overestimation and to an underestimation of future impacts.[52] For example, future evapotranspiration, one of the main determinants of water levels in the GLSL (as explained earlier), is difficult to project. Past projections estimated it by using GLSL air temperature projections as a proxy, a method that has recently been criticized as exaggerating projected water level declines. More accurate alternatives may require enhanced data collection across the region.[53]

More comprehensive data collection, further study and analysis, and enhanced investment in these activities are required to enable scientists to provide decision-makers with better projections of future water levels across the GLSL.

3. Uncertainties regarding water level fluctuations

Because the GLSL water system is so complex and dynamic, significant fluctuations in water levels are inherent to the GLSL, as already noted. Tracking these fluctuations reveals broad seasonal patterns and historic multiyear high and low periods of varying lengths, but the period of record is too short to define predictive cycles with certainty. As the IUGLSB concluded, “no precise patterns in fluctuating water levels are evident in the data records of the past century.”[54]

As a result, at this point it is impossible to predict with accuracy, strictly on the basis of water levels in a given lake in the present year, what water levels will be in that lake the following year. Similarly, while multiyear periods of high and low water levels occur regularly in the GLSL, it is impossible to predict with accuracy when a current period will end and a new one will begin. Scientific effort to identify predictable year over year and multiyear water levels fluctuation patterns is still ongoing.[55]

This is compounded by the fact that the GLSL system is susceptible to sharp and sudden one-year spikes or drops in water levels. This can occur within a particular multiyear period (such as the drastic drops of 1986-1988, after which high water levels returned) or herald a reversal into a new multiyear period (as was the case in 1997-1998).

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[52] A dramatic example of an underestimation of climate impacts, albeit outside the GLSL, is the faster than projected collapse of the West Antarctic ice sheet recently chronicled in Rignott et al., 2014.
[53] See Lofgren et al., 2011; MacKay and Seglenieks, 2013.
[54] IUGLS, 2009: 2.
[55] See for example Hudon, 1997; Sellinger et al., 2007; Hanrahan et al., 2008; Lamon and Stow, 2009; and Watras et al., 2014.

How multi-decadal future GLSL water levels projections are generated

In the traditional method of generating future GLSL water levels projections, “(AOGCMs) simulate the physical processes in the atmosphere, ocean, and land surface, and scientists use AOGCMs to understand the response of the global climate system to rising greenhouse gas concentrations. The models produce grid-based information including temperature, precipitation, humidity, and other climate variables at different time scales.”[56] “Fixed ratios of differences” derived from this information are then used in model runs that “[perturb] observed sequences of climate variables” to produce future projections of these climate variables.[57] In the GLSL, these observed sequences of climate variables are obtained from a hydrological model of the GLSL known as the LBRM (Large Basin Runoff Model), first developed by the Great Lakes Environmental Research Laboratory (GLERL) in the 1980s.[58]

“The global models, however, produce data that are not precise at regional or local scales. To support this need, researchers use statistical downscaling techniques to transform global climate model output into higher resolution projections that can be used to understand the impacts of climate change at the regional or local level. Downscaling often applies regionally specific historic data to calibrate the models, correcting climate variables like precipitation for factors such as topography.”[59]

The IUGLSB, for example, employed two recently-developed Regional Climate Models (RCMs) in dynamically downscaling a subset of upper Great Lakes results from Angel and Kunkel.[60] The RCMs “[took] boundary conditions from GCM projections as inputs and fully [resolved] the climate conditions, including local feedbacks, at a much higher resolution over a smaller area.”[61]

[56] Cruce and Yurkovich, 2011: 9.
[57] IUGLS, 2012: 53.
[58] Croley, 1983a; Croley, 1983b.
[59] Cruce and Yurkovich, 2011: 9.
[60] IUGLS, 2012: 51-53.
[61] IUGLS, 2012: 58.

When a sharp increase or decrease in water levels occurs in a given year, it is therefore difficult to tell, other than in the hindsight of decades, whether or not it signals a new multiyear trend. If climate change increases the occurrence as well as the severity of extreme droughts or storms, this uncertainty will become even more commonplace.

The last two years illustrate this uncertainty. As already noted, winter 2012-2013 saw record or near-record low water levels in Lake Michigan-Huron, and considerably low water levels in the rest of the basin save for Lake Ontario, following a 14-year period of low water levels in much of the basin. This was followed by an upwards rebound in water levels later in 2013 and 2014.

Notably, these fluctuations come on the heels of what could prove to be outlier seasons or years. 2012 was officially the warmest year on record in the contiguous US,[62] as well as in all US GLSL cities tracked by NOAA except for Erie and Toledo.[63] It was in a "virtual tie" for warmest on the Canadian side of the GLSL, and the fifth warmest in Canada as a whole, since Canadian recordkeeping began in 1948.[64]

By contrast, winter 2013-2014 was one of the coldest on record. On March 6, 2014, Great Lakes ice coverage reached 92.2 per cent, the second highest in the period of record and the highest since 1979, up from a low of 12.9 per cent in the winter of 2011-2012.[65] The December 2013-February 2014 period had the most snow on record in Detroit, and one of the ten heaviest snowfalls on record in Chicago, with well more than double the 1981-2010 normal snowfall in both cities.[66] Every GLSL US city for which snowfall is tracked by NOAA, except for Sault Ste. Marie, MI, experienced snowfall well above the 1981-2010 normal.[67]

It will take time before scientists can confidently tell whether the low water levels that followed the unusually warm 2012, or the higher water levels that are currently following the uncommonly cold winter of 2013-2014, prove to be one-time outliers or indicative of longer-term water level trends. GLERL scientist Ann Clites and state of Michigan climatologist Jeff Andersen both recently suggested in comments to the media that the winter of 2013-2014 is likely to prove an outlier.[68]

In sum, accurately predicting future GLSL water levels, then, is as difficult as it is necessary. Scientific knowledge regarding the hydroclimatic factors affecting GLSL water levels and the impact of climate change upon those factors is still evolving. Historic trends suggest both seasonal and multiyear fluctuations are possible and even likely, but that water levels in one year, in and of themselves, do not predict water levels in the succeeding year. Available projections offer a variety of possible high, medium, and low scenarios, with extreme high and low water level events likely to occur in given years, and both low and high water level multiyear trends are possible.

Some of this uncertainty is inherent to attempting to predict the future. But much of it can be reduced through more comprehensive data collection, additional research and analysis, and continued methodological improvements in climate modelling. Continuing and enhancing such scientific work is imperative for effective government decision-making and long-term planning in a region so affected by water level fluctuations. Informed government decision-making to deal with GLSL water levels must rely, as much as feasible, on a solid base of scientific evidence.

The question is whether government decision-makers can afford to wait until these uncertainties are reduced in a region where the lives of citizens and the health of both the economy and the environment is so bound up with its waters. The answer to this question is only partially dependent on projecting future water levels. More primarily, it is a matter of the environmental and economic stakes entailed in various possible future water levels scenario and whether they are high enough to potentially warrant action—a matter of sound long-term planning.

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[62] NOAA, n.d.d.
[63] NOAA n.d.e.
[64] EC, n.d.
[65] NOAA, n.d.c.
[66] NOAA, n.d.f.; NOAA, n.d.g.
[67] NOAA, n.d.f.
[68] Sheppard, 2014; White, 2014.

The Purpose, Scope, Structure, and Limitations of the Present Report

Study, Purpose, Scope & Structure

As just seen, GLSL decision-makers who must respond to (sometimes extreme) seasonal and year-over-year water level fluctuations while also planning for longer-term changes in water levels trends, face significant uncertainty regarding future GLSL water levels.

Responding to this uncertainty, the IUGLSB noted that "in terms of water management and lake regulation, the best approach is to make decisions in such a way as to not overly rely on assumptions of particular future climatic and lake level conditions or specific model projections. Robustness—the capacity to meet regulation objectives under a broad range of possible future water level conditions—must be a primary attribute of any new regulation plan."[69]

Indeed, flexibility to adapt to multiple possible future scenarios is prudent in long-term planning under conditions of high uncertainty. However, the level of risk entailed in those scenarios is also an important input. If certain scenarios pose significant risks to the GLSL's environment and/or economy, preparing for those scenarios more particularly may nonetheless be warranted. At the very least, prudent long-term planning must take such risks into account.

This entails assessing the environmental and economic risks and costs entailed in different possible future water level scenarios over a period of several decades (considered a reasonably long period in economic analysis). Both high and low water level scenarios should be studied. Scenarios that assume different plausible mixtures of extreme and moderate high and low water levels should also be analyzed.

In the present report we propose to undertake first steps in this direction. Specifically, we estimate, based on available data, the economic impacts of a worst-case low water levels scenario on five of the GLSL's key economic sectors and economic drivers. Under this scenario, water levels remain significantly low over several decades. As already noted (and explained in Figure 10 and Appendix 1), we draw upon a scenario that has been used in generating existing economic impact data, providing two variants for two different time points (present through 2030, which we label *SC2030*, and present through 2050, which we label *SC2050*).

The economic sectors analyzed in this report include:

» **Commercial shipping and harbours**
» **Tourism and recreational water activities**
» **Waterfront properties**
» **Hydroelectric generation**
» **Municipal, industrial, and rural water users**

We have chosen these sectors as our case studies on the basis of five criteria:

1) Identified importance
These case studies reflect five of the six interests identified by the IJC as the key interests served by the upper Great Lakes system.[70] Domestic and municipal water users, commercial navigation, and hydroelectric generation have been given order of precedence in IJC decision-making for all US-Canada boundary waters in the *Boundary Waters Treaty of 1909*.

2) Economic significance
All sectors are either economically significant on a region-wide scale, or key contributors to local economies in the GLSL.

3) Economic vulnerability to fluctuations in water levels
Each of these sectors relies on the region's waters for its economic viability, and could be significantly impacted by fluctuations in water levels, and especially by significant (in some cases even moderate) drops in water levels.

4) Availability of required data on impacts and vulnerabilities
For all sectors, sufficient data exists to enable credible analysis of the economic impacts of the same water levels scenario (specifically, a worst-case low water levels scenario).

5) Measurability on the basis of market impacts
All sectors lend themselves to analysis of market costs and impacts without the need to quantify non-market values.

For each sector case study, we analyze the economic impact of a worst-case low water levels scenario on that sector. In each case, we provide two impact estimates, a shorter-term one for the period through 2030 and a middle-term one for the period through 2050. Where the available data allows, we also provide impact estimates for each of the Great Lakes as well as for the St. Lawrence River. We then aggregate the sector-level impacts into region-wide impact estimates, and provide a

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[69] IUGLS, 2012: vi.

[70] IUGLS, 2012: 23.

broader discussion of what these findings mean for the region. We provide full descriptions of our methodologies in analyzing each case study in the Appendices.

We have chosen to focus on a worst-case low water levels scenario as our starting point for several reasons:

» In long-term planning under high degrees of uncertainty, it is considered prudent to take one's bearings from a more pessimistic scenario. The costs of errors from conditions being worse than anticipated are usually higher than the cost of errors from conditions being better. For example, costs sunk into preparing for a scenario that has not actually happened are often easier to absorb if the erroneous scenario was too pessimistic and reality turned out better than if the erroneous scenario was too optimistic and reality turned out worse. Starting from a worst-case low (or high) water levels scenario is therefore a reasonable recognition of asymmetric risks that could point to appropriate precautions decision-makers could take.

» In its *Advice to Governments on the Recommendations of the International Upper Great Lakes Study*, the IJC affirmed sharing concern "about the serious adverse effects of these low water levels," noting that "a key message that emerged from the nearly 3,500 comments received was strong public concern about the effects of extreme low water levels on lakeshore property owners, coastal habitat, recreational boaters and navigation interests."[71] Recent work on the state of climate change adaptation in the GLSL flagged a similar concern.[72] While concern is driven by recent experience with low water levels rather than by an assessment of their future likelihood, its prominence in the public debate warrants focusing on a worst-case low water levels scenario as a starting point.

» The worst-case low water levels scenario analyzed in the present report is the only scenario for which sufficient economic impact data is available for extrapolation across all selected case studies, as explained already.

We have chosen not to estimate impact values for time points later than 2050 because, that far into the future, conversion to net present value renders such values meaningless (see Appendix 1). In addition, that far into the future, adaptive or mitigative behaviour that may be undertaken in nearer decades could significantly alter the impact calculus in ways that cannot be predicted or taken account of in economic calculations. Given that water levels projections suggest water levels are likely to become lower in the second half of the 21st century if the root causes of climate change are not mitigated, this is a conservative choice on our part.[73]

While our primary focus in this study has been the economic impact analysis, a secondary aim of the present study has been to ascertain how far available data can go in assessing the economic impacts of GLSL water level futures and what the main data gaps and needs are. For this reason as well as to keep the size and scope of this study manageable, we chose to rely on publicly available economic impact data rather than collect or generate new fieldwork data. The only exception is the case of waterfront residential property values, where only non-public data is available.

Our choice to focus on a worst-case low water levels scenarios and to draw primarily on available economic impact data has imposed certain limitations on the present study, which we seek to mitigate throughout our report. In some cases, these limitations point to areas where further study is needed in the GLSL.

Study Limitations

1. Focus on one future water levels scenario leaves out other possible scenarios which also warrant similar impact assessments (e.g., especially worse case by water levels, and a mix of moderate levels with extreme spikes and drops). Similar assessment of flooding and coastal erosion risks as a result of extreme flood events is particularly warranted given such risks were flagged as a concern in the most recent IPCC assessment.[74]

   In this respect, our choice to focus on the worst-case low water levels scenario is not to be construed as suggesting that our findings paint a full picture of the economic impacts of GLSL water level fluctuations. Nor is it to be construed as suggesting this scenario is more likely than others to occur—there is too much uncertainty about future GLSL water levels to support such a claim.

   We mitigate this limitation by discussing, for each sector and region-wide, the economic vulnerabilities to both high and low water levels that the sector is susceptible to. Subject to data availability, we will endeavor to provide an assessment of flooding and coastal erosion impacts in subsequent research work.

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[71] IJC, 2013:9, 4.
[72] Gregg et al., 2012.
[73] Cruce and Yurkovich, 2011: 14, analyzing the 2080 results from Angel and Kunkel.
[74] Romero-Lankau et al., 2014: 16, 17.

2. Relying primarily on available economic impact data has carried over limitations inherent in the available data. Specifically, for reasons explained earlier (see Textbox, p. 14), we cannot draw upon the most current GLSL future water levels projections, and were forced instead to draw upon earlier projections that may have exaggerated future water levels declines. Nor can we reliably quantify offsetting positive impacts of low water levels, since the available economic impact data focuses on negative impacts. The limited scope of some of the available data required us to employ extrapolations and proxies in generating sectoral and regional impact estimates.

   Relying on available economic impact data also limited us to drawing on projections from downscaled AOGCMs. Some of the experts consulted for this report noted that such multi-decadal projections may underplay the role of timing and sequence and overplay the role of global climate drivers in determining water levels within multi-decadal timeframes. The same experts suggested this could be averted by complementing projections from downscaled AOGCMs with stochastically generated water supply projections. While this complementary approach could improve future economic impact analyses in the GLSL, economists studying climate impacts on the GLSL have yet to take advantage of it.

   We mitigate these limitations, firstly, by drawing, in our own economic analysis, on the most moderate of the future GLSL water levels scenarios on which available economic impact data is based. Second, we use 2012 as our baseline. Water levels in 2012 were particularly low, in some cases lower than the most current future water levels projections. This moderated the degree of water levels drop used in our calculations.

   Third, where we have to employ extrapolations, proxies, assumptions and other workarounds as a result of missing data, we do so conservatively. Fourth, we highlight positive impacts of low water levels where such were identified by the literature and consider, where we can do so credibly, the extent to which these positive impacts may offset the negative impacts of low water levels that we did analyze.

   Further study to generate new fieldwork-based economic impact data that fills these gaps for the GLSL is needed. We point out areas where such new data is needed throughout our analysis.

3. Focusing on economic impacts and on available economic impact data has meant leaving several important regional economic drivers outside of our impact calculations. In particular, data was not available to calculate impacts on commercial fishing, or to separate impacts on manufacturing from impacts on other shippers or water users. Sufficient data was also not available to calculate impacts on the ecological services provided by GLSL ecosystems, on human health, and on aesthetic and other non-market values.

   To mitigate this limitation, we provide a qualitative discussion of impacts on ecological services as part of our case studies analysis, and some discussion of impacts on manufacturing, commercial fishing, human health and non-market values as part of the report's findings.

   We decided not to quantify impacts felt by First Nations and Native American tribes as we feel an economic analysis would not capture the full nature of such impacts. We provide a narrative account of these impacts instead.

4. As with other available economic impact assessments, the present study assesses how future hydroclimatic changes would affect present infrastructure. In a region with a history of adaptation and adjustment to changing weather conditions, it is quite likely that there will be ongoing adaptation that affects multi-decadal economic impacts.

   However, it is impossible to predict the full extent of such adaptation or its longer-term impact. For example, while the costs of capital and maintenance dredging in both ports and marinas are known, and indeed are a key input in assessing the economic impact of low water levels on harbours and marinas, it is impossible to predict how much dredging will actually take place or how quickly, and to factor that into the economic impact assessment.

   We mitigate this limitation to some degree by limiting ourselves to analyzing impacts at time points no more than several decades far (2030 and 2050), even though lower levels are projected for time points beyond 2050. We also list, for each case study, the main adaptive behaviours likely to be taken in that particular sector.

The highlighted uncertainties and limitations underscore the importance of further scientific and economic data collection and analysis for effective decision-making in response to fluctuations in GLSL water levels. It is imperative to continue to study the interactions of hydroclimatic factors that affect GLSL water levels as well as the impacts of climate change on these interactions, and to use this knowledge in refining water level projections and assessing their relative likelihood. This entails continued and increased data monitoring and collection, more sophisticated and robust analysis, and continued advancement and refinement of climate modelling.


CSL TADOUSSAC

Part 2: Case Studies

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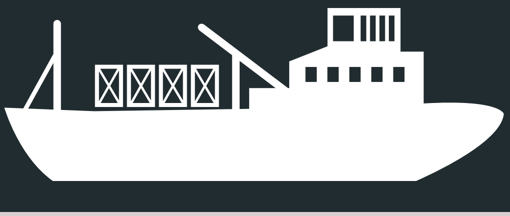

Commercial Shipping and Harbours

ESTIMATED IMPACT 2030	ESTIMATED IMPACT 2050
$1.18B	$1.92B

- 38 per cent of losses through 2030 ($446M) and 61 per cent of losses through 2050 ($117B) is due to loss of shipping capacity. The remainder would be felt by harbours.
- The iron ore industry (shippers and producers) could face losses to shipping capacity estimated at $220M through 2030 and $465M through 2050. Coal shippers and producers could face losses to shipping capacity estimated at $190M through 2030 and $373M through 2050.
- 61 per cent ($275M) of impact on harbours through 2030 and 56 per cent ($310M) of impact on harbours through 2050 due to maintenance and repair costs.
- Harbour repair, maintenance, and dredging costs are relatively spread out across the region downstream of Lake Superior, with Lake Erie taking the biggest hit.
- For an average sized freighter carrying 70,000 short tons, a lake level drop of 3.3 ft (1 m) would mean approximately a 14 per cent reduction in cargo load, and a drop of 16.4 ft (5 m) would reduce cargo by as much as 70 per cent.
- 50 to 270 short tons loss of cargo capacity per inch of lower water (depending on vessel size).
- Next best alternative to commercial shipping for all tonnage in the great lakes would lead to an increase in costs of $2.65B (CAD) per year
- Using a ton-miles per gallon measure of fuel economy, Great Lakes-St. Lawrence waterborne shipping emits 19% less GHGs than rail and 533% less than truck.

The GLSL Seaway System spans

OVER 2300 MILES

From the head of Lake Superior to the Atlantic Ocean, passing through all the Great Lakes as well as the St. Marys, St. Clair, Detroit and St. Lawrence Rivers, the Welland Canal, and the locks at Sault Ste. Marie and the St. Lawrence River.

THE SEAWAY SYSTEM IS MANAGED THROUGH A
binational partnership

TOTALLING
$4.4B (USD)
IN WAGES
IN 2010

NEARLY
93,000
direct jobs

THE SEAWAY SYSTEM PROVIDES NEARLY
134,000
indirect jobs

Over **355M** short tons
handled in the 15 international and 50 regional ports of the
GLSL SEAWAY SYSTEM IN 2010

Vessels vary in size, from about
200-740 feet in the Canadian fleet & 1000 feet in the US fleet

$4.6B (USD)
in federal, state/provincial and local
TAX REVENUE IN CANADA AND US
FROM THE GLSL SEAWAY SYSTEM IN 2010.

$33.6B (USD)
in direct and indirect
ECONOMIC ACTIVITY
generated in Canada and US
BY THE GLSL SEAWAY SYSTEM IN 2010.

Industries served include:

THE PRODUCERS AND USERS OF GRAINS AND OTHER AGRICULTURAL PRODUCT,
SAND, GRAVEL, AND STONE,
CEMENT, SALT, CHEMICALS,
IRON ORES, STEEL,
METAL SLAG, ASH, AND RESIDUE,
PETROLEUM PRODUCTS,
COAL AND COAL PRODUCTS, POTASH,
RAW SUGAR,
AND MANY DIFFERENT IMPORTED AND EXPORTED CONSUMER GOODS

The GLSL region is characterized by the high integration of its economic prosperity and environmental sustainability. Commercial shipping is typical of this integration. It utilizes GLSL's main resource—its water—to enable the region's manufacturing and trade activities to operate in a reliable, cost-effective, fuel efficient, low polluting and low emitting manner. Many of the GLSL region's industries depend on the availability of reliable and low-cost waterborne transportation.

Maintaining and regulating commercial shipping in the GLSL region is the responsibility of the federal governments of the US and Canada. They have a dual focus on shipping channels and on commercial ports and harbours.

The GLSL Seaway System for commercial navigation extends from the Atlantic Ocean to the head of Lake Superior, a distance of 2,300 miles. It utilizes a combination of natural waterways (the St. Marys, St. Clair, Detroit and St. Lawrence Rivers) and human-made structures (the St. Lawrence Seaway, the St. Lawrence River locks, the Welland Canal, and the Sault Ste. Marie Locks). It is operated through a bi-national partnership between the US and Canada, which enforces standards and regulations, maintains and distributes navigational data, and operates, dredges, and maintains the navigation channels.

Most commercial ports and harbours in the GLSL have a mix of private and public facilities. In Canada, 19 ports remain managed by independent arm's length port authorities managed under the federal government, while other ports are managed by provincial and local governments or private companies.[75] The maritime industry pays for maintenance dredging on the St. Lawrence River, while governments, through general revenues, pay for maintenance dredging in the rest of the GLSL Seaway System.

On the US side, most commercial ports are managed by public port authorities created by state or local government, with maintenance dredging the responsibility of USACE under specific project funding itemized in the federal budget. Some private companies manage their own ports.[76] Funding for this maintenance dredging is supposed to come from a nationwide harbour maintenance tax, though in practice a significant portion of those revenues is transferred to general revenues. Legislation that would dedicate these revenues first and foremost to harbour maintenance was signed into law in 2014.

A recent industry-commissioned assessment of the industry's economic footprint reported that in 2010, the GLSL Seaway System handled over 355.05 short tons (322.1M metric tons) of cargo and generated $33.6B (USD) in direct and indirect economic activity with a total of $4.6B (USD) in federal, state/provincial and local tax revenue in Canada and the US.[77] The report also found that 92,923 direct and 133,910 indirect jobs in Canada and the US were related to the industry, with direct jobs accounting for a total wage bill of $4.4B (USD) in 2010.[78]

Several factors introduce variability into the GLSL Seaway System. The fleet's ships vary in size, from about 200 ft (60.96 m) to about 1,000 ft (304.8 m) in length. The System's 15 international and 50 regional ports also vary in both size and depth. The System is utilized by a large variety of industries, including the producers and users of grains and other agricultural product; sand, gravel, and stone; cement; salt; chemicals; iron ores; steel; metal slag, ash, and residue; petroleum products; coal and coal products; potash; raw sugar; and many different imported and exported consumer goods. In some cases, waterborne shipping is the only economically viable means of transporting certain goods in the GLSL region.

[75] Marine Delivers, n.d.

[76] Marine Delivers, n.d.

[77] Martin Associates, 2011: 30-31.

[78] Martin Associates, 2011: 31.

FINDINGS: Identified impacts of fluctuations in GLSL water levels

Table 1 summarizes the major impacts of fluctuations in GLSL water levels on commercial shipping and harbours as identified in our research.

TABLE 1

Major impacts of fluctuations in GLSL water levels on waterborne commercial shipping and harbours as identified in our research

	Low water levels	High water levels
NEGATIVE –	» Reduced loads to maintain necessary under-keel clearance, increasing number of trips and total costs needed to move same amount of cargo » Reduced speed and more stoppages in transit in order to avoid grounding » Additional capital expenditures on fleet if more trips are needed » Risk to operation of industries that cannot viably ship by rail or truck » Losses, increased costs, and increased environmental risk from shift of other industries to rail or truck » Increased need for dredging and infrastructure maintenance/ replacement in harbours and navigation channels	» Damage/disabling of loading/unloading facilities » Risk to safe operation of navigation locks
POSITIVE +	» A longer navigation season due to reduced ice coverage » Reduced ice-breaking costs » Increased business to harbours due to additional trips from shippers	» Increased loads reducing number of trips and total costs needed to move same amount of cargo

As the IUGLSB pointed out, “In general, lower water levels will adversely impact [commercial navigation] interests more than higher levels.”[79] Already, ocean-going vessels operating in the GLSL Seaway System typically operate below their maximum capacity while lakers typically operate at minimal bottom clearances.[80]

Declines in water levels in the channels as well as harbour entrances could lower available bottom clearance and force shippers to lighten their loads. This could increase the number of trips required to move a given amount of cargo. Longer-term, this could require additional maintenance on existing vessels as well as capital expenditures to increase the fleet, especially with new vessels shaped to operate in shallower conditions. Additional traffic combined with potential shallowing in key harbours may force speed reductions and stoppages in transit, causing delays in delivering cargo.[81]

These losses and adaptation costs have been well documented. A 2002 analysis found that “a 1000-foot lake-going ship loses 270 tons of capacity per inch of lost draft, and an ocean-going vessel of about 740 feet loses 100 tons of capacity for each inch of lost draft.”[82] A 2006 analysis found that for an average sized freighter carrying 70,000 tons, a lake level drop of 3.28 ft (1 m) would mean approximately a 14 per cent reduction in cargo load while a drop of 16.4 ft (5 m) would reduce cargo by as much as 70 per cent.[83] In 2013, industry sources drawing on recent experience reported a loss of 50 to 270 tons of cargo per inch of lower water (depending on vessel size).[84]

The IUGLSB found that “for many commodities, alternate modes and routes are available and would become more competitive if the cost of water transport increases. Grain exports, for example, can avoid the Great Lakes by using rail shipments to lower St. Lawrence River ports, western Canadian ports, and the Port of Churchill, MB, or, in combination with barge transportation, Gulf of Mexico ports. A similar shift could occur for iron ore, which could be moved by rail or a combination of ocean transport and rail.”[85] Such adaptation, insofar as it shifts work from GLSL ports and shippers to ports and shippers outside the region would represent a further loss to the regional economy.

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[79] IUGLS, 2012: 27.
[80] IUGLS, 2012: 27.
[81] IUGLS, 2012: 27.
[82] Cruce and Yurkovich, 2011: 40, citing Quinn, 2002.
[83] Lentz, 2006: 7.
[84] Quoted in Williams, 2013.
[85] IUGLS, 2012: 27.

Alternatives to commercial shipping are typically more expensive and less fuel and GHG efficient.[86] A recent industry estimates suggested that overall, the GLSL Seaway System offers shippers savings estimated at $2.65B (CAD) per year over the next-best all land alternative, or $14.80 per short ton on average.[87] Another industry-commissioned study noted that to move 33,069.3 short tons (30,000 metric tons) of cargo by land would require 301 rail cars or 963 trucks.[88] The same study highlighted that, using a ton-miles per gallon measure of fuel economy, GLSL waterborne shipping is 14 per cent more fuel efficient than rail and 594 per cent more fuel efficient than truck while emitting 19 per cent less GHGs than rail and 533 per cent less than truck.[89]

In addition, not all industries can viably shift to alternative modes of transportation. In particular, heavy and bulky materials, such as cement, chemicals, or steel, can only be shipped by truck or rail in low quantities. This makes alternatives to commercial shipping less viable and possibly prohibitive for industries that mine, process, produce, or rely on such materials and products, especially where existing facilities have limited or no rail access. In a recent report, the US Department of Transportation found that 105 of 238 US-side receive-only facilities in the GLSL did not have direct rail access, including 21 in the cement and concrete industries and 20 in the sand and gravel industries.[90]

Even when shipped, such materials and products require deep water ports as a critical part of their business. Given that these are industries in which location competitiveness is often a key issue, these factors may cause companies processing or producing such materials to reconsider their GLSL manufacturing locations.

Low water levels also increase the costs of harbour maintenance. Additional (and costly) maintenance dredging, and in some cases even capital dredging, may be required to allow vessels to enter and leave ports, and shallower ports may be doubly hit as companies reroute shipments and partially unload at deeper ports. Wooden supports for aging docks and breakwaters could be damaged by dry rot and exposure to air and may need to be reconstructed.

In 1964, low water levels led to maintenance spending of approximately $843M (USD; 1988 dollars) to repair harbour infrastructure. A 2011 report found that the Duluth and Toledo harbours are in need of $177-298.5M (USD) and $71.4-122.8M (USD) in upgrades and repairs, respectively.[91] The Port of Indiana recently spent over $10M to repair a single pier structure damaged from accelerated decomposition and undercutting due to structural exposure from low water levels.[92]

The IUGLSB suggested that less ice coverage could extend the shipping season, leading to increased utilization of vessels and reduced stockpiling.[93] Low water levels have commonly been accompanied by less ice coverage in the past. This positive impact, however, may be limited by the fact that eight to ten weeks are needed to perform annual maintenance on the region's fleets.[94] Given that the shipping season is already close to ten months, the window for extending the shipping season due to reduced ice coverage is fairly narrow, usually a week or two. Reduced ice coverage, however, would probably reduce the costs of annual ice-breaking in the GLSL Seaway System.

If shippers adapt to low water levels by increasing the number of trips, this could mean more business for harbours, at least in the short term. Whether this gain becomes a long-term gain depends on whether adaptation by shippers and client industries is enough to stave off overall loss of business for the GLSL Seaway System. In addition, low water levels could increase competition among the region's ports both over shipping business and especially over government funding for maintenance dredging, repairs and other maintenance.

While commercial shipping in the GLSL is, as the IUGLSB noted, more sensitive to low water levels than to high water levels, it can still be impacted by high water levels. By the same token that declining water levels reduce shipping capacity and increase costs to move a given amount of cargo, "higher water levels may allow increased vessel loads, reducing the costs of moving given quantities of cargo."[95] However, this positive impact "is limited by the design capacity of vessels."[96]

The IUGLSB flagged that "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."[97] Additional research is needed to reliably isolate costs specific to commercial shipping and harbours from more general data, but this general data indicates the overall costs of flooding and coastal erosion could be significant.

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[86] United States Army Corps of Engineers Great Lakes and Ohio River Division, 2010.
[87] Reported in MariNova Consulting Ltd. et al., 2009: 115.
[88] English and Hackston, 2013: 12.
[89] English and Hackston, 2013: 6.
[90] United States Department of Transportation Maritime Administration, 2013: 34.
[91] Cruce and Yurkovich, 2011.
[92] Data provided by Georgian Bay Forever.
[93] IUGLS, 2012: 27.
[94] MariNova Consulting Ltd. et al., 2009: 54 and authors' interview with industry sources.
[95] IUGLS, 2012: 27.
[96] IUGLS, 2012: 27.
[97] IUGLS, 2012: 27.

For example, in 2003, the US General Accounting Office reported that in the fiscal years from 1992 through 2001, USACE spent over $195M (USD) on special authorized projects focused on flood damage reduction, and an additional $10M (USD) on erosion control, on the US side of the Great Lakes basin.[98] While most of this work was done in tributaries and reserves, it likely also benefited harbours as well as coastal residents and other GLSL interests. According to EC, the major flooding and erosion episodes which occurred in 1972-1973 and 1985-1987 caused over $209M (CAD; recalculated in 1998 terms) in overall damages on the Ontario shores of the Great Lakes.[99]

FIGURE 11

Map of commercial ports in the GLSL

Source: Chamber of Marine Commerce, modified from www.marinedelivers.com

Commercial shipping is an industry spread across the region, servicing and connecting all Great Lakes and the St. Lawrence River. Indeed, the GLSL is home to multiple ports of varying sizes (see Figure 11). While there are relatively more ports on Lakes Michigan and Erie, some of the region's major commercial ports, such as the ports of Duluth-Superior (the largest and busiest GLSL port), Saginaw, Hamilton, and Montreal, are located in other parts of the GLSL.

As a result, the economic impacts of fluctuations in water levels on shippers and the navigation system are regional in scope. At the same time, there will likely be significant local variability and some sub-regional variability in economic impacts on harbours, because such impacts depend on factors such as the size of the harbour, the age and nature of its infrastructure, its existing depth, what commodities pass through it, etc.

FINDINGS: Estimated future impacts of a worst-case low water levels scenario

Table 2 summarizes region-wide economic impacts on commercial shipping and harbours under a worst-case low water levels scenario as estimated based on the authors' analysis. Table 3 summarizes lake-by-lake economic impacts on harbours as estimated under a worst-case low water levels scenario based on the authors' analysis. The methodology used to arrive at these estimates is described in detail in Appendix 2.

TABLE 2

Estimated region-wide economic impacts under a worst-case low water levels scenario on commercial shipping and harbours (total-over-period, converted to 2012 USD)

Climate change scenario	Infrastructure repair and replacement costs	Slip dredging	Harbour dredging (outside of slips)	Loss of carrying capacity	Total
SC2030 % of Total	**$446M** 38%	**$9M** 1%	**$275M** 23%	**$446M** 38%	**$1.18B**
SC2050 % of Total	**$418M** 22%	**$22M** 1%	**$310M** 16%	**$1.17B** 61%	**$1.92B**

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[98] Authors' calculation from data in USGAO, 2003: 77-78.
[99] EC, n.d.b.

TABLE 3

Estimated lake-by-lake economic impacts under a worst-case low water levels scenario on harbours (total-over-period, converted to 2012 USD)

Climate change scenario	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario	St Lawrence River	Total
SC2030 % of Total	**$46M** 6%	**$142M** 19%	**$70M** 10%	**$292M** 40%	**$89M** 12%	**$92M** 13%	**$730M**
SC2050 % of Total	**$47M** 6%	**$162M** 22%	**$82M** 11%	**$274M** 37%	**$94M** 13%	**$90M** 12%	**$750M**

Our analysis estimates that a worst-case low water levels scenario could cost GLSL shipping $1.18B over the period through 2030 and $1.92B over the period through 2050 (converted to 2012 value and stated in USD). Loss of shipping capacity represents 38 per cent of the estimated impact through 2030 and 61 per cent of the estimated through 2050.

The direct risk of losses to carrying capacity would fall on the shipping industry. It is possible that some of these losses could be passed on to client industries, though it is difficult to project the degree to which that will occur. However, industry sources have noted to the authors that, as currently constituted, typical shipping contracts limit the industry’s ability to pass this risk to client industries.

The remainder of our estimated impact—$730M (62 per cent) of impact through 2030 and $750M (39 per cent) of the impact through 2050—would be felt by harbours. The primary impact on harbours, accounting for $446M (61 per cent of estimated harbour impacts) through 2030 and $418M (56 per cent of estimated harbour impacts) through 2050, stems from the costs of repairs and maintenance other than harbour dredging. Additional maintenance dredging or even capital dredging outside slips is another major component of harbour impacts, accounting for $275M (38 per cent of estimated harbour impacts) through 2030 and $310M (41 per cent of estimated harbour impacts) through 2050.

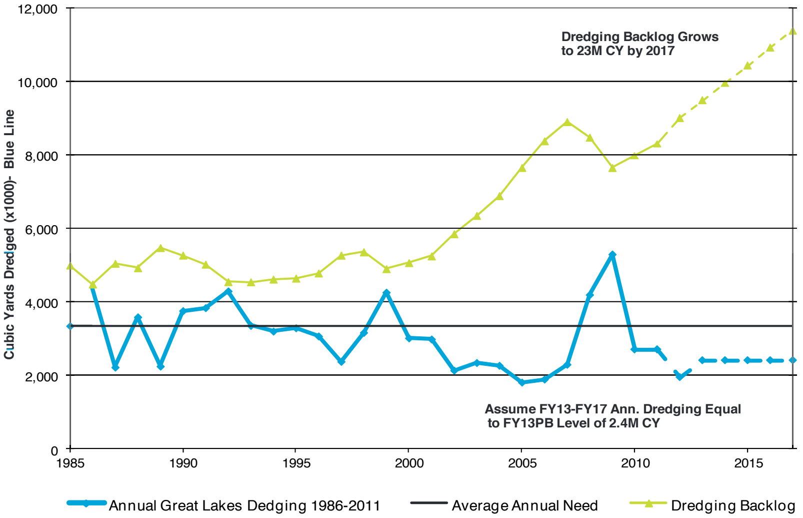
Both of these costs would probably be shared between port authorities and governments, especially federal governments, with significant government assistance needed to offset costs currently incurred by port authorities. Dredging is particularly worrisome because there is already a backlog in carrying out needed harbour maintenance dredging projects in GLSL harbours due to government funding falling short of maintenance dredging needs. In 2012, USACE projected that on the US side of the GLSL alone, dredging needs will reach close to ten times the 2012 level by 2017 (see Figure 12).

Notably, if low water levels persist or even continue to drop over the longer term (as projected by the worst-case low water levels scenario), the impact of loss of shipping capacity would continue to rise much more than the impact on harbours. This is because harbours incur more of their costs as water levels begin to shallow—for example, if infrastructure needs replacing due to dry rot after a 1.64 ft (0.5 m) drop in water levels, the new infrastructure should be able to withstand further drops. Shipping capacity, by contrast, continues to drop as water levels drop.

This is the reason that loss of shipping capacity accounts for 75 per cent of the impact through 2050 but only 59 per cent of the impact through 2030 combined with the fact that discounting to present value reduces longer-term values more than nearer-term ones, this also accounts for the fact that harbour repair and maintenance impacts estimated for the period from the present through 2050 are lower than for the (shorter) period from the present through 2030.

FIGURE 12

GLSL US-side federal harbour dredging backlog (2012-2017)



Source: USACE, modified from http://www.lre.usace.army.mil/Portals/69/docs/Navigation/NavFundingSummaries/FY12-13Dredging(4)/Dredging%20Backlog%20growth%20through%202017.pdf

TABLE 4

Estimated region-wide economic impacts of worst-case low water levels on loss of shipping capacity in GLSL raw commodities industries (total-over-period, converted to 2012 USD)

Climate Change Scenario	Iron ore	Grain	Stone/	Cement	Salt	Other dry	Liquid	Coal	Total
SC2030 % of Total	$220M 33%	$6M 1%	$89M 13%	$24M	$65M	$48M	$24M	$190M	$666M
SC2050 % of Total	$465M 34%	$23M 2%	$175M 13%	$46M 3%	$130M 10%	$107M 8%	$46M 3%	$373M 27%	$1365M

As shown in Table 3, harbour repair, maintenance, and dredging costs would be felt across the region, with Lake Erie seeing the biggest portion—40 per cent through 2030 and 37 per cent through 2050—followed by Lake Michigan at 19 per cent through 2030 and 22 per cent through 2050. This suggests that harbour repair and dredging needs would be higher in those lakes, but it is notable that those lakes also have the most ports in the region. Notably, Lake Erie is home to the most heavily dredged port in the GLSL, the Port of Toledo (see Local snapshot, next page).

It is impractical to try to divide loss of carrying capacity impacts on a lake-by-lake basis given that many ships in both GLSL fleets travel between lakes and sub-regions. It is possible, however, to estimate losses for certain industries—specifically, raw commodities—by updating industry-specific data provided by Millerd (see Table 4).

Millerd applied the same water levels scenario we use to industry data he obtained regarding trip travel routes, travel times, carrying capacity losses, past industry costs data, and other related information.[100] Notably, this is a fundamentally different methodology from that used in generating our broader shipping sector impact values (Tables 2 and 3). As a result, the values in Table 4 cannot be taken as a breakdown of the values in Table 2.

Our analysis shows the raw commodities industries most heavily impacted by losses in shipping capacity would be iron ore ($220M through 2030 and $465M through 2050) and coal ($190M through 2030 and $373M through 2050). This suggests ports more heavily reliant on these industries may see greater losses in traffic and business due to shipping capacity losses.

It is unclear how these costs, as well as the costs of lost shipping capacity in other industries or overall, might be split between shippers and client industries. As already noted, some shipping cost increases incurred by shippers due to low water levels could potentially be transferred to client industries, although typical industry contracts limit shippers' ability to do this. This entails a delicate balance between the viability and competitiveness of the shipping industry and that of the various client industries. Many industries operate in the GLSL precisely because the availability of relatively cheap and easy access to marine shipping makes those industries competitive. If this ceases to be the case, facilities or even whole industries might feel forced to relocate out of the region.

Any given industry, plant, mine, or other facility, has its own shipping cost increase cut-off point beyond which it is no longer competitive, and therefore its own elasticity to absorb shipping cost increases due to low water levels. Even when the producers of a certain commodity do not have a viable alternative to water-based shipping, purchasers could simply purchase the goods from producers based elsewhere.

However, the cut-off point beyond which a given industry or facility is no longer competitive cannot be ascertained without industry- and facility-specific data that is not publicly available. As a result, impacts on industry competitiveness under the worst-case low water levels scenario could not be reliably projected.

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[100] Millerd, 2005.

LOCAL SNAPSHOT: Port of Toledo

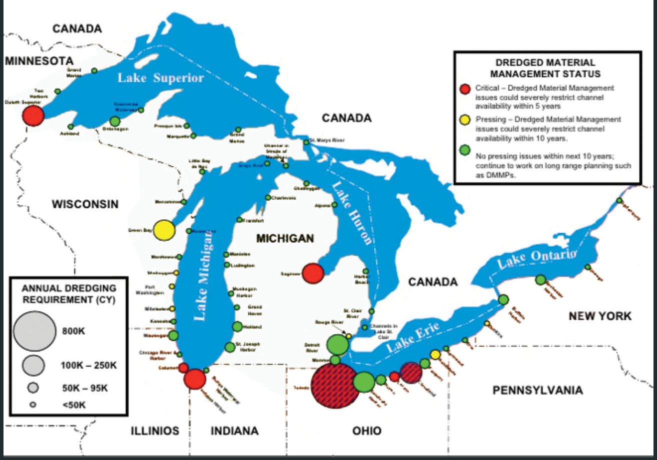
The Port of Toledo on Lake Erie is a commercial harbour with 28 slips. It is the most heavily dredged port in the GLSL and is a critical component of the economic viability of Northwest Ohio.[101] In 2013, the port shipped 9,748,078 metric tons, primarily of coal, limestone, titanium ore, pig iron, bulk sugar, and petroleum coke.[102] The Toledo Harbor, run by the Toledo-Lucas County Port Authority, has an annual economic impact of more than $1B (USD) and has helped create or retain more than 10,000 jobs in Northwest Ohio.[103]

Already located on the shallowest of the Great Lakes, the Port of Toledo is particularly susceptible to severe declines in water levels. To keep the port functioning, annual maintenance dredging needs can reach one million cubic yards.[104] This is the largest annual dredging project of any Great Lakes port, both in terms of cost and quantity dredged (see Figure 13). Toledo Harbour dredging alone constitutes 25 per cent of total Great Lakes dredging. Within five to ten years, dredged material management issues could severely restrict channel availability in the harbour.[105]

Bergeron and Clark estimated that dredging Toledo's slips and channel could cost $11-12M (USD). Infrastructure costs could vary between $72M (USD) and $123M (USD) depending on the condition of the infrastructure and the number of feet that would need to be dredged.[106]

FIGURE 13

Major GLSL US-side ports and dredging needs



Source: Toledo-Lucas County Port Authority, modified from McCrimmon, 2010.

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[101] Hull & Associates Inc., 2012: i.
[102] Patch, 2014.
[103] McCrimmon, 2010.
[104] Patch, 2014.
[105] Patch, 2014.
[106] Bergeron and Clark, 2011.

Tourism and Recreational Water Activities

ESTIMATED
IMPACT
2030

$6.65B

RECREATIONAL
BOATING & FISHING:
$6.59B

ESTIMATED
IMPACT
2050

$12.86B

RECREATIONAL
BOATING & FISHING:
$12.66B

- » 88 per cent of losses ($5.862B through 2030; $11.262B through 2050) is due to losses in boating days and annual boating expenditures (excluding fishing).
- » Lake Huron accounts for 35 per cent of the impact on marinas through 2030 and 36 per cent of this impact through 2050.
- » Lakes Huron and Michigan combine for 60 per cent of the impact on marinas through 2030 and 63 per cent of this impact through 2050.
- » A 1.9-ft drop in water levels to result in 29 marinas closing, losses of 1,498 recreational boating slips, and $6.3M in reduced annual expenditures in Georgian Bay and Severn Sound alone.
- » At least 5/8 of fish species in the region spawn in coastal wetlands that may be at risk of drying up due to declines in water levels.

It is estimated that up to
21M PEOPLE
participated in some kind of
recreational boating activity
ON THE UPPER GREAT LAKES IN 2009.

THE GREAT LAKES BASIN IS HOME TO AN ESTIMATED
1/3
of all recreational boaters registered in the US.

OVER 4,500 BUSINESSES
serve recreational boaters
in 8 US counties bordering Lake Ontario and the St. Lawrence River.

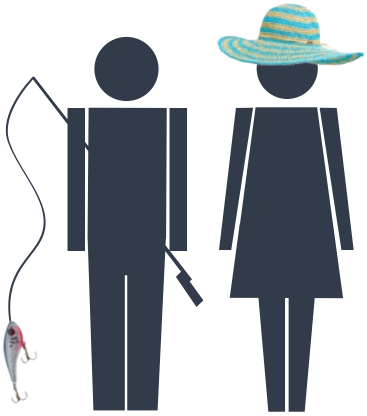
MORE THAN
5M boats,
ranging from kayaks to large motor yachts,
are registered in the upper Great Lakes region.

23.6M FISH CAUGHT
7.1M FISH RETAINED
on the Great Lakes in 2005.

2/3 OF ALL WILD FISH
in the Great lakes region use wetlands for spawning purposes,

Sport fishing and recreational boating in the region contribute just over
$10B (USD) ANNUALLY
to the region's economy.

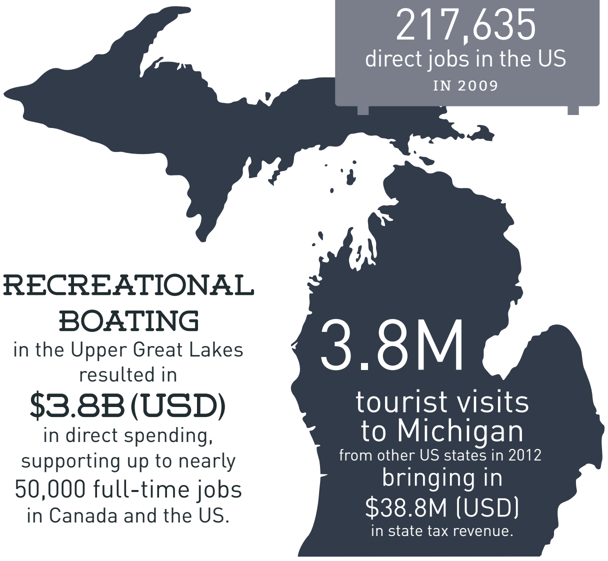
$14.9M (USD) in gross sales
343,845 labour hours
CONTRIBUTED IN 2009 BY CHARTER BOATING TO LOCAL ECONOMIES IN MICHIGAN STATE.



IN 2010
Ontario's Great Lakes regions had **73M tourist visits** with estimated spending of
$12.3B (CAD)

GREAT LAKES TOURISM PROVIDED
217,635
direct jobs in the US
IN 2009

RECREATIONAL BOATING
in the Upper Great Lakes resulted in
$3.8B (USD)
in direct spending, supporting up to nearly 50,000 full-time jobs in Canada and the US.



3.8M
tourist visits to Michigan
from other US states in 2012
bringing in
$38.8M (USD)
in state tax revenue.

The Great Lakes, the St. Lawrence River, and their tributaries and connecting channels have long been prime vacation and tourism destinations—the Niagara Falls, for example, is an icon that is recognizable all over the world. There is great variability in the attractions, activities, and experiences offered to tourists in the many large and small communities in the region where tourism and recreational water activities are a critical economic input. As the region diversifies its economy, the economic importance of tourism and recreational water uses is growing rapidly.

The data regarding the economic contribution of this sector is patchy but telling. The Ontario government reported that in 2010, Ontario's Great Lakes regions saw 73M tourist visits with estimated spending of $12.3B (CAD).[107] A report commissioned by the Michigan Sea Grant noted that in 2009, Great Lakes tourism accounted for 217,635 direct jobs in the US.[108] In all, tourism is a vibrant multi-billion dollar industry across the region, and represents one of the region's major growth opportunities.

The IUGLSB distinguished three components of the GLSL tourism industry: coastal tourism, recreational boating and fishing, and the cruise ship industry. Due to data limitations, the economic analysis in the present report focuses on recreational boating and fishing.

Many tourists (both visitors to the region and vacationing residents of the region) enjoy the lakes and other waterways of the region as places to swim or stroll along, as sights to be seen, or as a backdrop to other recreational activities. The IUGLSB found that, in areas bordering the upper Great Lakes alone, visitor tourism accounted for $55-60B (USD) in direct spending, supported over 650,000 jobs, and generated $7.5-7.75B (USD) in local and state/provincial taxes.[109] Pure Michigan reported that in 2012 the State of Michigan saw 3.8M tourist visits from other US states alone, bringing in $38.8M (USD) in state tax revenue.[110]

Other visitors and residents make active use of the waterways as boaters and/or anglers. The IUGLSB noted a recent decline in these activities, particularly a 30 per cent decline in participation in recreational fishing in the US Great Lakes between 1999 and 2006, and a 27 per cent decline in Ontario over a comparable period.[111] Water level fluctuations are one of several factors that affect this trend. Cross-generational changes in leisure patterns, for example, also contribute significantly to this trend.

Despite this decline, "millions of people [still] use boating experiences with family and friends on the Great Lakes to enhance the quality of their lives."[112] The IUGLSB estimates that up to 21M people have participated in some kind of recreational boating activity in the states and province on the upper Great Lakes in 2009, and that more than 5M boats, ranging from kayaks to large motor yachts, are registered in the upper Great Lakes.[113]

As a result, even with recent declines, recreational boating and fishing continue to make significant contributions to the region's economy. Where a 2005 report estimated an average $15.63B (USD) in annual spending by boaters in the region, a 2008 report estimated that sport fishing and recreational boating contribute $9.57B (USD) annually to the region's economy.[114] The IUGLSB estimated that recreational boating in the upper Great Lakes alone generates $3.8B (USD) in direct spending and supports up to nearly 50,000 full-time jobs in Canada and the US.[115]

In addition, recreational boating and fishing maintain critical secondary industries of marinas, boat retail and equipment rental businesses, housing and hospitality, and other downstream businesses, especially in many small communities in the region. In 2006, the International Lake Ontario-St. Lawrence River Study Board (ILOSLRSB) found, in the eight US counties bordering Lake Ontario and the St. Lawrence River alone, over 4,500 businesses that serve recreational boaters.[116] A more recent report commissioned by Michigan Sea Grant found that in 2009 in Michigan alone, charter fishing contributed $14.9M (USD) in gross sales and 343,845 labour hours to local economies.[117]

Recreational, non-commercial fishing is a vibrant water activity and major tourist attraction in the region. A 2008 report found that this activity contributed $7.4B (USD) to the regional economy.[118] Fisheries and Oceans Canada reported that in 2005, 23.6M fish of all species were caught on the Great Lakes, with close to 7.1M fish retained.[119] Two thirds of all wild fish in the GLSL (including fish with no food or fishing value) use wetlands for spawning purposes.[120]

The global cruise ship industry is growing rapidly. The IUGLSB found that "the Great Lakes region has yet to establish itself as a strong cruise destination", with only three cruise ships still operating in the Lakes as of 2010.[121]

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[107] Government of Ontario, 2012: 9.
[108] Vaccaro and Read, 2011: 2.
[109] IUGLS, 2012: 34.
[110] Cited in Sanchez, 2013.
[111] IUGLS, 2012: 35.
[112] IUGLS, 2012: 35.
[113] IUGLS, 2012: 34.
[114] GLC, 2005: 7; Krantzberg and De Boer, 2008: 102.
[115] IUGLS, 2012: 34.
[116] ILOSLRSB, 2006b: 46.
[117] O'Keefe and Miller, 2011: 1.
[118] Krantzberg and De Boer, 2008: 102.
[119] Fisheries and Oceans Canada, 2005.
[120] Michigan Sea Grant, n.d.
[121] IUGLS, 2012: 35.

The cruise ship industry is, however, quite vibrant on the St. Lawrence River. The Government of Quebec reported that in the 2012-2013 fiscal year, 126,000 cruise passengers visited Quebec St. Lawrence River ports, totaling $145.3 (CAD) in passenger expenditures in the province.[122] According to the Association of Canadian Port Authorities, the Port of Montreal hosted 51 cruise ships and 55,000 passengers in 2012, while the Port of Quebec hosted 83,000 cruise passengers in 2011.[123]

In 2010, the Tourism Intelligence Network estimated cruise ship related spending in Quebec at $138M (CAD), with 76 calls and 121,714 passengers in the Port of Quebec, and 26 calls and 40,208 passengers in the Port of Montreal in 2009.[124]

For users, the value of touristic or recreational water activities is driven by 'the tourist/boating/fishing experience'. The economic value of this industry is therefore susceptible to factors that diminish either users' enjoyment or, in the case of first time users (such as many coastal tourists), the expectation of such enjoyment. Such factors may relate to the object of enjoyment, such as the aesthetics of a beach or a view or the availability of fish, or to the effort and cost entailed in the enjoyment of those objects, such as boat maintenance/repair costs or ease of access to water.

For many communities in the region, the local economy depends to a large degree on tourism and recreational activities. The high caliber of their natural environment is, for such communities, the basis of their value as a vacation destination. Diminish their pristine character, and visitors might go elsewhere. As a result, this may be the sector where the impacts of fluctuating water levels are perhaps most directly felt by the greatest number of people.

FINDINGS: Identified impacts of fluctuations in GLSL water levels

Table 5 summarizes the major impacts of fluctuations in GLSL water levels on tourism and recreational water activities as identified in our research.

Fluctuating water levels have differing impacts on coastal tourism, recreational boating and fishing, and the cruise ship industry. According to survey data collected for the IUGLSB, coastal tourists "for the most part, have not taken water levels into consideration when making their travel plans, and that most businesses surveyed did not see water levels as an issue that affected the performance of their business." Nonetheless, in the same survey, businesses "indicated that lower water levels were more detrimental to tourism activities than higher water levels."[125]

TABLE 5

Major impacts of fluctuations in GLSL water levels on tourism and recreational water activities as identified in our research

	Low water levels	High water levels
NEGATIVE –	» Damage to the quality and image of tourist attractions such as beaches, risking local tourism industries » Narrowing of access channels to marinas resulting in closures and bottlenecks » Increased risk of boats running aground, with ensuing costs of damage or salvage » Loss of water access if water by marina slips or private boat launches becomes too shallow » Risk of exposure and damage to boating and marina infrastructure » Increased dredging and maintenance costs for marinas to ensure access and usability » Loss of spawning grounds could result in reduction in fish stocks and risk to species variety » Risk of cruise ships touching bottom or being forced to reroute, and of having to transport passengers by lifeboat or bus as a result	» Risk of flooding of boat launches and parking lots » Risk of floating debris damaging boats or halting boating/fishing activity » Risk of rapid flows and of floating debris/ice interrupting cruise ship activity
POSITIVE +	» Reduced ice coverage and longer spans of higher temperatures could lead to a longer boating season » Enlarged public beach area, if extended beach is sandy and cleanup costs can be absorbed	» None identified

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[122] Ministère des Finances et de l'Économie Québec, 2013: 83.
[123] Association of Canadian Port Authorities, n.d.
[124] Tourism Intelligence Network, 2010.
[125] IUGLS, 2012: 35.

As already noted, the value of tourism for tourists is in the 'tourist experience' or 'vacation experience'. Fluctuations in water levels would thus impact coastal tourists' decision on a vacation/visit location insofar as they diminish the tourist's expectation of enjoyment. In other words, the main threat of fluctuating water levels to coastal tourism is reputational: the extent to which low or high water levels impact a destination's image as a tourist attraction.

Beach closures, damage, or loss of aesthetic appeal could therefore affect coastal tourists' choice of destination insofar as a destination becomes known as suffering from such impacts. Such impacts can result from both high (closures due to flooding, loss of access due to erosion, debris requiring cleanup) and low (beaches turning rocky due to receding waters, or acquiring odorous vegetation) water levels, although the IUGLSB only raised the latter as a point of potential concern.[126]

Coastal tourists choose their destinations based on multiple factors. It is difficult to disaggregate and therefore quantify individual factors affecting this decision. As we explain Appendix 3, there is data available to disaggregate the impact of low water levels from other factors affecting recreational decisions only in the cases of boaters and anglers.

Similarly, high or low water levels could affect the cruise ship sector insofar as they diminish the cruising experience, for example by creating departure delays, mid-cruise stoppages, or reroutings. The IUGLSB, in the context of lake cruising, noted that low water levels had already caused instances of cruise ships nearly touching bottom at entrances to certain ports, forcing cruise ship companies to transport passengers by life boat or by bus from an alternative port.[127]

Concern over touching ground due to low water levels could arise on the St. Lawrence River as well, depending on the depth of port entrances and the river on different cruise routes. High water levels could also affect the cruising experience to the extent that they cause rapid river flows and/or floating ice and debris. Further study is needed to identify and quantify the impacts of both high and low water levels on the St. Lawrence River cruise ship industry.

Recreational boating and fishing is the segment of tourism most directly affected by low water levels—and for which such impacts are the most reliably quantifiable. Because boaters and anglers are often repeat users, additional costs and accumulated struggles and bad experiences due to fluctuations in water levels directly affect their decisions on resuming the activity at the same location.

Within this segment of tourism, we distinguish three impact components: impacts on boating days and on annual boating related expenditures, impacts on fishing days and fish catch rates, and impacts on marinas. Of course, many anglers fish off boats and are therefore susceptible to the same impacts as boaters. We separate impact on fishing days from impact on non-fishing boating days in our own analysis of the worst-case low water levels scenario to avoid double counting these impacts.

The IUGLSB noted that low water levels could render boating lanes, marina entrances and docks, or private boat launches too shallow to use. Low water levels may also cause bottlenecks entering narrowing access channels, and could cause boaters to run aground or get entangled in aquatic vegetation and debris, requiring costly salvage and/or repairs.[128] An independent 2009 study expected a 1.97 ft (60 cm) drop in water levels would result in 29 marinas closing and losses of 1,498 recreational boating slips in Georgian Bay and Severn Sound alone.[129]

These impacts could lead to lost boating days as boaters find themselves unable to take their boats out to the water or having to spend potential boating days on boat repairs instead. The risk of such impacts occurring might also sway boaters from undertaking a boating excursion they would have otherwise, contributing to loss of boating days.

For example, a report commissioned by the ILOSLRSB found that during the low water levels of the 2002 boating season on Lake Ontario and the St. Lawrence River, an average of eight boating days per boater were lost due to the impacts of low water levels.[130] Notably, this report's methodology accounted for boaters' different reasons for reducing or ceasing their activity, thereby isolating the impact of low water levels from other factors such as changing tastes and demographics (see Appendix 3).

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[126] IUGLS, 2012: 35.
[127] IUGLS, 2012: 36.
[128] IUGLS, 2012: 36.
[129] Stewart, 2009: 121.
[130] Connelly et al., 2005: 28.

Low water levels could mean a longer boating season and a potential increase in boating days if they are accompanied by reduced ice coverage, a shorter freezing period, and warmer temperatures.[131] Data on whether this would translate into new boaters or new/longer trips by existing boaters is not available. It would depend on boaters' willingness to take advantage of the opportunity to boat more in months that are not as warm as at the peak of the boating season and that are outside summer break at schools/universities.

Receding waters could increase the size of public beaches, at least insofar as the newly recovered beach area is sandy, and cleanup costs can be absorbed. The benefits of this could accrue to coastal tourists and to the municipalities hosting them, as long as low water levels persist.

The literature does not flag positive impacts for recreational boating and fishing from high water levels. If the economic potential of these activities is already fully tapped at average or moderately high water levels, it is possible that there may not be additional benefits to be accrued for these activities from higher water levels.

High water levels could adversely affect boating activities inasmuch as they submerge or damage marina infrastructure or private boat launches, or cause flood debris that could damage boats' ability to float in the water.[132] Nonetheless, the IUGLSB found that risks to marinas as a result of low water levels are more adverse than those that result from high water levels.[133]

Fewer boating days may also mean less spending on trips, equipment, and boat maintenance or purchase. This would add losses to marina owners, equipment renters, boat sellers, and other downstream businesses. For example, the aforementioned study of Georgian Bay and Severn Sound estimated that the marina closings it expected under a 1.97 ft (60 cm) drop scenario would mean $6.3M (CAD) in reduced annual expenditures.[134]

Some boaters may adapt to prohibitive or damaging water level fluctuations by moving their boat to other, less-impacted, marinas. However, owners of bigger boats may find it particularly difficult to find alternative docking options under widespread low water level conditions.

In the short term, some of this impact could be offset by gains for businesses that provide boat salvage, repair, or replacement parts. However, should the need for such services recur, boaters may decide to shift their boating activity elsewhere or abandon it altogether, posing a risk for these businesses in the longer term.

Marinas could adapt to the narrowing of access channels and the shallowing of slips by introducing floating docks (where possible) or by increasing their maintenance dredging activities. Low water levels could also expose and damage boating infrastructure such as docks, piers, and seawalls, especially when such infrastructure is made of wood and thus susceptible to dry rot.[135] This would mean increased maintenance activities. Some of these increased marina dredging and maintenance costs could be passed on to recreational boaters.

As noted earlier, high water levels could submerge or damage marina slips. Nonetheless, the IUGLSB noted that "marinas typically are more adversely affected by low water level conditions, while high water levels are more of a nuisance than a serious problem."[136]

Anglers who fish from boats are susceptible to the same impacts as other boaters. However, anglers (both boaters and non-boaters) face additional vulnerability to extreme fluctuations in water levels insofar as such fluctuations, especially when combined with changes to water temperatures, affect fish populations and therefore catch.

80 per cent of sport fishing species need wetlands and streams to spawn. Those wetlands and streams can dry up or become inaccessible as water levels recede, risking both fish stocks and species variety.[137] Fracz and Chow-Fraser, in a recent study of Georgian Bay fisheries, estimated that at least around 50 of the 80 fish species in the region spawn in coastal wetlands that may be at risk of drying up due to declines in water levels.[138]

It is possible that population decreases in sport fishing species as a result of wetland losses could be offset by gains from reproduction in new wetlands forming at the new low water points. Fracz and Chow-Fraser, however, found that the loss in wetlands used for fish reproduction outweighs the gains made from new wetlands forming at the new low water point.[139] It is unclear whether or not this finding, made in the context of Georgian Bay, applies to wetland losses in other parts of the region.

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[131] Cruce and Yurkovich, 2011: 62.
[132] Connelly et al., 2005; IUGLS, 2012: 36.
[133] IUGLS, 2012: 36.
[134] Stewart, 2009: 121.
[135] IUGLS, 2012: 36.
[136] IUGLS, 2012: 36.
[137] Cruce and Yurkovich, 2011: 21; Fracz and Chow-Fraser, 2013.
[138] Fracz and Chow-Fraser, 2013: 151.
[139] Fracz and Chow-Fraser, 2013: 167.

Notably, different species of fish will probably have different responses to drying wetlands and warming waters, which could affect the behaviours of anglers. Some fish species may be able to adapt and change their spawning habits, but many fish also resist such adaptation. For example, as explained on p. 85-86, the combination of spring water temperature and flood level/duration exerted critical effects on the spawning success of northern pike and yellow perch and resulted in mass mortality of spawning carps in Lake Saint-Pierre on the St. Lawrence River.[140]

GLSL ecosystems, including wetland ecosystems, have evolved to adapt to the basin's wide range of natural (unregulated) fluctuations. Such ecosystems could respond to high as well as to low water levels, at least when those fluctuations are not compounded by the impacts of other human activities such as physical encroachment, chemical pollution, and biological invasions.[141]

It is important to keep in mind that, in the long term, the bulk of boating and fishing losses will probably be borne not by boaters and anglers themselves, but rather by the businesses that support these activities and the governments that regulate them. In the short term, boaters and boater-anglers may adapt (and pay for that adaptation), for example, by changing locations within the region (in which case their spending will not be lost to the region, just shifted within it) or switching to shallower boats (which would boost businesses that sell such boats). Nonetheless, the ILOSLRSB concluded that pervasive low water levels are more likely to cause boaters and anglers to seek alternatives outside the region.[142]

There is significant sub-regional variation in this sector's susceptibility to the impacts of high or low water levels. The mix of recreational activities varies from community to community, and different recreational activities may be concentrated in specific areas of the region. The cruise ship sector, for example, is disproportionately concentrated on the St. Lawrence River. Loss of recreational value will therefore not be distributed in a standardized manner across the region.

There is also significant variability among the region's marinas in terms of capacity, ability to absorb water level declines without the need for additional maintenance or capital dredging, and the resources available for both mitigative and adaptive action.

FINDINGS: Estimated future impacts of a worst-case low water levels scenario

Table 6 summarizes the region-wide economic impacts on recreational boating and fishing under a worst-case low water levels scenario as estimated based on the authors' analysis. Table 7 summarizes the lake-by-lake economic impacts on marinas under a worst-case low water levels scenario as estimated based on the authors' analysis. The methodology used to arrive at these estimates is described in detail in Appendix 3.

TABLE 6

Estimated region-wide economic impacts under a worst-case low water levels scenario on recreational water activities (total-over-period, converted to 2012 USD)

Climate Change Scenario	Recreational boating trips + annual spending	Sport Fishing	Marinas slip losses and adaptation costs	Total
SC2030 % of Total	**$5.86B** 88%	**$725M** 11%	**$65M** 1%	**$6.65B**
SC2050 % of Total	**$11.26B** 88%	**$1.4B** 11%	**$191M** 1%	**$12.86B**

TABLE 7

Estimated lake-by-lake economic impacts of worst-case low water levels scenario on marinas (total-over-period, converted to 2012 USD)

Climate change scenario	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario	St. Lawrence River	Total
SC2030 % of Total	**0** 0%	**$18M** 28%	**$23M** 35%	**$12M** 18%	**$12M** 18%	**0** 0%	**$65M**
SC2050 % of Total	**$<1M** <1%	**$46M** 24%	**$69M** 36%	**$38M** 20%	**$38M** 20%	**0** 0%	**$191M**

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[140] Hudon et al., 2010: 156.

[141] For a comprehensive overview of this in the context of the St. Lawrence River see Talbot, 2006.

[142] ILOSLRSB, 2006b: 40.

Our analysis estimates overall recreational boating and fishing impacts under a worst-case low water level scenario could be $6.65B through 2030 and $12.86B through 2050 (converted to 2012 value and stated in USD).

Lost boating days and reduced boater annual expenditures (not including boater-anglers) account for the bulk of this impact—88 per cent under both time projections. The critical factor in this impact value is that, based on the data from turn of the 21st century low water levels years, we estimate a future loss of boating days equivalent to about a third of the boating season. Our analysis suggests that if this materializes, the region's annual rate of boater attrition could be ten per cent by 2050. If either the actual loss of boating days, or the rate of boater attrition, is lower, this impact will be lessened.

Losses to sport fishing—which include loss of fishing days for boater-anglers (and concomitant losses in annual expenditures) and losses due to lower catch rates for both boater and land-based anglers—make up 11 per cent of the total estimated impact for both time projections.

We believe part of the reason that these losses are significantly smaller than impacts on boaters may have to do with differing activity patterns. Boating is often a family/group activity that involves using the boat for travel (increasing wear and tear), while fishing is typically undertaken by one or two people on a mostly still boat. As a result, boating entails higher expenditure rates per boat per day than does fishing. The fact that recreational fishing has already seen significant attrition over the last few decades might also in part account for its relatively smaller impact.

Notably, since boater-anglers are also boaters, lost fishing days are also lost boating days insofar as a lost fishing trip is not replaced by a boating trip (which is unlikely given the different nature of both activities). To avoid double counting, we separate lost fishing days and concomitant losses in annual boating expenditures incurred by boater-anglers from the parallel losses for boaters.

Declines in boater expenditures, the lion's share of the recreational water activities impact, would likely be borne not by boaters and anglers themselves, but rather by the businesses that support these activities and the governments that regulate them. These losses would be mitigated to the extent that boaters and anglers adapt to low water levels without abandoning the activity or relocating it outside the region.

While it is impossible to predict the extent of this adaptation, our analysis relies on data regarding lost fishing days and expenditures from years when such adaptation was probably already taking place. The impact of these adaptations may therefore already be reflected in the data we use in our analysis, at least to some degree.

Low water levels may not be the only cause of lost boating days. Indeed, as observed earlier, some attrition in boating and fishing activity may be due to the aging of the boater/angler population and changing leisure patterns. However, the available data controlled for this by asking survey respondents to quantify boating days lost specifically due to lower water levels.[143] Their finding of eight boating days lost per boater per season, which we use in our calculations, pertains specifically to days lost due to lower water levels.

As explained earlier, the conditions that bring about lower water levels could also result in the annual boating season starting earlier or ending later. While we cannot take full account of this in our analysis, this is partially factored into our calculations because our main data—the findings of Connelly and her colleagues based on a 2002 survey and the GLCs finding that in the 2004 boating season the average boater spent 23 days boating[144]—were generated when low water levels and the conditions facilitating them were already at work.

Marina slip losses and additional adaptation expenditures are smaller still, making up roughly one per cent of the total impacts on recreational water activities. The primary factor affecting this impact is boat slip losses, which could increase significantly if water levels decline beyond the more moderate degree projected through 2030.

Of course, if this were to happen, it could also result in increased loss of boating/fishing days. We have been able to isolate marina losses from fishing and boating losses enough to avoid double counting the impact, but we note that marinas' adaptation investments may therefore reduce the boating and fishing impact, though the degree of this cannot be predicted.

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[143] Connelly et al., 2005: 28.
[144] GLC, 2005: 6.

Marina impacts are the only impacts related to recreational water activities for which the data enabled a sub-regional breakdown. Our analysis suggests that Lake Huron would be hit the hardest, accounting for 35 per cent of the impact through 2030 and 36 per cent of the impact through 2050. Between them, Lakes Michigan and Huron account for 60 per cent of the impact through 2030 and 63 per cent of the impact through 2050. Impacts on Lakes Erie and Ontario are smaller but still notable, with each making up 18 per cent of the total impact through 2030 and 20 per cent of the total impact through 2050. Lake Superior and the upper St. Lawrence River would remain relatively unaffected by marina losses as a result of low water levels.

The factors accounting for the difference in marina impacts between the lakes are the number of marinas, the number of slips per marina, and the type of infrastructure in each marina (especially whether or not the marina has, or can employ, floating slips that are more easily adjustable to water level fluctuations). Since those factors are roughly similar between Lakes Erie and Ontario, we use Lake Erie data regarding costs per one foot of water level drop as a proxy for Lake Ontario, where such data was not available. For this reason, impact values for both those lakes were virtually the same.

LOCAL SNAPSHOT: Lake Saint-Pierre (St. Lawrence River)

The lower St. Lawrence River alternates between narrow corridors (less than 2.49 miles /4 km) and wide but fairly shallow fluvial lakes (width more than 3.11 miles / 5 km and mean depth less than 16.4 ft / 5 m). Lake Saint-Pierre is the last and largest (more than 115.83 miles^2 / 300 km^2) of these fluvial lakes before the tidal, freshwater estuarine portion of the St. Lawrence River.

About 1.9M people, nearly 25 per cent of Quebec's population, live in the watershed draining directly into Lake Saint-Pierre, including the two First Nations communities of Abénaquis from Odanak and Wôlinak. Many small communities in the area rely on the natural resources of Lake Saint-Pierre for direct and indirect employment in the tourism, hunting and fishing industries.

With over 29,652.6 acres (12,000 hectares) of high and low marshes, Lake Saint-Pierre accounts for nearly 80 per cent of St. Lawrence River marshes. The ecological value of the large, unfragmented wetland habitat provided by Lake Saint-Pierre has been recognized by its status as a Ramsar Wetland and as a UNESCO Biosphere Reserve, and through its inclusion as a protected site under the Eastern Habitat Joint Venture for Wildlife.

Lake Saint-Pierre supports a large population (more than 1,300 nests) of nesting great blue herons, a major staging area for migratory waterfowl (more than 800,000 ducks and geese annually), and 167 species of nesting birds.[145] In Lake Saint-Pierre alone, wildlife observation and hunting brought $25M (CAD) annually between 1997 and 2004, against $1.6M (CAD) in monitoring and farmers' compensation.[146]

Lake Saint-Pierre's permanently submerged areas, as well as its spring floodplain, are home to 13 amphibian species and 79 fishes, many of which are exploited by sports and commercial fisheries alike. In 2003, recreational fishing activities yielded about 36,000 fishing days, translating to around $1.3M (CAD) in spending regionally, and supported 37 seasonal jobs.[147] Winter ice fishing also represents an important regional income, with about 58,800 fishing days, translating into around $932,000 (CAD) and supporting 45 seasonal jobs.[148]

Commercial landing of yellow sturgeon, American eel, yellow perch and 11 other fish species in Lake Saint-Pierre yielded $460,000 (CAD) in 2007 and $270,000 (CAD) in 2008 to the 38 licenced fishermen of the region.[149] Since May 2012, a five-year moratorium on commercial and sports fishing for yellow perch has been enforced following the collapse of this important regional resource. Although recruitment overfishing plays a role in the closure, other causes such as predation of juveniles by invading species and reduction in habitat carrying capacity resulting from cumulative stressors (including changes in the flood regime) are also under study.

In Lake Saint-Pierre, a strong negative relationship was observed between seasonal water level fluctuations and the percentage of emergent plant cover. Under low water levels, the lake becomes a large (149.42 miles^2 / 387 km^2) marshland that supports a high emergent plant biomass whereas under high water levels, the lake shifts to a vast (193.44 miles^2 / 501 km^2) open-water body dominated by submerged vegetation and algae.[150]

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[145] St. Lawrence Centre, 1996.
[146] Based on data from Collard et al., 2010.
[147] Based on data from Daigle et al., 2005.
[148] Based on data from Daigle et al., 2005.
[149] Based on data from Collard et al., 2010.
[150] Hudon, 1997; Vis et al., 2007.

LOCAL SNAPSHOT: Georgian Bay

Georgian Bay has experienced significantly low water levels since 1999, which has led to direct mitigation costs as well as indirect costs associated with impacts to wetlands, fisheries, residents, marinas, boaters, and tourism. According to analysis by Georgian Bay municipalities, 19 of the 44 communities in Georgian Bay have spent a combined $8M (CAD) responding to low water levels in 2013, with overall spending for all communities estimated at close to $20M (CAD).[151]

Much of this was spent to ensure water access and infrastructure usability for recreational boaters and fishers as well as for cottagers, both critical inputs into local economies in Georgian Bay.

Georgian Bay municipalities report that costs related to maintaining water access are spiking in many Georgian Bay marinas. For example, dredging costs required to offset 2013 marina slip losses in the Township of Carling were estimated at $330,000 (CAD).[152]

In another example, Spider Bay Marina in the north zone of Georgian Bay anticipated 2013 marina slip losses due to decreasing water levels to result in a subsequent loss of $26,700 (CAD) in revenue.[153] Current dredging projects in the marina are estimated to cost more than $30,000 (CAD) to complete and would not be sufficient to maintain the marina if water levels continue to decline.[154] Drilling and blasting costs are estimated at $3M (CAD), which is not a financially viable option.[155]

Under very low water levels, residents of Georgian Bay can face significant costs in order to maintain access to water. Based on a survey sample of 358 people from a population of 2,765 residents, the Georgian Bay municipalities report estimated that necessary marina dredging, blasting, modifications to docks or new docks, and modifications to water lines or pumps, could cost nearly $30M (CAD) for Georgian Bay residents.[156]

Georgian Bay's wetlands, which sustain its plentiful fish stocks, have already been impacted by low water levels. Sustained low water levels since 1999 have led to an estimated loss of 24 per cent of Georgian Bay coastal wetlands critical to fish spawning and nursery habitat.[157] Low water levels have also resulted in greater vegetation homogeneity and increased density of floating plant life, compromising the quality of the habitat and reducing the diversity of fish it can support.[158]

Georgian Bay wetlands are particularly susceptible to low water levels because the Georgian Bay wetlands, with the exception of the southeastern portion of the Bay, are on Canadian Shield granite rock. The granitic Precambrian Shield rock erodes very slowly, often preventing lake-ward expansion of wetlands when water levels become low. Instead, these wetlands can become disconnected from the main body of water.[159]

Fracz and Chow-Frazer estimated that if Georgian Bay water levels drop and remain below 577.26 ft (175.95 m) by 2050, as much as 50 per cent of the total number of coastal wetlands will become inaccessible and 48 per cent of the total wetland surface area will be inaccessible to fish, resulting in a loss of 7,838.18 acres (3,172 hectares) to wetlands. Within individual wetlands, 23–95 per cent of the area could be inadequate for fish habitat.[160] This could have a significant negative impact on Georgian Bay's recreational fishing industry.

[151] Case Book, 2013: 2.
[152] Case Book, 2013: 11.
[153] Case Book, 2013: 8.
[154] Case Book, 2013: 8.
[155] Case Book, 2013: 8.
[156] Case Book, 2013: 9-10.
[157] Fracz and Chow-Fraser, 2013: 163.
[158] Fracz and Chow-Fraser, 2013: 165-166.
[159] Fracz and Chow-Fraser, 2013: 152.
[160] Fracz and Chow-Fraser, 2013: 163.

Waterfront Properties

ESTIMATED IMPACT 2030	ESTIMATED IMPACT 2050
$794M	$976M

- » 51 per cent of the impact through 2030 and 63 per cent of the impact through 2050 is concentrated in Lake Huron. 43 per cent of the impact through 2030 and 31 per cent of the impact through 2050 is concentrated in Lake Erie.
- » Between 2003 and 2012, when other market impacts on property values are held constant, water levels declines can be linked to an estimated 14 per cent loss in property values per one foot (30.48 cm) of lake level drop for residential properties in Ontario municipalities adjacent to GLSL shores (excluding municipalities with no residential waterfront properties designated by MPAC as "seasonal/recreational").

TOTAL VALUE OF residential waterfront properties in Ontario municipalities adjacent to GLSL shores in 2012: **$28.5B (USD)**

93,400 waterfront properties* along Upper Great Lakes shorelines and connecting channels supporting about 233,000 full-time or seasonal residents**

Estimated economic importance*** of waterfront properties in the upper Great Lakes to:

CANADA	US
$39B (USD)	$66B (USD)

10,000 COTTAGES along the eastern & northern shores of Georgian Bay contribute over $100M (CAD) TO THE LOCAL AND REGIONAL ECONOMY.

Value added to a property in the Great Lakes-St. Lawrence region due to being:

ON THE WATERFRONT

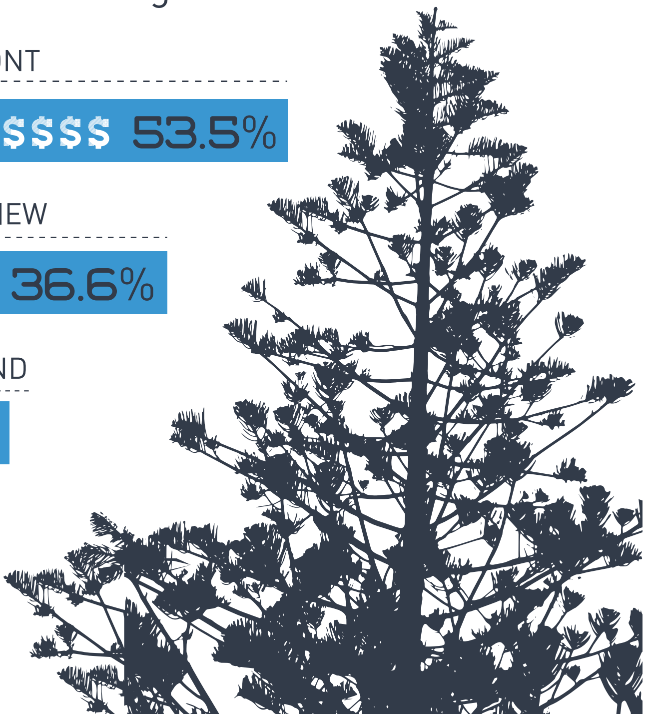
$$$$$$$$$$$$$$ 53.5%

HAVING A WATER VIEW

$$$$$$$$$$ 36.6%

NEAR A MARSHLAND

$$$$ 19.4%



*63,700 in the US and 29,700 in Canada

**159,000 in the US and 74,000 in Canada

***property values and taxes to local, state/provincial and federal governments

Residential properties along GLSL shores have long been highly desirable destinations, whether as year-round homes, second homes, or seasonal recreational properties. The IUGLSB, for example, found that in the upper Great Lakes alone "there are an estimated 93,400 properties along ... shorelines and connecting channels (63,700 in the US and 29,700 in Canada), including year-round homes, second homes and seasonal recreational properties. These riparian properties support about 233,000 full-time or seasonal residents (159,000 in the US and 74,000 in Canada)."[161]

Many of the region's residents have cherished memories of time spent with family and friends at their 'cottage on the lake'. Indeed, the IUGLSB noted that "the demand for shoreline properties is expected to be maintained in the coming decades throughout much of the upper Great Lakes ... It is anticipated that most of the shorelines of Lake Michigan-Huron (excluding Georgian Bay) in both Canada and the US, will be developed as residential in 50 years." [162]

Residential waterfront properties are also an important input to local economies throughout the region. Residents' expenditures are critical to local economies while increasing the tax base of various levels of government. Property taxes (themselves dependent on property values) are critical components of municipal revenues. The IUGLSB estimated the economic importance (property values + taxes to local, state/provincial and federal governments) of residential waterfront properties in the upper Great Lakes to be between $39B (USD) and $66B (USD).[163] Georgian Bay Forever estimated that the 10,000 cottages along the eastern and northern shores of Georgian Bay contribute over $100M (CAD) to local and regional economies.[164]

Residential waterfront and near-waterfront properties receive significant added value from their location, lakefront view, and water and beach access. A 2008 report found that 53.5 per cent, 36.6 per cent, and 19.4 per cent is added to the value of a property in the GLSL due to being on the waterfront, having a water view, or being near a marshland, respectively.[165] Based on data provided to the authors by Ontario's Municipal Property Assessment Corporation (MPAC), property values of residential waterfront properties in Ontario municipalities adjacent to GLSL shores totaled $28.5B (CAD) in 2012.[166]

FINDINGS: Identified impacts of fluctuations in GLSL water levels

Table 8 summarizes the major impacts of fluctuations in GLSL water levels on residential waterfront properties as identified in the literature.

TABLE 8

Major impacts of fluctuations in GLSL water levels on residential waterfront properties as identified in our research

	Low water levels	High water levels
NEGATIVE –	» Reduced waterfront access when water recedes from piers, boat launches, and beaches, and costs to extend such structures to new water line » Diminished aesthetic appeal of waterfront view due to mud, muck, rocks, and unappealing vegetation revealed by receding waters » Repairs to exposed piers and boat launches suffering from dry rot » Property value drops as a result of above risks for properties in shallowing-risk locations » Reduced municipal property tax revenues as a result of property value drops » Reduced economic activity due to reduced use of affected seasonal properties	» Risk of flooding and reduced access to homes » Reduced waterfront access when piers, boat launches, and sandy beaches are flooded » Diminished aesthetic appeal of waterfront due to beach erosion or storm debris » Erosion and moisture damage to shore protection and beach use structures » Increased insurance costs » Property value drops as a result of above risks for properties in flood/erosion-risk locations » Reduced municipal property tax revenues as a result of property value drops » Reduced economic activity due to reduced use of affected seasonal properties
POSITIVE +	» Strengthening of property values and of resulting property tax revenues for properties in flood/erosion-risk locations » Enlarged beach area, if extended beach is sandy and cleanup costs and higher property tax payments can be absorbed	» Strengthening of property values and of resulting property tax revenues for properties in shallowing-risk locations

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[161] IUGLS, 2012: 31.
[162] IUGLS, 2012: 31.
[163] IUGLS, 2012: 32.
[164] Data provided by Georgian Bay Forever.
[165] Pompe, 2008: 432.
[166] Authors' calculation.

GLSL shores are also host to commercial properties, agricultural and park land, and, in some urbanized area, condominiums. We follow the IUGLSB in focusing on residential waterfront properties as the major segment of waterfront properties in the GLSL. Data tracking changes to non-residential property values over time is particularly difficult to come by.

Waterfront property values are highly vulnerable to water level fluctuations. Many users' enjoyment of their properties—aesthetic, physical, or emotional—is tied to water levels being within a certain subjectively experienced or expected "normal" range. Fluctuations beyond that range deeply mar owners' (current or prospective) enjoyment of their property.[167] These subjective valuations, in turn, drive the market value of such properties up or down.

More tangibly, as already noted , research found that waterfront access and view add 53.5 per cent and 36.6 per cent, respectively, to the value of a GLSL property.[168] In principle, both waterfront access and waterfront view are vulnerable to flooding as well as to shallowing of beachfront. Waterfront access would be reduced when piers, boat launches, and sandy beaches are flooded or when water recedes away from them.[169] Waterfront view would diminish in its aesthetic value when a beach erodes or is covered in flood debris due to high water levels, as well as when low water levels reveal mud, muck, rocks on a beach or expose it to unappealing vegetation.[170]

The effect of these risks on property values depends on a property's vulnerability, which varies with location and can stem from geological and hydroclimatic factors, human intervention, as well as legislation and building codes. For properties in flood/erosion-risk locations, such as south Lake Michigan or the southern shore of Lake Ontario for example, high water levels would depress property values while low water levels would strengthen property values.

For properties in locations more vulnerable to shallowing, such as Saginaw Bay and Georgian Bay for example, low water levels would depress values while high water levels would strengthen property values. A recent report from Georgian Bay municipalities, for example, estimated property values in Georgian Bay to have dropped 25 per cent during the recent period of low water levels on Lake Michigan-Huron.[171]

Fluctuations in water levels can also exact significant tangible costs from property owners. Rising waters may flood or reduce access to homes, and cause erosion and moisture damage to shore protection and beach use structures.[172] Receding waters may require extending piers and boat launches or repairing/replacing them due to exposed dry rot, similar to marina infrastructure discussed earlier. Increased risk of such damage could also depress property values.

Increased risk of such damages could also lead to increased insurance costs and in some case even refusal by insurers to insure properties. This could depress property values as well, because typically changed insurance rates kick in at sale. In upstate New York, for example, increases in premiums for properties insured under the National Flood Insurance Program introduced in late 2013 depressed property values and home sales, prompting Congressional legislative action to delay enactment of the new premiums until the Federal Emergency Management Agency completes its study of the area's flood risk designations.[173] Future purchase and investment decisions thus could be affected by a property's water levels vulnerability today.

In some cases, bluffs or sandy beaches may benefit from lengthening by receding waters or from deepening by rising waters.[174] In the case of extended beaches, however, realizing their benefit may require significant cleanup which may not always be affordable to private owners.

Property value decreases, in turn, diminish property tax revenues for municipalities highly dependent on such revenues. When these impacts reduce actual use of these properties, expenses otherwise spent within local economies would also diminish.

Data tracking property value over time, that can be disaggregated to isolate GLSL waterfront properties from non-waterfront properties and from inland properties, is not publically available. In the US, such data is tracked at the county level. Only in Ontario have we been able to find the needed data in the hands of a single central entity (MPAC). The economic impact analysis below therefore reflects only residential waterfront properties in Ontario municipalities adjacent to GLSL shores.

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[167] IUGLS, 2012: 32.
[168] Pompe, 2008: 432.
[169] IUGLS, 2012: 32.
[170] IUGLS, 2012: 32.
[171] Case Book, 2013: 44.
[172] IUGLS, 2012: 32.
[173] Tampone, 2013.
[174] Cruce and Yurkovich, 2011: 32; IUGLS, 2012: 32.

Our analysis of MPAC data confirms that in the period between 2003 and 2012, when other market impacts on property values are held constant, a one-foot (30.48 cm) drop in water levels can be linked to an estimated 14 per cent decline in property values for residential waterfront properties in Ontario municipalities adjacent to GLSL shores (excluding, as explained below, municipalities that contain no residential waterfront properties designated as "seasonal/recreational" by MPAC). We are looking into options for acquiring and analyzing similar data for other parts of the region, particularly from flood/erosion-risk areas, in future research.

FINDINGS: Estimated future impacts of a worst-case low water levels scenario

Table 9 summarizes the estimated Ontario-wide economic impacts to accrue under a worst-case low water levels scenario to residential waterfront property values in Ontario municipalities adjacent to GLSL shores, as estimated based on the authors' analysis. Table 10 summarizes the estimated lake-by-lake economic impacts to accrue to such properties under the worst-case low water levels scenario, based on the authors' analysis.

TABLE 9

Estimated Ontario-wide economic impacts under a worst-case low water levels scenario on residential waterfront property values in Ontario municipalities adjacent to GLSL shores (total-over-period, converted to 2012 USD)

Climate change scenario	Impact
SC2030	$794M
SC2050	$976M

TABLE 10

Estimated lake-by-lake economic impacts under a worst-case low water levels scenario on residential waterfront property values in Ontario municipalities adjacent to GLSL shores (total-over-period, converted to 2012 USD)

Climate change Scenario	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario	St Lawrence River	Total
SC2030 % of Total	**0** 0	**N/A** N/A	**$403M** 51%	**$340M** 43%	**$51M** 6%	**0**	**$794 M**
SC2050 % of Total	**$4M** 0.4%	**N/A** N/A	**$612M** 63%	**$301M** 31%	**$59M** 6%	**<$1M** 0	**$976 M**

The methodology used to arrive at these estimates is described in detail in Appendix 4. The data covers three time points (2003, 2008, and 2012). According to MPAC, pre-2003 data cannot be reliably compared to data from 2003 onwards due to changes to the way MPAC codes its data.

Notably, for reasons explained in Appendix 4, the estimates provided exclude waterfront properties from municipalities on the Ontario GLSL shores which contain no residential waterfront properties that are classified by MPAC as "seasonal/recreational".

We do include in our estimates the three municipalities on the shores of Lake St. Clair and the St. Clair River. For consistency with the rest of this report, where Lake St. Clair was not treated as a separate sub-region, in our lake-by-lake analysis we include waterfront properties in Essex and Chatham-Kent counties in the Lake Erie totals, and properties in Lambton County in the Lake Huron totals.

In addition, we did not obtain MPAC data for metropolitan waterfront properties. While there already is research linking property values to waterfront access and view in waterfront properties outside metropolitan areas, the literature is unclear about such a link in metropolitan waterfront properties, where buyers will probably have different considerations driving purchase decisions and property values. Further study is needed to fill this gap.

Our analysis estimates that, under the worst-case low water levels scenario, residential waterfront property values in Ontario municipalities adjacent to GLSL shores could drop by $794M through 2030 and $976M through 2050 (converted to 2012 values and stated in USD). This decline would be on top of declines in property values that have already occurred before 2012.

Not surprisingly, residential properties on the shores of Lake Huron—which in 2012 represented 68 per cent of total Ontario waterfront property values—account for the largest portion of this impact, 51 per cent of the total estimated loss through 2030 ($403M) and 63 per cent of the total estimated loss through 2050 ($612M). However, residential properties on the Ontario shores of Lake Erie also account for a major portion of this impact, with 43 per cent of the total estimated loss through 2030 ($340M) and 31 per cent of the total estimated loss through 2050 ($301M).

While the data acquired from MPAC was broken down at the municipal level, the number of observations for each municipality was too small to allow for credible statistical analysis below the lake-by-lake level. For this reason we do not distinguish properties located in shallowing-risk areas from properties located in other areas. Given that properties in shallowing-risk areas are more likely to see bigger drops in property values, the fact that our results mix the two serves to counteract the risk that our results would be too driven by shallowing-risk properties.

It is uncertain why property values are projected to continue dropping in Lake Huron but not in Lake Erie as we move from the shorter-term projection period to the middle-term one. It is possible that in the case of Lake Erie, this is in part due to the effect of discounting a longer time span to 2012 values. However, it is possible that this is also in some part related to the fact that by 2012 water levels in Lake Huron had dropped to near historic lows and that our worst-case low water levels scenario projects them to drop well below historic lows by 2050, whereas Lake Erie's 2012 water levels were closer to historic means and our worst-case low water levels scenario projects them to drop only to close to historic lows, but not below that.

Impacts on residential waterfront properties on the Ontario shores of the St. Lawrence have proven negligible after present value conversion due to our use of 2012 water levels (which were significantly low on the St. Lawrence River) as a basis of comparison.

It is methodologically incorrect to apply current municipal tax rates (average or range) to our impact estimates to ascertain over-period property tax losses, because those impact estimates cover a multidecadal period during which municipal tax rates could change quite markedly. Nonetheless, it is probable that these losses in property values would also translate into losses in tax revenues for local municipalities dependent on property taxes.

Lake Ontario properties account for a smaller portion of the overall estimated Ontario-side property value loss (6 per cent in both projection periods). However, it should be remembered that the focus of our analysis are non-metropolitan and residential waterfront properties, which are fewer on Lake Ontario than on Lakes Huron and Erie. Lake Superior, where there are even fewer residential waterfront properties, and where our worst-case low water levels scenario projects only small declines, therefore accounts for a negligible amount of the impact through 2030 and 0.4 per cent of the impact through 2050.

As explained in Appendix 4, these findings are limited to lakefront Ontario-side properties, many of which are at a low risk of flooding. This is due both to geography and hydrology, and to provincial regulations requiring residential properties to be built at a certain minimal distance from shore. It is likely that expanding the study population to other jurisdictions, and particularly to flood-risk jurisdictions such as those on the south shores of Lake Michigan, on flood-risk parts of Lake Erie, on the New York shores of Lake Ontario, and on the New York and Quebec shores of the St. Lawrence River, would mitigate our impact findings, though it is unknown by what degree.

LOCAL SNAPSHOT: Disconnecting islands in Lake Huron and Georgian Bay: Manitoulin Island and the Beausoleil First Nation

Low water levels in Lake Huron and Georgian Bay are having a notable effect on island communities and their coastal links.

For example, Manitoulin Island is connected to the mainland via the *Chi-Cheemaun* ferry, which runs from May to October. The *Chi-Cheemaun* ferry is vitally important to local businesses on the Bruce Peninsula, North Shore, and Manitoulin Island. The ferry service leads to the creation of between 159 and 255 full-time jobs, between $9.2M (CAD) and $15.6M (CAD) in economic activity, and between $8.8M (CAD) and $12.4M (CAD) in labour income each year.[175]

If no ferry service existed, traffic to the region would be reduced by 19-59 per cent, reducing tourists in the Manitoulin-Tobermory region by tens of thousands.[176] In addition, as the only means of access to Manitoulin Island, if the ferry service were lost, members of the South Baymouth community would probably relocate and their property values would be negatively impacted.

Short-term repairs to docks to ensure continued ferry service would cost approximately $300,000 (CAD).[177] If Lake Huron water levels get even lower in the long term, the channel leading from Georgian Bay into South Bay and the ferry's South Baymouth dock could require blasting, at an estimated cost of $30M (CAD), to ensure continued ferry service.[178]

In 2013, the Chi-Cheemaun ferry season was delayed due to unprecedented low water levels in the channel at South Baymouth.[179]

Manitoulin Island is not alone. On the southern tip of Georgian Bay, the Christian, Beckwith, and Hope Islands are home to the Beausoleil First Nation, of the Anishnaabe peoples.

Two ferries normally serve the communities of the islands but low water contributed to one ferry running aground—the *Sandy Graham* is currently being repaired at a cost of $400,000 (CAD) and the Beausoleil First Nation was forced to rent a replacement barge at a cost of $300,000 CAD).[180] Low water levels have reduced the number of passengers the second ferry, the *Indian Maiden*, can carry from 70 to 40, and a number of emergency ambulance runs have been cancelled.[181]

The estimated cost to dredge the harbour and fix the ferry dock on the islands is $600,000 (CAD). Water quality has also been compromised due to turbidity. Low water levels are having significant impact on the local economy and would threaten the Beausoleil First Nation's culture and livelihood.[182]

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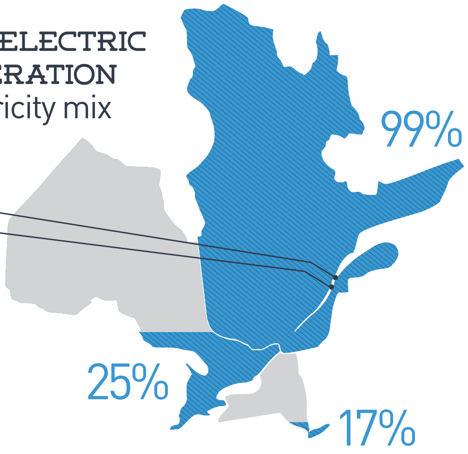
[175] CPCS, 2013: i.
[176] CPCS, 2013: 5.
[177] Aulakh, 2013.
[178] Manitoulin Expositor, 2013.
[179] Sasvari, 2013.
[180] Case Book, 2013: 22.
[181] Case Book, 2013: 22.
[182] Case Book, 2013: 22.

Hydroelectric Generation

ESTIMATED IMPACT 2030	ESTIMATED IMPACT 2050
$951M	$2.93B

» 96.6 per cent of the impact through 2050 is from facilities on or between Lakes Erie and Ontario.

HYDROELECTRIC GENERATION
electricity mix



Hydroelectric facilities at Moses-Saunders & Beauharnois-Les Cèdres produce electricity valued at approximately

$1.5B (USD)

AT 2006 MARKET RATES.

HYDROELECTRIC PRODUCTION EMITS

LESS CARBON DIOXIDE PER KWH

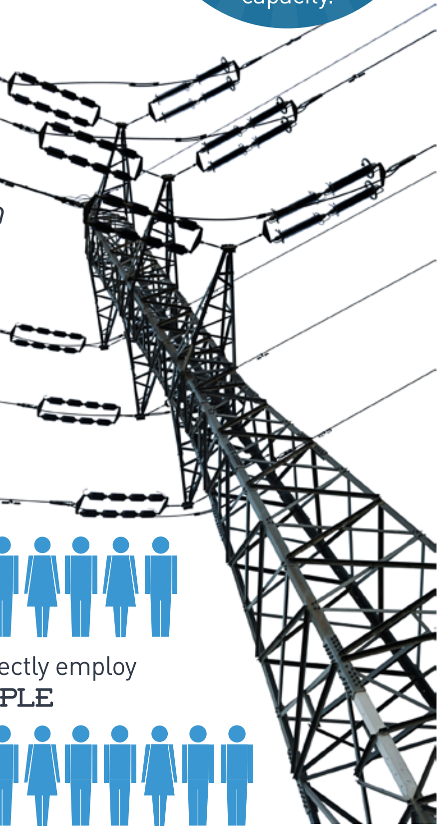
than the most likely replacement sources, such as natural gas & coal-fired electricity.

HYDROELECTRIC POWER MAKES UP ROUGHLY

1/7

of the GLSL electricity capacity.

A typical hydropower station has a potential lifespan in excess of 100 years, longer than most other power generating infrastructure.



Ontario's hydropower producers directly employ

MORE THAN 1,600 PEOPLE

Hydroelectric power is a clean, renewable, reliable, flexible, and less expensive energy source.[183] As such, it epitomizes the integration of economic development and environmental sustainability that characterize the region.

Although hydroelectric power only makes up roughly 1/7th of the region's electricity generating capacity, it nonetheless plays an important role in the region's energy markets.[184] It is the region's most prominent—and cheapest—source of renewable energy. Its longevity—a hydropower station has a potential lifespan in excess of 100 years, longer than most other power generating infrastructure[185]—makes hydroelectric generation an economically attractive long-term investment.

The importance of hydroelectric power to the region is clearly evident in the fact that it was placed third in the order of precedence for binational water management under the *Boundary Water Treaty of 1909*, with a clear instruction to maintain a sufficient water supply for GLSL hydroelectric generators to continue to run their generators and turbines.[186] As a result, the needs of the industry are an important consideration in the decision-making of the IJC's Lake Superior, Niagara, and St. Lawrence Boards of Control

The region's states and provinces differ in their respective energy mix as well as their energy demand patterns. This creates significant variation among the region's jurisdictions in terms of their relative reliance on different energy sources. In Quebec, for example, almost all electricity is hydroelectric, although much of it comes from Northern Quebec and Labrador rather than the St. Lawrence River.

Hydroelectric generation is also an important component in the energy mix of Ontario and New York. It is a rather small component in the energy mix of other US Great Lakes states, but can be a significant input in the local energy mix or economy, for example in Northern Michigan and Northeastern Wisconsin.

Table 11 illustrates the percentage of the energy mix made up by hydroelectric generation in GLSL jurisdictions in January 2014, the latest for which data was available in both Canada and the US at the time of writing.

Where hydroelectric generation has a large role, it makes a significant economic contribution. In 2006, the ILOSLRSB estimated that the hydroelectric facilities at Moses-Saunders and Beauharnois-Les Cèdres produce energy valued (using 2006 market rates) at approximately $1.5B (USD).[187] Ontario's hydroelectric producers directly employ more than 1,600 people and contribute more than $140M (CAD) a year in resource royalties to the Ontario government.[188]

Hydroelectric plants in the region come in all sizes. The four plants on the Niagara River (Sir Adam Beck I and II on the Canadian side along with the Robert Moses and Lewiston plants on the US side) are the most well-known, playing a defining role in the region's self-image. The Robert Moses Niagara Power Plant is the fourth largest hydroelectric plant in the US and the largest in the GLSL, with a generating capacity of 2,515 MW. Quebec's Beauharnois, on the St. Lawrence River, is the largest on the Canadian side, with a generating capacity of 1,911 MW. By contrast, the three plants (two on the US side) on the St. Marys River combine for a generation capacity of about 115 MW. Table 12 lists the 15 largest hydroelectric facilities (by installed capacity) on or near GLSL shores.

The majority of hydroelectric generation facilities are either conventional (dammed) or run of the river (RoR). Conventional facilities store water, usually from a large river, in a reservoir, and release it back into the river as needed. RoR facilities generate power directly from the flow of the river, though they may have small reservoirs to help optimize their performance. Conventional facilities have greater flexibility to adjust quickly to changing short-term energy demands.

Our scan of available data shows that most of the region's hydroelectric facilities are RoR. None of the region's conventional facilities, most of which are in Michigan and Wisconsin, have a generation capacity greater than 30 MW. There are also some relatively large pumped storage facilities in the region.

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[183] IUGLS, 2012.
[184] Authors' calculation.
[185] IEA, 2010.
[186] Lentz, 2006: 10; IUGLS, 2012: 28.
[187] ILOSLRSB, 2006a: 15.
[188] OWA, 2014.

TABLE 11

Percentage of hydro power in net electricity generation in GLSL jurisdictions (January 2014)

	IL	IN	MI	MN	NY	OH	PA	WI	ON	QC
Hydro	<0.1	0.2	0.8	<0.1	17.0	0.2	1.5	1.5	24.8	99.2

Sources: Statistics Canada, n.d.; United States Energy Information Administration, n.d.

TABLE 12

15 largest hydroelectric facilities on or near GLSL shores (by installed capacity)

Facility	Type	Installed capacity (MW)	State/province
Robert Moses	RoR	2,525	NY
Beauharnois	RoR	1,906	QC
Sir Adam Beck II Generating Station	RoR	1,499	ON
R. H. Saunders Station	RoR	1,045	ON
Franklin D Roosevelt Power Project	RoR	912	NY
Sir Adam Beck I Generating Station	RoR	498	ON
Lewiston	Pumped Storage	240	NY
Sir Adam Beck Pump Generating Station	Pumped Storage	174	ON
DeCew Falls II	RoR	144	ON
Les Cèdres	RoR	103	QC
MacKay	RoR	62	ON
Rivieres des Prairies	RoR	54	QC
Francis H. Clargue	RoR	52	ON
Andrew	RoR	47	ON
RG&E	RoR	45	NY

Source: Data collected from Wikipedia and industry sources[189]

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[189] Surprisingly, the most comprehensive source aggregating power plant-level basic information (such as location, type, and installed capacity) is by jurisdiction lists provided by Wikipedia, whose contributors comprehensively collected this information, mostly in 2010, typically from the webpages of the relevant utilities. With two exceptions, we have restricted ourselves to plants on or near GLSL shores (including connecting waterways), thereby excluding facilities upstream of tributaries such as the Mississigi River east of Sault Ste. Marie in ON (thereby excluding the privately owned Wells generating station, a 239 MW conventional facility), the Allegheny River in PA (thereby excluding the 435 MW Seneca Pumped Storage Generating Station) and QC stations on the Gatineau, Ottawa and Saint-François rivers. See: http://en.wikipedia.org/wiki/List_of_power_stations_in_Illinois; http://en.wikipedia.org/wiki/List_of_power_stations_in_Indiana; http://en.wikipedia.org/wiki/List_of_power_stations_in_Michigan; http://en.wikipedia.org/wiki/List_of_power_stations_in_Minnesota; http://en.wikipedia.org/wiki/List_of_power_stations_in_New_York; http://en.wikipedia.org/wiki/List_of_power_stations_in_Ohio; http://en.wikipedia.org/wiki/List_of_electrical_generating_stations_in_Ontario; http://en.wikipedia.org/wiki/List_of_electrical_generating_stations_in_Quebec; http://en.wikipedia.org/wiki/List_of_power_stations_in_Pennsylvania; http://en.wikipedia.org/wiki/List_of_power_stations_in_Wisconsin.

FINDINGS: Identified impacts of fluctuations in GLSL water levels

Table 13 summarizes the major impacts of fluctuations in GLSL water levels on hydroelectric generation as identified in the literature.

TABLE 13

Major impacts of fluctuations in GLSL water levels on hydroelectric generation as identified in our research

	Low water levels	High water levels
NEGATIVE –	» Decreased (and after a certain point, lost) generation with resulting revenue losses should reservoir levels or river flows decline » Increased costs and GHG emissions if lost generation is replaced with electricity from sources that are more expensive or larger GHG emitters » Significantly increased long-term costs should new facilities need to be built to replace lost generation » Reduced flexibility to respond to fluctuations in energy demand, especially if lost capacity is from conventional facilities	» Missed opportunity and suboptimal operations should reservoir levels or river flows increase beyond a facility's capacity or need to use them in generating electricity » Risk of local flooding should surplus water be released from a reservoir/river » Increased risk of erosion in power canals and tailrace » Increased risks to the structural integrity of hydropower infrastructure » More frequent need to operate the gates at a dam to release surplus water
POSITIVE +	» Offset of surplus generation, so long as demand conditions do not make lost hydroelectric generation needed again » Benefits to GLSL jurisdictions who have surplus energy they can sell to jurisdictions in need of lost capacity replacement	» Increased generation and resulting revenues (up to a certain point) should reservoir levels or river flows increase

Both conventional and RoR facilities are vulnerable to fluctuations in water levels, though the IUGLSB concluded that "low water conditions have more of an impact on hydroelectric generation" than do high water conditions.[190] Cruce and Yurkovich noted that "in 1999, hydro-electricity production fell significantly at the Niagara and Sault St. Marie facilities, corresponding with lower river flow rates and lake levels."[191]

Generation from conventional facilities depends primarily on the amount of water available in the reservoir, which typically declines when water levels decline and increases when water levels rise. Generation from RoR facilities depends primarily on the strength of the flow of water through the plant, which typically declines when water levels decline and increases when water levels rise. In both cases generation losses translate into lost revenues for the generating facility.

For both types of facilities, high water levels can increase production only up to an upper threshold, determined by the capacity of reservoirs (in conventional facilities), the facility's physical infrastructure, and energy demand at the given time. Beyond that upper threshold, the facility must release "surplus" water from the reservoir without using it for generation, resulting in missed opportunity and suboptimal operations.[192]

The IUGLSB adds that high water levels may also "cause local flooding and generate erosion concerns in power canals and tailrace, and may increase risk to structural integrity of hydropower infrastructure."[193] High water levels may also "necessitate more frequent operations of the gates at a dam (e.g., the St. Marys River compensating works)."[194]

When water levels (and production) decline, both types of facilities also face a lower limit, beyond which the amount of water in the reservoir or the flow of the river is no longer sufficient to generate electricity. According to the IUGLSB, "over the longer term, drought, or any event that threatens the long-term, reliable supply of water, is the greatest risk to hydroelectric generation interests."[195]

Jurisdictions vary in the extent to which they must supplement energy underproduction through (potentially costly) energy purchases or offload energy overproduction through (potentially cut-rate) energy sales. Quebec, for example, enjoys significant flexibility in adjusting to energy supply and demand, internally and in neighboring jurisdictions, thanks to its reliance on conventional hydroelectric facilities, albeit from outside the GLSL basin.

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[190] IUGLS, 2012: 29.
[191] Cruce and Yurkovich, 2011: 45, citing the Canadian Council of Ministers or the Environment.
[192] IUGLS, 2012: 29.
[193] IUGLS, 2012: 29.
[194] IUGLS, 2012: 29.
[195] IUGLS, 2012: 29.

Unless hydroelectric production is lost at a time when there is surplus production in the given electricity system, lost production would have to be replaced from alternative sources. Replacement sources could be out-of-basin hydroelectric facilities (typically in northern and eastern Quebec or in Manitoba) or non-hydroelectric sources, most likely natural gas or coal.

Unlike hydroelectric plants, natural gas and coal-fired facilities have to purchase fuel, the costs of which vary. These facilities also emit more carbon dioxide per kWh in comparison to hydroelectric power, albeit to varying degrees, with natural gas generally being a cleaner burning fuel than coal.

In addition, both coal fired and nuclear facilities tend to have more limited plant lifetimes than hydroelectric facilities.[196] If reduced hydropower generation resulted in the need for the construction of new generating plants, the added capital costs of this new infrastructure could increase electricity rates for customers.

Unless hydroelectric production is lost at a time when there is surplus production in the given electricity system, lost production would have to be replaced from alternative sources. Replacement sources could be out-of-basin hydroelectric facilities (typically in northern and eastern Quebec or in Manitoba) or non-hydroelectric sources, most likely fossil fuels, primarily—given the recent growth in gas-fired generation capacity in the region— natural gas. Unlike hydroelectric plants, fossil fuel facilities have to purchase fuel, the costs of which vary. And natural gas plants, the cleanest fossil fuel source, still emit almost 20 times the carbon dioxide emissions per kWh in comparison to hydroelectric power.

In addition, both fossil fuel fired and nuclear facilities tend to have more limited plant lifetimes than hydroelectric facilities. Also, if reduced hydropower generation resulted in the need for the construction of new generating plants, the added capital costs of this new infrastructure could increase electricity rates for customers.

Production losses as a result of low water levels could benefit jurisdictions experiencing overproduction, and hence being forced to sell off surplus power at a loss, by offsetting this loss. As long as both overproduction and low water levels persist, this offset will continue to provide a benefit, albeit with some loss in flexibility to adjust generation quickly and efficiently to short-term increases in demand. However, should long-term demand rise again while low water levels persist, or after hydroelectric facilities have been permanently closed, lost production might need to be made up by more expensive and/or more GHG-heavy generation.[197]

Revenue losses due to declining hydroelectric generation would be felt primarily by the three jurisdictions most reliant on such generation, namely, Quebec, Ontario, and New York. In other Great Lakes states, impacts would be felt primarily in local communities that rely on smaller generation facilities. Northern Michigan, where multiple such facilities operate, is particularly susceptible to this risk.

Notably, insofar as replacement electricity would be purchased from other GLSL jurisdictions, such jurisdictions would be benefitting from low water levels conditions.

To a smaller degree, low water levels may also impact non-hydroelectric generation facilities. Coal and natural gas facilities that depend on the GLSL Seaway System for the shipping of fuel or parts may incur additional costs due to the impact of low water levels on the region's shipping sector, as discussed earlier.[198] Facilities which use water for cooling and steam generation, may—similarly to other water users (discussed below) and depending on plant location—face additional expenses in extending pipes where the waterline has dropped below the pipe or in bringing in more water where shallower waters have become warmer.[199] An industry source noted to the authors that any plant drawing water faces reduced production when water warms up.

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[196] WNA, 2011: 6.

[197] IEA, 2010: 43

[198] Cruce and Yurkovich, 2011: 45.

[199] Cruce and Yurkovich, 2011: 45.

FINDINGS: Estimated future impacts of a worst-case low water levels scenario

Table 14 summarizes the region-wide economic impacts on revenue from hydroelectric generation under a worst-case low water levels scenario as estimated based on the authors' analysis. Table 15 summarizes the sub-regional economic impacts on revenue from hydroelectric generation under a worst-case low water levels scenario as estimated based on the authors' analysis. The methodology used to arrive at these estimates is described in detail in Appendix 5.

TABLE 14

Estimated region-wide economic impacts under a worst-case low water levels scenario on revenue from hydroelectric generation (total-over-period, converted to 2012 USD)

Climate Change Scenario	Impact
SC2030	$951M
SC2050	$2.93B

TABLE 15

Estimated lake-by-lake economic impacts under a worst-case low water levels scenario on revenue from hydroelectric generation (total-over-period, converted to 2012 USD)

Climate change scenario	Superior/Huron	Erie/Ontario	St Lawrence River	Totals
SC2030 % of Total	**0** 0	**$951M** 100%	**0** 0	**951M**
SC2050 % of Total	**<$1M** 0	**$2.83B** 97%	**$99M** 3%	**2.93B**

As explained in Appendix 5, our economic impact analysis focuses on a study sample of 17 facilities: Clergue (St. Marys River, RoR), Edison Sault (St. Marys River, RoR), Saint Marys Falls (St. Marys River, RoR), Cascade (Seguin River, RoR), Adam Beck 1 (Niagara River, RoR), Adam Beck 2 (Niagara River, RoR), Adam Beck PSG (Niagara River, pumped storage), Robert Moses (Niagara River, RoR), Lewiston (Niagara River, pumped storage), Decew Falls (Welland River, RoR), Varrick (Lake Ontario/Oswego River, RoR), RG&E (Lake Ontario, RoR), Franklin D Roosevelt Power Project (upper St. Lawrence River, RoR), Saunders (upper St. Lawrence River, RoR), Beauharnois (lower St. Lawrence River, RoR), Les Cèdres (lower St. Lawrence River, RoR), and Rivière-des-Praries (lower Rivière-des-Praries, RoR). The 17 facilities in our study sample combine for a total generation capacity of 9,416.2 MW.

A majority of the 17 facilities in the study sample are located on channels connecting two Great Lakes. In those cases, we apply to those facilities water level drops for the upstream Lake as this would determine how much water and flow is available to the facility. For the same reason, our sub-regional analysis breaks down impacts by sub-regions that encompass two lakes instead of the lake-by-lake breakdowns employed in the other case studies.

Our analysis of these 17 facilities suggests that, under the worst-case low water levels scenario, GLSL hydroelectric generation could see losses from decreased production valued at $951M through 2030 and $2.93B through 2050 (converted to 2012 value and stated in USD). Virtually all of the impact through 2030 and the bulk of the impact through 2050 ($2.83B, 96.6 per cent) would be concentrated in Lakes Erie and Ontario.

Two main factors combine to produce this concentration of impacts in the Erie-Ontario sub-region as well as the acceleration of impact over the longer projection period (present through 2050) relative the shorter one (present through 2030). First, the facilities on or between Lakes Erie and Ontario (Adam Beck 1, Adam Beck 2, Adam Beck PSG, Robert Moses, Lewiston, Decew Falls, Varrick, and RG&E) account for the majority of hydroelectric generation capacity in the study sample. Second, impacts on the biggest of these facilities (Adam Beck 1, Adam Beck 2, Adam Beck PSG, Robert Moses, Lewiston, Decew Falls) were assessed using water level projections for Lake Erie, which is immediately upstream of these facilities, and which is projected to drop significantly below 2012 levels under the worst-case low water levels scenario.

It should be noted that Niagara facilities in and of themselves drive impact estimates up because the water management regime on the Niagara River, determined by international treaty, requires maintaining the Niagara Falls at a certain minimum level and add requirements for other water uses. The likely result is that, should water in Niagara River decline significantly, hydroelectric generation on the river would be the first and hardest hit among its binationally protected uses.

The same factors drive results for other sub-regions. The four facilities in the Superior-Huron sub-region (Clergue, Edison Sault, Saint Marys Falls, and Cascade) are fairly small, and the worst-case low water levels scenario projects no drop in water levels for Lake Superior through 2030, and only a very moderate drop through 2050 relative the 2012 benchmark. As a result, the impacts projected for these facilities are very small. However, impacts on these facilities are still possible—see the discussion of Cloverland's Edison Sault facility in the Local snapshot below. These impacts could have significant effects on local economies even if the regional footprint of the four Superior-Huron facilities is small.

Because the facilities on the upper and lower St. Lawrence River are bigger generators, they could experience more significant impacts should water levels on the St. Lawrence River start to decline more dramatically, as our worst-case low water levels scenario projects for the period through 2050.

Our economic impact analysis assumes lost production would have to be replaced by increased production from non-hydroelectric sources, and that in most cases this would mean natural gas. It is possible that some of the lost production would be replaced by hydroelectric electricity from elsewhere in the region or from out of region sources, reducing our estimated impact insofar as these hydroelectric replacements remain cheaper than natural gas. This impact would also be reduced insofar as the replacement power is purchased from another GLSL jurisdiction, and insofar as lost production occurs in a particular jurisdiction at a time of overproduction (in which case it would offset the impact of selling off surplus electricity at a loss).

Decisions on the extent and source of replacement energy, as well as whether lost production would offset overproduction, would probably be made on the basis of energy market conditions at that point in time. As a result, it is impossible to predict the extent to which production losses would offset overproduction, or what the sources of needed replacement energy would be. Our analysis therefore follows standard economic methodology in holding factors that could affect these future decisions, other than low water levels, constant.

As noted earlier, high water levels could increase hydroelectric production and resulting revenues to the industry, but only up to a facility specific upper threshold. Additional ground-level research would be required to ascertain that threshold for the facilities in the study sample so as to determine what those increased revenues might be and how they stack up against the risks posed by low water levels to the industry. The IUGLSB, at least, was skeptical these high water levels gains would outweigh the industry's low water levels risks.[200]

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[200] IUGLS, 2012: 29.

LOCAL SNAPSHOT: Cloverland Electric Cooperative's Edison Sault Facility

Cloverland Electric Cooperative has already seen its hydroelectric output affected by low water levels, but not in the way it expected.

Cloverland Electric Cooperative, a member-owned non-profit electric utility, was established in 1938 and serves five counties in northern Michigan (Chippewa, Mackinac, Schoolcraft, Delta, and Luce), as well as the Michigan cities of Sault Ste. Marie and St. Ignace. Cloverland Electric Cooperative is based in Dafter, just south of Sault Ste. Marie.[201]

The Cooperative purchased the private utility Edison Sault Electric in 2009, a deal which included buying the Sault Ste. Marie run-of-the-river hydroelectric plant.[202] The 36-MW plant was completed in 1902, at which time it was the second largest hydroelectric plant next to Niagara Falls, and it draws water from a 3.5 km canal on St. Marys River that runs from near Ashmun Bay on the west to downstream of the Sabin Lock on the east.[203] The plant provided power to a Union Carbide factory between 1910 and 1963, before it was purchased by Edison Sault Electric.[204]

The problems with the hydroelectric plant started in 2012, when the Cooperative noticed that the plant's output was dropping by 60-80 per cent at times, before bouncing back to normal.[205]

The Cooperative soon realized that this change in output was not due to a problem inside the plant, but rather a result of low water levels. Low water levels in Lake Superior meant that the amount of water the plant can use had been reduced, from 18,000 cubic ft (509.7 cubic m) a second in 1997 to 12,500 cubic ft (353.96 cubic m) a second in 2012. At the same time, water levels in the plant's discharge area were also low. As a result, water was no longer covering the plant's draft tubes, the part of the plant where the water goes after it passes through the turbine. Therefore, air was entering the tubes, reducing the vacuum around the turbine and thereby the efficiency of the turbine.[206]

To fix the problem, in late 2012 workers lowered 36 concrete blocks, each weighing 1984.16 lbs (900 kg) into the water to create a weir 4.92 ft (1.5 m) high and 13.12 ft (4 m) long outside the discharge pits on the west side of the plant. As the discharged water hits the weir, it backs up to cover the draft tubes, effectively temporarily raising the water level and ensuring the vacuum around the turbines is maintained. This fix cost the Cooperative $300,000 (USD).[207]

The need for such work has been rare in the plant's 100-year history. In 1923, workers extended the draft tubes by about 30 cm for the same reason.[208]

[201] Cloverland Electric Cooperative, n.d.a; n.d.b.
[202] Cloverland Electric Cooperative, n.d.a.
[203] Cloverland Electric Cooperative, n.d.c.
[204] Cloverland Electric Cooperative, n.d.a.
[205] Kowalski, 2013.
[206] Cloverland Electric Cooperative, 2013; Kowalski, 2013.
[207] Cloverland Electric Cooperative, 2013; Kowalski, 2013.
[208] Kowalski, 2013.

Municipal, Industrial & Rural Water Users

ESTIMATED IMPACT 2030	ESTIMATED IMPACT 2050
$34M	$39M
INTAKE/OUT MAINTENANCE/ REPAIR/EXTENSION: $6M	INTAKE/OUT MAINTENANCE/ REPAIR/EXTENSION: $4M

» Groundwater supplies drinking water to 8.2M people in the Great Lakes-St. Lawrence basin, including 82 per cent of the rural population.

» Groundwater supplies 14 per cent of industrial water and 43 per cent of agricultural water in the GLSL basin.

Over 40M people

IN THE REGION GET THEIR DRINKING WATER from GLSL lakes, waterways, and groundwater.

THIS FIGURE REPRESENTS 0.0006 % OF THE TOTAL VOLUME OF THE FIVE GREAT LAKES.

29,800 Mgal

(112,000 ML)

water withdrawn daily in the upper Great Lakes basin.

MORE THAN

99%

of water withdrawn for human uses across the region is returned to the basin.

WATER USAGE BY PERCENTAGE:

POWER GENERATION

75%

INDUSTRIAL USES

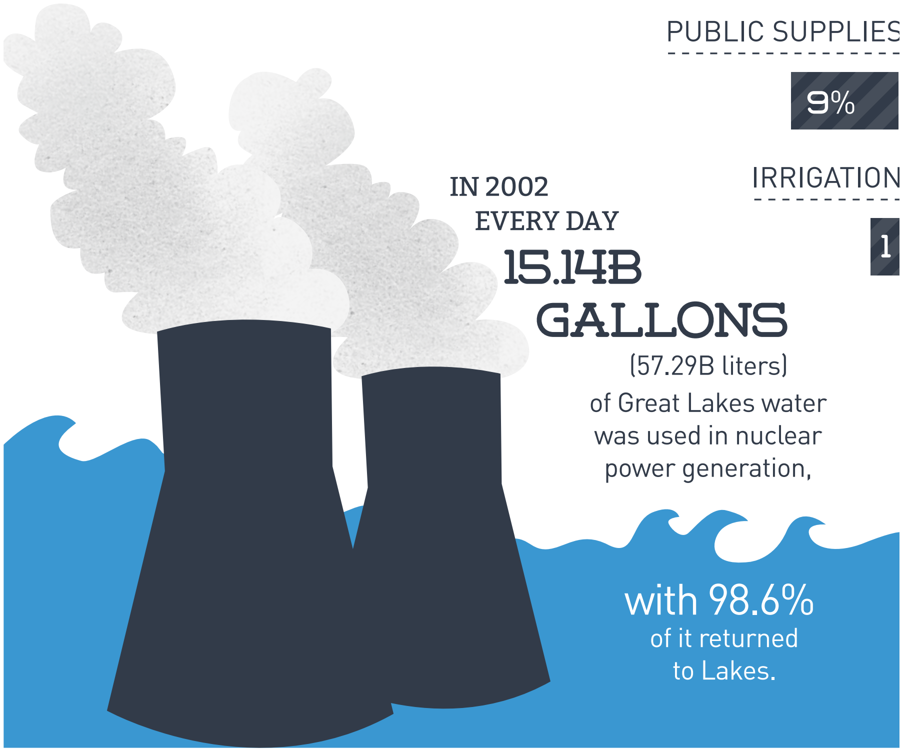
13%

PUBLIC SUPPLIES

9%

IRRIGATION

1



IN 2002 EVERY DAY

15.14B GALLONS

(57.29B liters)

of Great Lakes water was used in nuclear power generation,

with 98.6% of it returned to Lakes.

Life in the GLSL region relies on the water of the basin's lakes and rivers. Over 40M people in the region get their drinking water from GLSL lakes, waterways, and groundwater. The region's agriculture relies on the basin's waters for irrigation. Many of the key industrial sectors at the heart of the region's economy—manufacturing plants, nuclear power plants, and mining, to name a few—rely on water as a key input. A thriving water-based technology sector is one the biggest high growth success stories of the region.

The interests of water users have been top of mind in binational water management decisions in the region since the Boundary Waters Treaty of 1909 placed domestic and municipal ('sanitary') water users first in its order of precedence.[209] This importance is as political as it is economic, as "many residents using public water supply systems believe that the water 'should always be there when they turn on the tap'."[210]

In the upper Great Lakes, about 29,800 Mgal (112,000 ML) is withdrawn daily for human use, mainly for power generation (75 per cent), industrial uses (13 per cent), public supplies (9 per cent), and irrigation (1 per cent).[211] This figure represents 0.0006 per cent of the total volume of the five Great Lakes.[212] More than 99 per cent of water withdrawn for human use in the region is eventually returned to the basin.[213]

The cost-effective availability of water to be used as an operational input is a critical component of the viability and competitiveness of much of the region's industry. A 2006 study noted that "water from the Great Lakes serves more than 75% of the total industrial demand in the basin", with "steel production, food processing, petroleum refining, the manufacture of chemicals, and paper production" singled out as particularly "dependent on a steady water supply."[214]

The same study also notes that "as of 2002, 15.14 billion gallons (57.29 billion liters) of water were withdrawn from the Great Lakes per day for nuclear power usage, with all but 0.22 billion gallons (0.83 billion liters) or approximately 1.4% of the total water used being returned to the lakes."[215] Nuclear power is a major source of electricity in the GLSL, especially in Illinois, Michigan, New York, and Ontario.

Due to resident expectation of secure (and largely subsidized) clean water supplies as well as sewage and stormwater removal, GLSL municipalities must incur the often significant costs of maintaining and repairing water systems. In 2012, the IUGLSB expected population growth "to have only a moderate impact on water uses in the region, as per capita usage of water tends to decline with population growth," and was therefore more concerned with increased pressure for out of region diversions due to urban growth in nearby areas.[216] However, should climate change increase migration to the GLSL from global and North American areas affected, for example, by coastal flooding or droughts, water use in the region could increase as well.

Citing the IJC, Cruce and Yurkovich noted that "groundwater provides drinking water to 8.2M people, 43 per cent of the agricultural water, and 14 per cent of the industrial water in the Great Lakes basin."[217] For many of these residents and businesses (especially farms), groundwater is the only or primary source of water.

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[209] IUGLS, 2012: 24.
[210] IUGLS, 2012: 25.
[211] IUGLS, 2012: 25.
[212] IUGLS, 2012: 25.
[213] IUGLS, 2012: 25.
[214] Lentz, 2006: 9.
[215] Lentz, 2006: 9.
[216] IUGLS, 2012: 25.
[217] Cruce and Yurkovich, 2011: 22.

FINDINGS: Identified impacts of fluctuations in GLSL water levels

Table 16 summarizes the major impacts of fluctuations in GLSL water levels on municipal, industrial, and rural water users as identified in the literature.

TABLE 16

Major impacts of fluctuations in GLSL water levels on municipal, industrial, and rural water users, as identified in our research

	Low water levels	High water levels
NEGATIVE –	» Increased pumping/piping costs should low water levels require additional pumping or extending existing pipes » Extension or relocation of existing intake inlets or outflow outlets should water levels drop below their present location » Public health risks should exposed inlets be contaminated by algae, plant growth, or sediment » Public health risks should water around water treatment outlets shallow to the point that outflows fail to dilute » Loss of water supply to homes or farms reliant on groundwater » Risk of introduction of underground contaminants into the water system	» Flood damages to sewage/drainage infrastructure » Flooding of homes by stormflow or rising waterways » Flooding of homes by overflowing sewage/drainage systems » Flood damage to rural homes, wells, and farmland » Increased insurance costs
POSITIVE +	» Benefits to industries providing materials, tools, and services for responses and adaptations to above negative impacts	» Benefits to industries providing materials, tools, and services for responses and adaptations to above negative impacts

Municipal and industrial water systems are susceptible to both high and low water levels in different ways. Particular vulnerabilities depend on local geography and hydrology as well as on existing infrastructure, and are spread across the region.

A decline in water levels could damage existing pumps or pipes, affect pressure in cooling systems, increase pumping costs, or require extension or replacement.[218] Should water levels drop below the present location of intake inlets or outflow outlets, those inlets or outlets may need to be extended or relocated.[219] For example, the Georgian Bay municipality of Killarney recently found it would cost it $6-10M (CAD) to relocate the municipal water inlet should intermittent disruptions due to low water levels become permanent.[220]

The latter risk may be limited within historical lows, though the data on this is partial. ECT and Veritas found that, among the 39 intake and outflow facilities in the Great Lakes upstream of the Niagara Falls that reported elevation data, none would have to cease operations at historic lows, and only four would face problems. Even at 3.28 ft (1 m) below historic lows, while 11 of the 39 facilities reported problems with operations would occur, only one reported that it would have to cease operations.[221] For Lake Ontario and the St. Lawrence River, nine of the ten responding intake facilities and 30 of the 32 responding wastewater treatment facilities reported critical water levels below historic lows, meaning that they would only become vulnerable if water levels drop below historic lows.[222] Notably, sample sizes for both surveys were relatively small.

Untreated water from treatment facilities must be released at a certain depth below the surface to ensure sufficient dilution. Lower water levels could put such outflows in shallow waters or even above the water line, meaning that such untreated water might remain undiluted, increasing contamination around or downstream of water intakes.[223]

In intake systems, receding waters may also leave sediment, plant growth and bacteria-producing algae that might contaminate water supplies, increasing public health risks and requiring additional maintenance.[224] For example, a 2011 report found that water facilities on the St. Lawrence River alone spend $3.7M (USD) and $4.1M (USD) per year each on treatment of bacteria and plant growth in water systems, respectively.[225] A recent Lake Erie Ecosystem Priority report noted that ten public water utilities in Ohio reported that responding to 2009 algal bloom events entailed additional control costs totaling $417,200 (USD) for the ten water utilities.[226]

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[218] ILOSLRSB, 2006b: 125-126; ECT and Veritas, 2011: 44.
[219] IUGLS, 2012: 25.
[220] Case Book, 2013: 15.
[221] ECT and Veritas, 2011: 2.
[222] ILOSLRSB, 2006b: 125-127.
[223] ILOSLRSB, 2006b: 124.
[224] Cruce and Yurkovich, 2011: 21; IUGLS, 2012: 25, 38.
[225] ECT and Veritas, 2008: 44.
[226] LEEP, 2014: 38.

Impacts on different withdrawal facilities are likely to vary, depending on factors such as intake depth, location, infrastructure, and amount of water withdrawn.[227] For example, when surveyed as to their major vulnerabilities, water treatment facilities in New York and Ontario expressed more concern over algae impacts than over low water levels impacts.[228]

Intervening factors may also be at play, alongside low water levels, in these impacts. For example, spring warming may have played a role in at least some incidents of algae growth affecting Ontario and New York facilities.[229]

Should water levels decline to the point of disrupting the supply of drinking water, this would be especially ill-received in a region where identity and quality of life are so intertwined with fresh water.

High water levels could also result in various kinds of damage to intake and outflow facility infrastructure as well as to wastewater, drainage, and water supply systems, especially due to flooding.[230] In their aforementioned study of facilities upstream of the Niagara Falls, ECT and Veritas found more concern over rising water levels than over declining water levels among facilities. Problems were expected to occur in 7 out of 39 facilities at historic high (compared to four facilities at historic lows), and in 22 out of the 39 at one meter above historic lows (compared to 12 facilities at one meter below historic highs). At one meter above historic highs, three facilities faced ceasing operations, compared to one at one meter below historic lows.[231]

Governments are often on the hook for flood damages to water systems as well as to roads, bridges, and other public infrastructure.[232] Governments could also end up reimbursing or supporting residents when overflowing sewage flows back into their homes. Residents themselves, of course, could suffer significant damage to properties and belongings due to flooding.[233] A single flood event could cause hundreds of thousands of dollars worth of damages. For example, the July 8-9, 2013 Ontario floods, the result of an extreme summer storm, have resulted in infrastructure damage estimated at $944M (CAD).[234]

Because the economic analysis in the present study focuses on a worst-case water levels scenario, we do not project what the costs of these high water levels impacts might be. Data regarding past flooding impact suggests these costs could be quite significant, and could very well outweigh the costs of low water levels to municipal systems as estimated below. It is possible that adaptive behaviours already taken due to previous high water level episodes could reduce future flooding costs, though the degree to which this would happen cannot be projected.

Rural residents and farms located in floodplains are also susceptible to flooding damages to their homes and properties, similar to urban residents. High water levels are unlikely to carry risks to groundwater access or supply beyond flood damage to wells.

Groundwater access is vulnerable to low water levels. Should groundwater levels decline below the current depth of a well, that well will need to be deepened or replaced.[235] According to 2013 interviews with industry sources the costs of extending or replacing wells can vary significantly, but a conservative estimate (used in our analysis below) suggests the current cost in Ontario of deepening a well by ten linear feet is at least $3000 (CAD). This cost includes set up charges, environmental rehabilitation fees, charges for actual digging, and other typical expenses. The major cost components are the environmental rehabilitation fee, a flat rate charge of $1500 (CAD) for clean-out and re-caulking of the sides of the well, and the set up charge, a flat rate of $800 (CAD). Actual digging is charged at $50 (CAD) per foot. Notably, these costs apply to both digging a new well and to deepening an existing one, with the main difference between the two operations being the amount of digging required.

Where groundwater requires additional treatment, communities could face additional costs. For example, the First Nation of Shawanaga, near Parry Sound, ON, found after both its wells dried up that switching to drawing drinking water directly from Georgian Bay or from a replacement well would require upgrading or replacing the filtration plant used to treat that water.[236]

Flowing groundwater also helps clear natural and human-made contaminants from the soil in its path. As explained by one of the report's reviewers, groundwater often flows through centuries-old paths, which therefore tend to be relatively clear of such contaminants, even if the surrounding soil is not. When groundwater recedes and the surrounding soil becomes brittle, the contaminants in the soil may become exposed and be carried away into the groundwater and eventually the rivers and lakes, especially if a period of receding water is followed by heavy rain.

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[227] IUGLS, 2012: 25.
[228] ILOSLRSB, 2006b: 125.
[229] ILOSLRSB, 2006b: 125.
[230] ECT and Veritas, 2011: 43; IUGLS, 2012: 25.
[231] ECT and Veritas, 2011: 2.
[232] IUGLS, 2012: 25.
[233] IUGLS, 2012: 25.
[234] TD Economics, 2014: 4.
[235] IUGLS, 2012: 25.
[236] SBA, n.d.

The impacts of both high and low water levels would be beneficial to the businesses and industries that perform the necessary repair and maintenance work and that provide materials and tools necessary for such work. Because it is difficult to project the ways in which impacted residents and municipalities might respond or adapt to these risks, it is impossible to project what these benefits may amount to or the extent to which they may counterweigh the negative impacts.

FINDINGS: Estimated future impacts of a worst-case low water levels scenario

Table 17 summarizes the region-wide economic impacts on municipal, industrial and rural water users under a worst-case low water levels scenario, as estimated based on the authors' analysis. The methodology used to arrive at these estimates is described in detail in Appendix 6.

TABLE 17

Estimated region-wide economic impacts under a worst-case low water levels scenario on municipal, industrial, and rural water users (total-over-period, converted to 2012 USD)

Climate Change Scenario	Intakes and Outflows	Well Drilling	Total
SC2030 % of Total	**$6M** 18%	**$28M** 82%	**$34M**
SC2050 % of Total	**$4M** 10%	**$35M** 90%	**$39M**

Our analysis estimates that, under the worst-case low water levels scenario, rural water users in the GLSL could face $28M through 2030 and $35M through 2050 in costs related to the expansion or replacement of groundwater wells (converted to 2012 value and stated in USD). This is a substantial impact on what in many cases are private households and farms.

According to our analysis, municipal and industrial users would face decidedly smaller costs—$6M through 2030 and $4M through 2050—to maintain, repair, or otherwise adapt intake inlets and outflow outlets to the declines projected under the worst-case low water levels scenario. The impact through 2050 is lower than the impact through 2030 due to the effect of discounting to 2012 value.

This is probably due to the fact that, as explained earlier, the number of impacted facilities is fairly low unless water levels decline to a very significant degree. This, however, would mean that this impact could be spread among a small number of facilities, possibly meaning a very significant cost to the municipalities or companies running those facilities, as the above anecdotal evidence regarding the town of Killarney and the Shawanaga First Nation attests.

Even though we have not been able to analyze impacts under a high water levels scenario, existing data regarding flood damages, which shows single flooding events in a particular area could cause damages in the hundreds of thousands of dollars, suggests high water level impacts could outweigh these impacts over the decades through 2050. In this respect, these users are probably more vulnerable to high water levels than to low water levels.

Our analysis suggests the bulk of this impact would accrue earlier. Our expectation is that adaptations made to early low water levels occurrences would have enough contingency to absorb significant additional drops in water levels. For example, we expect rural users who deepen or replace wells will add certain depth beyond what is immediately needed as a contingency.

In addition, as already noted, many municipal and industrial intake inlets and outflow outlets may not be at risk of needing extension or replacement unless water levels drop to extreme degrees. Such levels are beyond those projected under our worst-case low water levels scenario, but under some projections may be reached in the second half of the 21st century. That impact could therefore rise significantly in the second half of the 21st century.

LOCAL SNAPSHOT: Montreal’s Water Supply Challenges

Montreal’s water supply comes primarily from the St. Lawrence River, with the Atwater and Charles-J. Des Baillets Water Supply Plants (WSPs) supplying water to 1.5M people on Montreal Island. The capacity of Montreal’s WSPs to provide an adequate water supply is directly affected by water levels in the St. Lawrence River.[237]

The minimum water level necessary for pumps to operate properly varies depending on individual water intakes. During low water conditions, intake depths in the St. Lawrence range from 1.64 to 21.00 ft (0.5 to 6.4 m), with an average depth of 7.87 ft (2.4 m), compared with an Ontario-side average of 43.96 ft (13.4 m) and a US-side average of 31.5 (9.6 m) for Lake Ontario.[238]

Low water levels in the St. Lawrence River in 1999 and 2001 affected the operation of Montreal’s WSPs but without serious consequence.[239] The capacity of Montreal’s WSPs allows for 90 per cent of water supply demand to be met even without using the most vulnerable intake well.[240] Nevertheless, if extremely low water levels occur in the future, Montreal could face water supply shortages and water quality issues due to weed and algae growth.[241]

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[237] Carrière et al., 2007.
[238] Carrière et al., 2007.
[239] Carrière et al., 2007.
[240] Carrière et al., 2007.
[241] ILOSLRSB, 2006b: 125.

Ecological Services

GLSL ecosystems make important contributions to the wellbeing of the region. Ecosystems help clear pollutants from air and water, offer natural flood control, and provide habitat and spawning grounds for animal and plant species, among other ecological services. Decision-makers should not overlook impacts on these services when assessing responses to fluctuations in water levels.

Extreme fluctuations in water levels can have substantial impacts on fragile wetland ecosystems. Wetlands provide habitat (food, shelter, breeding/spawning, nursery) services to mammals, birds, fish, reptiles, amphibians, invertebrates, and water vegetation.[242] They are particularly important as fish spawning grounds and as staging areas for the migration and breeding of waterfowl.[243]

In order to spawn and breed, many species require specific water levels and water temperature conditions. Certain species also require specific water quality and vegetation conditions, which are also affected by water levels and water temperature conditions.[244]

Seasonal and interannual water level fluctuations are essential to maintaining the health of wetlands and therefore species diversity and population abundance.[245] Hudon and her Colleagues, for instance, showed that the effects of water temperature and level, singly and in combination, can be critical variables in determining fish population strength, particularly in shallow riparian areas, which constitute the most important yet the most elusive fish spawning and nursery habitats.[246]

For example, Hudon and her colleagues found that northern pike in Lake Saint-Pierre had their best hatching years when June water levels exceeded 16.08 ft (4.9 m) above the International Great Lakes Datum of 1985 while June air temperatures exceeded 65.48°F (18.6°C). For yellow perch, six out of the eight best hatching years in the time series studied occurred when June water temperatures exceeded 61.16°F (16.2°C). By contrast, the shallowing of spawning grounds combined with a rise in water temperatures due to warm and dry weather explained a 2001 episode of mass carp mortality in Lake Saint-Pierre, where carp spawn in shallow grounds once water temperatures reach 62.6°F (17°C).[247]

This finding was significant in light of water level declines and water temperature rises in the St. Lawrence River in recent decades. Hudon and her colleagues also found that the fish growing season was five weeks longer in the warmest years relative the coolest years in the 1919-2007 study period.[248] In addition, St. Lawrence River water has been slower to warm up in the spring but remained warmer in the fall compared to its tributaries, meaning fish migrating seasonally between water masses could face enhancing or reducing their thermal budgets by 1.8-3.6°F (1–2°C) daily.[249] Notably, Hudon and her colleagues showed that St. Lawrence River water temperatures are 3.6-5.4°F (2–3°C) warmer under low water levels than under high water levels.[250]

Should the combination of shallower spawning grounds and warmer water temperatures persist in a given ecosystem, species that prefer such conditions are likelier to thrive, which could alter the makeup of that ecosystem. When these conditions are accompanied with changes to the timing and magnitude of seasonal flow variations, an even narrower range of species—those more adaptable to such changes—may be favoured. More broadly, should water and climate conditions in the GLSL increasingly resemble the current conditions of more southern water systems, GLSL waterways could become more susceptible to invasions from species imported (intentionally or unwittingly) from those water systems.[251]

Low water level conditions could further induce a change in the distribution of plant biomass along the shore, with a high biomass of terrestrial plants uplands, followed by bare mudflats and a high biomass of submerged plants in shallow waters.[252] Such discontinuity reduces habitat quality for nesting waterfowls (ducks), owing to the disappearance of wet areas sheltered from sight by high marsh vegetation (for example, cattails).

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[242] Mortsch, 1998: 403.
[243] Mortsch, 1998: 400.
[244] Mortsch, 1998: 403.
[245] Toner and Keddy, 1997; Mortsch, 1998: 391, 400, 403.
[246] Hudon et al., 2010.
[247] Hudon et al., 2010: 156.
[248] Hudon et al., 2010: 152.
[249] Hudon et al., 2010: 155.
[250] Hudon et al., 2010: 150-151.
[251] Kling et al., 2003: 2.
[252] Hudon, 2004.

Low water levels could markedly alter wetland vegetation. Aggressive perennial grass species (including *Phalaris arundinacea* and exotic *Phragmites australis*) and facultative annual plant species can invade the dried up (previously marshy) areas, displace indigenous species, crowd them out, or drive them away by blocking off sunlight or food sources.[253]

As previously shallow waters dry up and are replaced by dry ground, annual terrestrial plants could displace submerged plants species previously found in those shallow waters.[254] Under prolonged low water levels, filamentous green algae proliferate in shallow water and colonize emergent waterlogged mudflats.[255]

Changes in the patterns of tributary discharge (alternating between low flow and abrupt rise in discharge following storm events) could modify the pattern of particle deposition in wetlands. Decreased runoff from the land, particularly in summer, can decrease the deposition of material from uplands to wetlands. The material that does enter wetlands is retained longer before high-water pulses flush it downstream, thus contributing to the infilling of shallow areas, which become progressively more terrestrial.[256] For example, since the low-water level episodes of 1999 and 2001, willow swamps have colonized previously submerged areas of Lake Saint-Pierre, immediately downstream of the Richelieu, Yamaska and St. François rivers.

Wetlands can also function as filters, removing pollutants such as heavy metals and pesticides.[257] This service, however, often reduces natural wetland diversity, as it favours species that are able to withstand water turbidity and high nutrient and contaminant concentrations. Notably, contaminant concentrations may also be increased under high water levels conditions, should floods (especially in tributaries) wash away chemicals such as pesticides from farmlands.

Prolonged low water conditions could therefore result in a decline in the diversity of wetland plant species, higher levels of pollutants, and lower levels of dissolved oxygen. These effects might compromise ecosystem function in the long-term.[258]

Notably, prolonged low GLSL water levels could also open new wetland habitats in areas previously submerged.[259] Fracz and Chow-Fraser concluded that, in Georgian Bay fisheries, the loss in wetlands used for fish reproduction outweighs the gains made from new wetlands forming at the new low water point.[260] New wetland formation may offset other impacts due to the drying of wetlands.

Low water levels may have several other environmental impacts beyond impacts on wetlands, especially in interaction with other climate change impacts. For example, warming climate and increased duration of the growing season could intensify the stability and the duration of the vertical stratification of the lakes into a warm upper layer lying on top of a cool lower layer of the Great Lakes. This stratification could inhibit the flow of dissolved oxygen from the upper to lower layers, in which biological activity progressively depletes oxygen, thus resulting in a deep water habitat unsuitable for fish populations. This is a particular concern in the shallower Lake Erie, where deepwater oxygen depletion is already observed and might be exacerbated by low lake levels.[261]

The interaction between low water levels, likely adaptations to them, and other climate change impacts could also pose risks to ecosystems and the ecological services they perform. For example, in rivers with navigation channels, channel dredging to counteract shallowing can concentrate river flow to the channels and away from riverbanks, which could modify the sedimentary regimes in areas in which wetlands are found.

Short-term or long-term water management practices could also affect ecosystems. For example, storing more water in Lake Ontario in spring and early summer to be released into the St. Lawrence River in late summer or fall, as has occurred in 1999 and 2001, can reduce the spring and summer St. Lawrence River discharge.[262] When combined with already low water levels, this can correlate with increases in pollutant concentrations and in invasive species colonization downstream.[263] Research has shown that the maintenance of diversified wetlands requires some degree of seasonal and interannual water level variations.[264]

All these impacts could exert a toll on GLSL ecosystems and the ecological services they provide. The science and econometrics of assessing the economic values of ecological services have made great strides in recent years. Nonetheless, it remains a specialized field. For example, it is difficult to estimate the cost of the extinction of a species outside of traditional markets such as the fisheries industry.[265] As a result, the direct economic impacts of low water levels on the ecological services provided by the GLSL ecosystem are not estimated in the present report.

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[253] Hudon et al., 2005b.
[254] Hudon et al., 2005a.
[255] Cattaneo et al., 2013.
[256] Kling et al., 2003: 32.
[257] Mortsch, 1998: 403.
[258] Lishawa et al., 2010.
[259] Gregg et al., 2012: 17.
[260] Fracz and Chow-Fraser, 2013: 167.
[261] Smith, 1991.
[262] Carpentier, 2003.
[263] Hudon, 2004.
[264] Toner and Keddy, 1997.
[265] Krantzberg and De Boer, 2008: 106.

FIRST NATIONS

First Nations and Native American Tribes

First Nations and Native American tribes in the GLSL region have a uniquely rich and multifaceted relationship with the region's watersheds. As noted by the IUGLSB, "for thousands of years, and continuing into the present, Native American communities and First Nations have relied on the natural resources of the Great Lakes to meet their economic, cultural and spiritual needs."[266]

Any consideration of responses to fluctuating GLSL water levels must occur in partnership with the region's First Nations and tribes, and with serious consideration of their perspectives and needs. As the IUGLSB further noted, "a fundamental ongoing concern of indigenous peoples is the extent to which they are involved in the decisions of governments in the US and Canada with regard to the Great Lakes."[267]

For many First Nations and tribes, the region's lakes and rivers play a central role in their culture, religion, and sense of identity as the destined stewards and guardians of the lakes. Many also draw sustenance and livelihood from the region's waters and the plant and wildlife they sustain. Because this way of life is so economically, culturally, and spiritually bound to the health of the Great Lakes and the region's other waterways, First Nations and tribes are disproportionately vulnerable to changing water levels and regimes.[268]

While there are economic facets to the relationship of GLSL First Nations and tribes to the region and its waterways, taken as a whole this relationship far transcends the economically quantifiable. For this reason, we have not sought to quantify these impacts as part of our analysis of the economic impacts of the worst-case low water levels scenario. In the present section, we wish to provide, instead, some narrative account of these impacts.

First Nations and Native American tribes in the Great Lakes Basin

There are a great number of First Nations and tribes located in the GLSL Basin. The US officially recognizes 35 'Indian Tribal Nations' with reservations in the GLSL Basin while Canada officially identifies more than 50 First Nations communities in the Great Lakes Basin.[269] Taking self-definition into account, the actual number of First nations and tribes in the region is likely much higher.

First Nations and tribes lived in the region for thousands of years prior to the arrival of Europeans. Water levels in the Great Lakes reached their modern levels between 4000 and 5000 years ago, and First Nations and tribes established themselves on the shorelines of the region's rivers and lakes between 2900 and 4500 years ago.[270]

Each Tribal Nation is a unique legal, political, and social entity and one voice cannot speak for all. But Great Lakes First Nations and tribes do share important traditional knowledge, common cultural heritage, and objectives.[271] First Nations and tribes identify a common "interdependence with and reliance upon natural resources to meet subsistence, economic, cultural, spiritual, and medicinal needs,"[272] and "share many of the same challenges facing the health and sustainability of [these] resources."[273]

People and place: First Nations and Native American tribes' perspectives on the Great Lakes

The region's First Nations and tribes have a holistic perspective of the Great Lakes ecosystem, which is rooted in a traditional culture and relationship with the land that dates back millennia. This perspective, along with a treasure-trove of inherited traditional knowledge regarding the Great Lakes habitat, inform decisions that First Nations and tribes and their members make regarding the region's waterways, and the partnerships and actions they may engage in to ensure the continued health of these waterways.[274]

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[266] IUGLS, 2012: vi.
[267] IUGLS, 2012: vi.
[268] Sky, 1997.
[269] GLRC, 2005: 1.
[270] Cooper and Stewart, 2009: 4.
[271] GLRC, 2005: 14.
[272] GLRC, 2005: 2.
[273] Treaty Tribes of the Great Lakes and Pacific Northwest, 2013: 6.
[274] Treaty Tribes of the Great Lakes and Pacific Northwest, 2013: 10.

The region's First Nations and tribes depend on the GLSL basin's natural resources for "cultural, spiritual and economic survival."[275] First Nations and tribes are intimately linked to their natural surroundings, and especially to the earth and the water: "I've been taught that our people come from the land and that we are shaped by the land. Aboriginal history and self-understanding is conveyed across generations by stories and teachings that are grounded in particular landscapes ... for the Aboriginal people of the Great Lakes, there is both a physical and spiritual aspect to identity and landscape."[276]

Fishing and farming in the Great Lakes

Fishing is part of the way of life of many GLSL First Nations and tribes. Commercial fishing is an essential component of the economy of many First Nations and Tribal communities. Subsistence fishing is also very common and fish comprise a large part of the diet for many GLSL First Nations and tribes.[277] This makes such First Nations and tribes particularly vulnerable to climate impacts that affect fish populations and spawning grounds.

Wild rice, which grows in coastal areas on the GLSL region, is another traditional food source that is particularly sensitive to changes in weather conditions and water levels. Wild rice is still an important staple and ceremonial food in some Tribal Nations, such as the Ojibwa, Pottawatomi and Odawa.[278] The Ojibwa revere wild rice as part of the prophecy that brought them to the GLSL region; the tribe "would know we were home when we came to that place where the food grows on the water."[279]

Stewardship and treaty rights

Many GLSL First Nations and tribes view water as sacred. All life depends on water, which is being threatened by human-caused pollution and climate change.[280] Therefore, GLSL First Nations and tribes share the objective of "protecting and restoring water quality and quantity" in the GLSL.[281] The Haudenosaunee Environmental Task Force, for example, "challenges all people to use a holistic view of the Great Lakes" and to "realize humans are a part of the environment."[282] This is done with the understanding that "all decisions must be carefully considered to assess the impact on the environment, society, and on seven future generations," as "our actions of today will affect all our children and our children's children physically, emotionally, and spirituality."[283]

GLSL First Nations and tribes are actively involved in monitoring and controlling of water quality and invasive species. Groups such as the Chippewa Ottawa Resource Authority take an active role in protection and restoration efforts in the region.[284] In November 2004, over 100 First Nations and tribes from the US and Canada met in Sault Ste. Marie, Michigan and nearly unanimously agreed to cooperate in the preservation of the Great Lakes.[285]

Beyond tradition, First Nations and tribes also have legal rights to fish and other natural resources in the region, which are protected by various federal treaties and state/provincial agreements in Canada and the US.[286] Courts in the US have established Native American tribes as co-managers of GLSL resources, which led to the establishment of resource conservation agreements and inter-sovereign cooperation.[287]

For example, US federal courts recognized that the rights of the Michigan Anishinaabek are "unabridged, aboriginal, tribal right[s] to fish derived from thousands of years of occupancy and use of the fishery of the waters of Michigan."[288] While there has been only limited use of litigation related to water levels, treaty rights may require federal and state/provincial governments to maintain certain water levels as part of preserving these natural resources.[289]

Consultation and recognition of GLSL First Nations and tribes' rights regarding the GLSL basin and ecosystem has been inconsistent in spite of constitutional recognition of treaty rights in both the US and Canada. Part of the difficulty is the jurisdictional complexity, which involves Federal, state, provincial, bi-national and regional agencies, as well as industrial, commercial and recreational interests.

The risks of GLSL low water levels for First Nations and Native American tribes

Low water levels could pose several profound risks and challenges to First Nations and tribes in the region. The drying or shallowing of spawning grounds may severely affect both commercial and subsistence fishing for First Nations and tribes that rely on wetland-spawning and shallow water fish species (impacts on deepwater fish species are unclear). Low water levels could also devastate wild rice growing. Thus, key subsistence ingredients for many members of the region's First Nations and tribes are put at risk by low water levels. Notably, high water levels could also pose risks to wetlands, fish populations, and wild rice growing.

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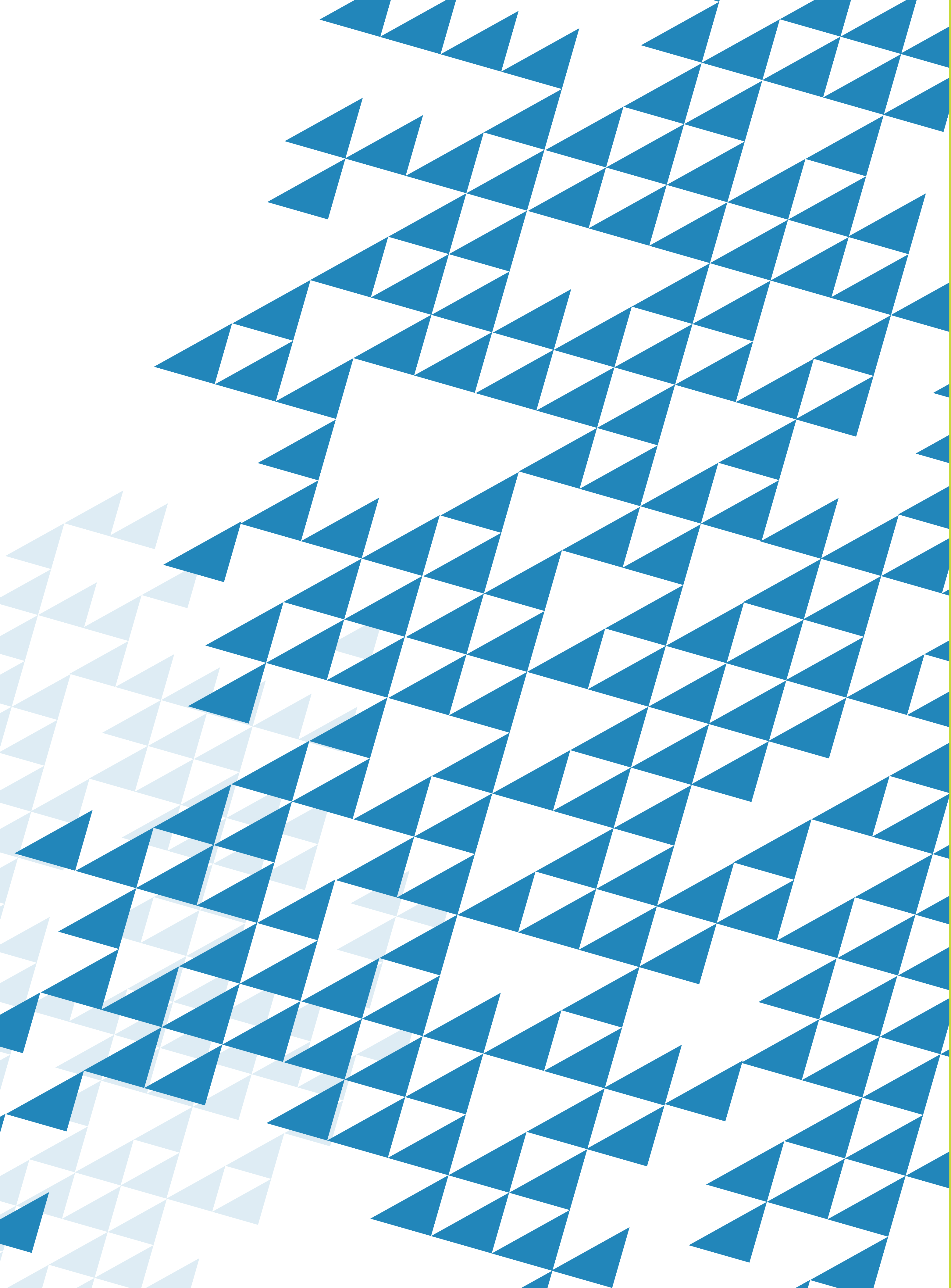
275 Treaty Tribes of the Great Lakes and Pacific Northwest, 2013: 6.
276 Johnston, n.d: 2.
277 GLIN, n.d.b.
278 Mertz, 2013.
279 Mertz, 2013.
280 Haudenosaunee Environmental Task Force, 2005.
281 Treaty Tribes of the Great Lakes and Pacific Northwest, 2013: 5.
282 Haudenosaunee Environmental Task Force, 2005.
283 Haudenosaunee Environmental Task Force, 2005.
284 Chippewa Ottawa Resource Authority, n.d.
285 Singel and Fletcher, 2006: 1295.
286 GLIN, n.d.b.
287 Singel and Fletcher, 2006: 1290.
288 Singel and Fletcher, 2006: 1293.
289 Singel and Fletcher, 2006: 1294.

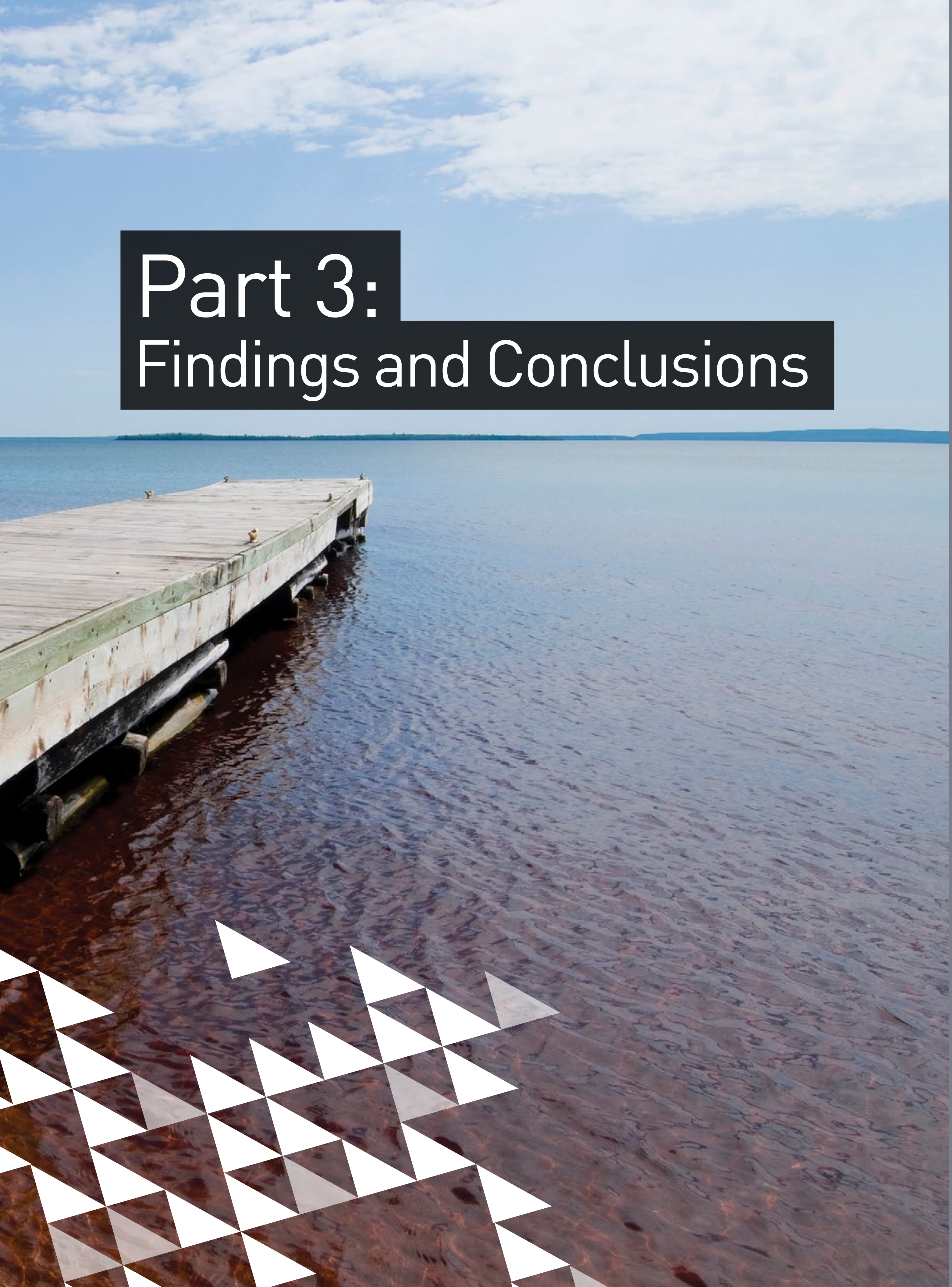
Loss of local subsistence sources would require replacement through purchase from outside communities, increasing financial strain on First Nation and Tribal communities and their members. At the same time, insofar as such communities rely on commercial fishing as an economic driver, this source of income may also be put at risk by both high and low water levels.

Given the central and spiritually anchoring role that the region’s waters and waterways play for many First Nations and tribes, and given the centrality of the sense of responsibility for the health of these waterways to the spiritual life of many First Nations and tribes, a diminishing of these waters may also exact a spiritual toll. This, however, is difficult to assess without the cultural knowledge of a member of these communities.

While these impacts are not quantifiable in economic terms, they are nonetheless a critical part of the story of the impact of extreme fluctuations in water levels in the GLSL region. As such, they require consideration as the region moves forward towards solutions to the challenges of low and high water levels. First Nations and Native American tribes should be at the table for the ongoing discussions, research and mitigative and adaptive action this will entail.



Part 3:
Findings and Conclusions



The GLSL faces an unpredictable water future. Much of the region has gone through nearly three decades of (sometimes extreme) high water levels followed, since 1998-1999, by 14 years of (sometimes extreme) low water levels. In much of the region, the last 12 months have seen higher water levels than in preceding years.

For much of the first decade of the 21st century, most projections expected water levels in much of the GLSL to continue dropping over the next several decades. We found that this is no longer the case. Updated models, more recent data, and methodological improvements have resulted in a broad range of water levels projections, from close to historic highs to (in Lakes Michigan-Huron and Ontario) well below historic lows.

The scientific understanding of the ways different climate factors interact to affect GLSL water levels, and of the ways those climate factors may be affected by climate change, is also evolving. It cannot even be predicted whether the recent rebound in water levels will continue or reverse back over the next few years.

For GLSL decision-makers, this spells significant uncertainty. High water levels, low water levels, and moderate water levels are all possible future scenarios for the GLSL. Extreme weather events, substantially raising or dropping water levels for a season or a year are also possible, perhaps even likely. Prudent long-term planning must take this uncertainty into account and allow for much adaptability in future plans.

But prudent long-term planning must also take stock of risks and vulnerabilities, and prepare for the worst. This is especially true in the GLSL, where the region's economy relies on the region's waters, and is therefore susceptible to fluctuations in water levels.

Our study of five key industries and interests in the region—commercial shipping and harbours, recreational water activities, residential waterfront properties, hydroelectric generation, and municipal/industrial/rural water users—has found significant vulnerability to low water levels in all five case studies, with at least some vulnerability to high water levels in all five case studies and substantial vulnerability in two case studies (residential waterfront properties and municipal/industrial/rural water users).

Low water levels—identified risks and vulnerabilities

TABLE 18

Potential risks and vulnerabilities of low water levels as identified in our research

Commercial shipping and harbours	Tourism and recreational boating and fishing	Residential waterfront properties	Hydroelectric generation	Municipal, industrial, and rural water users
» Reduced loads to maintain necessary under-keel clearance, increasing number of trips and total costs needed to move same amount of cargo » Reduced speed and more stoppages in transit in order to avoid grounding » Additional capital expenditures on fleet if more trips are needed » Risk to operation of industries that cannot viably ship by rail or truck » Losses, increased costs, and increased environmental risk from shift of other industries to rail or truck » Increased need for dredging and infrastructure maintenance / replacement in harbours and navigation channels	» Damage to the quality and image of tourist attractions such as beaches, risking local tourism industries » Narrowing of access channels to marinas resulting in closures and bottlenecks » Increased risk of boats running aground, with ensuing costs of damage or salvage » Loss of water access if water by marina slips or private boat launches becomes too shallow » Risk of exposure and damage to boating and marina infrastructure » Increased dredging and maintenance costs for marinas to ensure access and usability » Loss of spawning grounds could result in reduction in fish stocks and risk to species variety » Risk of cruise ships touching bottom or being forced to reroute, and of having to transport passengers by lifeboat or bus as a result	» Reduced waterfront access when water recedes from piers, boat launches, and beaches, and costs to extend such structures to new water line » Diminished aesthetic appeal of waterfront view due to mud, muck, rocks, and unappealing vegetation revealed by receding waters » Repairs to exposed piers and boat launches suffering from dry rot » Property value drops as a result of above risks for properties in shallowing-risk locations » Reduced municipal property tax revenues as a result of property value drops » Reduced economic activity due to reduced use of affected seasonal properties	» Decreased (and after a certain point, lost) generation with resulting revenue losses should reservoir levels or river flows decline » Increased costs and GHG emissions if lost generation is replaced with electricity from sources that are more expensive or larger GHG emitters » Significantly increased long-term costs should new facilities need to be built to replace lost generation » Reduced flexibility to respond to fluctuations in energy demand, especially if lost capacity is from conventional facilities	» Increased pumping/piping costs should low water levels require additional pumping or extending existing pipes » Extension or relocation of existing intake inlets or outflow outlets should water levels drop below their present location » Public health risks should exposed inlets be contaminated by algae, plant growth, or sediment » Public health risks should water around water treatment outlets shallow to the point that outflows fail to dilute » Loss of water supply to homes or farms reliant on groundwater

The literature has identified multiple risks that interests in the five case studies could face due to low water levels. Table 18 summarizes potential risks and vulnerabilities of low water levels as identified in our research.

Commercial shippers could face reduced loads to maintain necessary bottom clearance, and a resulting need to add trips and capital expenses to move the same amount of cargo. Shippers could also face delays and disruptions en route to their destinations or at the entrances to ports. Ports could be faced with increased dredging, maintenance, and repair needs to deal with shallowing harbours and entrances or with infrastructure suffering from dry rot. Governments may also face increased demands for maintenance and capital dredging in navigation channels.

Industries using GLSL marine shipping could be faced with increased costs to ship their products or to receive needed raw materials. If shipping cost increases reach a critical point, such industries may opt for land-based shipping alternatives or, if such alternatives are not viable, for relocation away from the region. Increased use of land-based transportation would also increase infrastructure demands and environmental costs.

Recreational boaters and anglers could find themselves unable to access lakes and waterways due to the shallowing of slips and boat launches. They could also face risks of grounding, requiring costly repairs. Anglers could face lower catches due to reduced number of fish as a result of the drying of spawning grounds. These impacts could lead to lost boating and fishing days, and a concomitant loss in annual boater/angler expenditures, which would be felt primarily by downstream businesses. Marinas could face increased dredging, repair and maintenance costs to deal with shallowing slips and launches, narrowing access channels and resulting bottlenecks, and exposed infrastructure suffering from dry rot.

Other segments of the tourism industry could also be adversely impacted by low water levels. Cruise ships could face the risk of running aground at shallowed port entrances, being forced to use alternative ports and bus customers to their destinations, or to transport customers to shore via lifeboats. Receding beaches exposing rocky terrain or taken over by vegetation could require additional cleaning and could lose their aesthetic appeal. More broadly, low water levels could damage the region's image and appeal as a pristine water-focused tourism destination.

Residential waterfront properties could be vulnerable to loss of water access as water recedes away from boat launches and piers, and to loss in the aesthetic value of waterfront view as receding water reveals muck or mud and newly revealed beach is taken over by vegetation. Both impacts could lead to a decrease in the property's value, which in waterfront properties is often linked to water access and waterfront view.

Residential waterfront property owners could also face increased cleanup, repair, and maintenance costs, for example to repair piers or boat launches suffering from dry rot. In seasonal properties, if these impacts reduce seasonal use, expenditures spent in local economies could also suffer. Municipal property taxes could also be reduced if property values drop.

Hydroelectric generators could face decreased production should declining water levels reduce river flow in RoR facilities or reservoirs in conventional facilities. Beyond a facility-specific decline threshold, facilities might be forced to cease operations. Should the electricity system need to replace lost production from more expensive or more polluting sources, increased costs and emissions could ensue, especially if new generation facilities need to be built. The electricity system could also lose some flexibility to respond quickly to short-term shifts in energy demand.

Municipal and industrial users face risks of extending or relocating pipes where water levels decline below existing inlets (for water intake systems) or outlets (for sewage, discharge and other water outflow systems), increased cleaning and maintenance of pumps and pipes that remain under (now shallower) water, and other increased pumping and piping costs. Growth of bacteria producing algae and other vegetation at now shallower inlets, and reduced dilution of untreated sewage at now shallower outlets, could increase public health risks. Farms and rural resident could be faced with costly deepening or replacement of wells that have dried up due to declines in groundwater levels.

Some of these vulnerabilities have a wide geographic impact. Hydroelectric production losses, to the extent that they translate into increased costs to the electricity system of a given state or province, would be distributed across that state/province. Losses due to reduced shipping capacity that get absorbed by shippers would be concentrated in those shippers, without a particular geographic concentration unless that shipper ceases operations, which would hurt all localities which ports it served.

Most of these vulnerabilities, however, are localized, affecting certain localities in the region more than others. Table 19 notes the kinds of local economies that would be more vulnerable to low water levels impacts.

TABLE 19

Low water levels vulnerabilities for local economies

Case study	Vulnerabilities higher where local economies rely more heavily on:
COMMERCIAL SHIPPING AND HARBOURS	» Ports » Industries that depend on maritime shipping to ship product or receive raw materials
TOURISM AND RECREATIONAL BOATING AND FISHING	» Coastal tourism » Cruise ship visitors » Marinas » Boat making, salvage, repair » Secondary expenditures by boaters
RESIDENTIAL WATERFRONT PROPERTIES	» Municipal property tax revenues (shallowing-risk areas) » Secondary spending by seasonal waterfront property users
HYDROELECTRIC GENERATION	» Hydroelectric electricity » Hydroelectric generation facilities (for employment, service and maintenance, secondary expenditures)
MUNICIPAL, INDUSTRIAL, AND RURAL WATER USERS	» Surface water or groundwater for drinking » Sewage treatment to maintain beaches or water sources clean enough to use » Industries that rely on water intakes as input or cooling agent

While specific impacts and vulnerabilities are localized, local economies where at least some of these vulnerabilities are present can be found throughout the region. In this respect, the risks and vulnerabilities low water levels could pose to the GLSL are regional in scope.

TABLE 20

Estimated region-wide economic impacts under a worst-case low water levels scenario (total-over-period, converted to 2012 USD)

Climate change scenario	Commercial shipping and Harbours	Tourism and recreational boating and fishing	Ontario-side residential waterfront properties	Hydroelectric generation	Municipal, industrial, and rural water users	Total
SC2030 % of Total	**$1.18B** 12%	**$6.65B** 69%	**$794 M** 8%	**$951M** 10%	**$34M** 0.4%	**$9.61B**
SC2050 % of Total	**$1.92B** 10%	**$12.86B** 68%	**$976 M** 5%	**$ 2.93B** 16%	**$39M** 0.2%	**$18.82B**

Low water levels—economic impacts under a worst-case low water levels scenario

What could these risks actually mean to the regional economy? To address this question, we assess what could be the economic impacts of some of the major identified vulnerabilities, for each of these case studies, in two projection periods (present through 2030 and present through 2050), under a projected worst-case low water levels scenario. We then aggregate these impacts into a regional picture, and where available data enabled it, into sub-regional pictures as well.

Table 20 summarizes the region-wide economic impact values as estimated by our analysis. Our analysis estimates that under a worst-case low water levels scenario, the low water levels impacts analyzed could amount to $9.61B over the period through 2030 and $18.82B over the period through 2050 (converted to present value and stated in 2012 USD). Notably, these values include direct impacts only, without taking into account indirect and induced impacts such as job and productivity losses or lost tax revenue. For context, the GLSL's annual GDP is 4.9 trillion (USD).

Disaggregating our impact findings back to the sector level shows the largest impacts being faced by the recreational boating and fishing sector, with estimated losses to the tune of $6.65B over the period through 2030 and $12.86B over the period through 2050. These amounts represent 69 per cent of the estimated region-wide impact through 2030 and 68 per cent of the estimated region-wide impact through 2050.

88 per cent of the impact on this sector ($5.86B through 2030 and $11.26B through 2050) is accounted for by lost boating days and reduced boater annual expenditures (not including boater-anglers). This suggests the brunt of this impact would probably be borne by secondary industries servicing boaters. Additional losses related to the fishing activity make up an additional 11 per cent ($725M through 2030 and $1.4B through 2050).

These impacts depend on the extent to which boaters and anglers are willing to resume their activity rather than relocate or abandon it in the face of lower water levels. What degree of further decline would trigger these reactions will probably depend on local conditions and personal considerations.

Effective adaptation by marinas to eliminate the risk (and perception of risk) that a boater/angler might show up at the marina only to realize slips are too shallow to launch or marina entrances are congested due to narrowing could therefore reduce this impact to some degree. There is little adaptation, however, that can reduce the shallowing of one's preferred boating or fishing grounds unless the user is willing to adapt by finding new boating/fishing grounds or switching to a boat with a smaller draft.

Impacts on the region's shipping sector account for 12 per cent ($1.18B) of the estimated total impact through 2030 and 10 per cent ($1.92B) of the estimated total impact through 2050. The main driver of this impact ($446M and 38 per cent through 2030, $1.17B and 61 per cent through 2050) is lost shipping capacity, which is directly tied to degrees of water levels decline and is therefore expected to accelerate should water level declines accelerate in mid-century (and even more so in the second half of the 21st century), as the worst-case low water levels scenario projects.

The amount of cargo a vessel can carry is inevitably determined by the shallowest point in the vessels route. Insofar as this point is at a port or a human-made navigation channel, dredging trouble points could reduce this impact. Otherwise, little adaptation is available to reduce shipping capacity losses beyond shippers adding trips and vessels. Current industry contracts may limit the ability of shippers to pass portions of these cost increases to client industries.

Data was not available to fully break down vulnerabilities by client industry. A breakdown of raw commodities industries only shows the most heavily impacted of these industries would be iron ore ($220M through 2030 and $465M through

2050) and coal ($190M through 2030 and $373M through 2050), stone/aggregate ($89M through 2030 and $175M through 2050), and salt ($65M through 2030 and $130M through 2050).

The point beyond which marine shipping would no longer be the most cost-effective means of shipping product or raw materials differs not only among industries but also among individual facilities. Adaptation by switching to alternative, land-based, modes of transportation may not be available to all facilities and could increase both the economic and the environmental costs of shipping. In some cases, beyond a certain level of shipping cost increases, facilities may become non-viable at present locations, though this level is facility-specific.

The remainder of the estimated impact on the shipping industry stems from costs related to harbours (infrastructure repair and replacement, and the costs of harbour and slip dredging). At least some of these costs could end up being borne by the respective federal governments. Early adaptation (dredging and infrastructure repair and replacement), insofar as it targets water levels that are lower than those present at the time of work, would help stave impact increases should water levels continue to drop. This accounts for the expectation that the portion of harbour impacts would be smaller in the longer projection period (through 2050) than the shorter one (through 2030).

Lost hydroelectric production as a result of low water levels accounts for 10 per cent ($951M) of the estimated total impact through 2030 and 16 per cent ($2.93B) of the estimated total impact through 2050. The increase in this impact over the longer projection period reflects the fact that Lake Erie water levels are expected to decline well below their 2012 levels over the longer projection period. Lake Erie water levels drive our estimates for the Niagara Falls generation facilities, which account for more than half the capacity in our study sample. Adaptive measures by the Niagara River Board of Control may therefore reduce this estimated impact. Notably, production in affected facilities would decrease as water levels decrease, up to a facility-specific threshold point below which the facility ceases to operate.

For methodological reasons explained earlier, our analysis of losses in property values as a result of low water levels under our worst-case scenario is limited to residential waterfront properties in Ontario municipalities adjacent to GLSL shores. Our analysis estimates property value declines of $794M through 2030 and $976M through 2050, accounting for 8 per cent of the estimated total impact through 2030 and five per cent of the estimated total impact through 2050. These values do not include repair and maintenance costs incurred by these properties or downstream losses to municipal property tax revenues or to local economies. We have not able to assess impacts in other parts of the GLSL, which could actually be positive in flood-risk areas and therefore, from a region-wide perspective, offset some of these property value losses.

Losses to water users make up a small portion of the overall estimated impact (0.4 per cent through 2030 and 0.2 per cent through 2050). In the case of municipal and industrial water users, this is probably due to the fact that most of the region's inlets and outlets would remain under water should water levels drop only to the levels projected under our worst-case low water levels scenario, averting the biggest and costliest risk low water levels pose to these users.

Impacts on groundwater users ($28M through 2030 and $34M through 2050), representing the estimated costs of deepening wells that have dried up due to declines in groundwater levels, are relatively small from a region-wide perspective but quite notable for users themselves, who tend to be farms and private households. If these adaptations take place, users should have enough contingency to withstand additional water level drops, reducing the impact over the longer projection period.

Due to the limitations of available data, only some of the analyzed impacts could be broken down at the sub-regional level. These include impacts to harbours, marinas, hydroelectric generation, and residential waterfront property owners in Ontario municipalities adjacent to GLSL shores. These impacts, summarized in Table 21, represent 25 per cent of the estimated overall impact through 2030 and 24 per cent of the estimated overall impact through 2050.

TABLE 21

Estimated region-wide economic impacts under a worst-case low water levels scenario (total-over-period, converted to 2012 USD)

Lake	Climate change scenario	Harbours	Marinas	Ontario-side residential waterfront properties	Hydroelectric generation
SUPERIOR	*SC2030*	**$46M**	0	0	*SC2030:* $0M *SC2050:* <$1M
	SC2050	**$47M**	$<1M	$4M	
HURON	*SC2030*	**$70M**	$23M	$403M	
	SC2050	**$82M**	$69M	$612M	
MICHIGAN	*SC2030*	**$142M**	$18M	N/A	N/A
	SC2050	**$162M**	$46M	N/A	N/A
ERIE	*SC2030*	**$292M**	$12M	$340M	*SC2030:* $951M *SC2050:* $2.83B
	SC2050	**$274M**	$38M	$301M	
ONTARIO	*SC2030*	**$89M**	$12M	$51M	
	SC2050	**$94M**	$38M	$59M	
ST. LAWRENCE RIVER	*SC2030*	**$92M**	0	0	0
	SC2050	**$90M**	0	0	$99M

This partial sub-regional analysis suggests that while some parts of the region are expected to be more heavily affected than others, no part of the region is spared. Notably, impacts that we do not analyze or cannot break down to the sub-regional level could disproportionately affect sub-regions that appear less affected by the analysis in Table 21.

Of the impacts we can break down sub-regionally, Lake Erie makes up the biggest portion of estimated impacts. Due to the high concentration of commercial ports on Lake Erie it is the sub-region most vulnerable to impacts on harbours. On its Ontario shores, Lake Erie could also be vulnerable to significant property value drops, though that vulnerability could be offset by vulnerability to property value drops due to high water levels on some of its US shores, which we do not analyze. Lake Erie is also expected to share with Lake Ontario most of the impact of losses in hydroelectric generation.

On our analysis, Ontario-side Lake Huron is the Ontario GLSL region most vulnerable to property level drops. This is not surprising given the combination of extensive waterfront cottage land and significant shallowing-risk characterizing much of its Ontario shoreline, especially in Georgian Bay. Lake Huron is also expected to be the most vulnerable to marina impacts, though Lake Michigan could also be quite vulnerable to this impact. Lake Michigan is also quite significantly vulnerable to impacts on harbours.

As explained elsewhere, we cannot break down impacts on recreational boating and fishing other than those affecting marinas sub-regionally. Distribution of marina impacts is in part determined by the number of marinas and slips in a sub-region. Insofar as the number of marinas and slips in a sub-region is indicative of boating and fishing activity in that sub-region, Lakes Huron and Michigan could be areas in the region more vulnerable to the broader impacts on recreational boating and fishing.

Lake Ontario shares almost the entirety of the estimated impact on hydroelectric generation with Lake Erie. However, given that electricity produced at the Niagara facilities, which account for more than half of the capacity in our study sample, is used primarily by New York and Ontario, it is fairly safe to expect much of this impact to be borne by Lake Ontario. Lake Ontario also bears notable, though not the largest, components of the impacts on harbours, property values, and marinas.

Our analysis suggests the St. Lawrence River would see harbour impacts of a magnitude similar to Lake Ontario, as well as notable hydroelectric generation impacts through 2050. We suspect that impacts we cannot analyze or break down sub-regionally, and especially impacts on lost shipping capacity, could increase the St. Lawrence River impact estimate. A more nuanced analysis of the St. Lawrence River is needed to arrive at more conclusive findings regarding impacts on this sub-region.

Lake Superior is the only sub-region that to show very low effects for all estimated impact values we have been able to disaggregate sub-regionally. We expect, however, that a significant part of the impact due to lost carrying capacity will be borne by Lake Superior. According to the IUGLSB, about 50 per cent of Great Lakes commodity shipments pass through the Sault Ste. Marie locks.[290] Of the commodities shipped in the region, 37.5 per cent of tonnage is accounted for by iron ore, 18.5 per cent by coal, and 12.6 per cent by stone and aggregate.[291] Shipping from Lake Superior accounts for significant portions of at least the iron ore component.

Many of these impacts would be directly borne by the impacted individual users, businesses and companies. However, governments could also bear considerable direct and indirect impacts should markedly low water levels persist in the region.

Governments at all levels could face increased maintenance or even capital dredging expenditures—even where they are not formally required to fund such dredging, as happened in Michigan in 2013. Where public utilities or public generators own hydroelectric facilities, they could incur what losses low water levels bring. Municipal government will bear the increased costs of supplying clean drinking water to their residents. All levels of government could see tax revenue losses as a result of decreased tourist activities, recreational activities, and recreational property use, although local governments in smaller communities that are highly dependent on revenues from such activities may be disproportionately affected by this.

Due to our methodology, we cannot calculate indirect macroeconomic impacts in any economically meaningful way (as explained in Appendix 1).

It is likely that many of the negative impacts we have found will to some degree be mitigated through adaptive behaviours—as has often occurred in the past. While some short-term adaptive behaviours are more predictable, and in a few cases we even have the data to take adaptive behaviours into account in our calculations, in general we find it impossible to forecast with any credibility what economic impacts such adaptive behaviours might have over the 40-year span for which we are estimating impacts.

Low water levels—identified benefits

The literature has identified some positive impacts that could be accrued from low water levels and that could therefore offset some of the negative impacts discussed earlier. Table 22 summarizes potential benefits of low water levels as identified in our research.

Our research suggests that some of these positive impacts may have marked upper limits. For example, low water levels could be accompanied by a shorter freezing period and therefore a potentially longer shipping and boating/fishing season. However, necessary annual maintenance places a cap on the extent to which the shipping season can be extended from current levels. And boater/angler's preference towards summer activity over early spring / late fall activity may limit the extent to which a shorter freezing period contributes overall boating or fishing days to the season.

TABLE 22

Potential benefits of low water levels as identified in our research

Commercial shipping and harbours	Tourism and recreational boating and fishing	Residential waterfront properties	Hydroelectric generation	Municipal, industrial, and rural water users
» A longer navigation season due to reduced ice coverage » Reduced ice-breaking costs » Increased business to harbours due to additional trips from shippers	» Reduced ice coverage and longer spans of higher temperatures could lead to a longer boating season » Enlarged public beach area, if extended beach is sandy and cleanup costs can be absorbed	» Strengthening of property values and of resulting property tax revenues for properties in flood/erosion-risk locations » Enlarged beach area, if extended beach is sandy and cleanup costs and higher property tax payments can be absorbed	» Offset of surplus generation, so long as demand conditions do not make lost hydroelectric generation needed again » Benefits to GLSL jurisdictions who have surplus energy they can sell to jurisdictions in need of lost capacity replacement	» Benefits to industries providing materials, tools, and services for responses and adaptations to above negative impacts

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290 IUGLS, 2012.
291 Martin Associates, 2011.

Other positive impacts may not be sustainable beyond the short-term. Harbours could benefit from extra work if shippers are forced to make additional trips to cover for lost shipping capacity. Businesses that provide salvage, repair, or replacement parts to boaters, maintenance and repair to municipal and industrial water systems, and well-digging services or equipment and materials to groundwater users could benefit from increased business. Jurisdictions with excess hydroelectric power could benefit from selling it to jurisdictions that are short due to lost hydroelectric production.

However, these benefits would only last insofar as users are intent on continuing their activity and adapting to new water levels conditions. If industries turn to alternative means of shipping their goods or relocate from the region, if boaters and anglers relocate or abandon their activity, if jurisdiction suffering hydroelectric production losses opt for longer-term capacity replacement by turning to alternative means of generation, or if water users find alternative water sources, these downstream benefits could prove short-lived. Similarly, for jurisdictions with short-term or intermittent energy production, loss of hydroelectric production provides a benefit as long as overproduction lasts.

On the other hand, some benefits could be longer-lasting. For jurisdictions with more chronic electricity overproduction, loss of hydroelectric production could prove a long-term benefit. Residential property value increases in flood-risk areas could be sustained as long as the low water levels trend is not reversed. The benefit to municipalities seeing their public sandy beaches extended due to receding waters could similarly be sustained as long as water levels remain low. Reduced ice-breaking costs could also be sustained as long as the freezing season remains shortened.

With the longer-lasting benefits, the key question is the magnitude of the benefit and concomitantly, the extent to which the benefit would offset the costs of low water levels (and in the case of increases in residential waterfront property values, also whether they outweigh the residential waterfront property value increases from high water levels felt in flood-risk areas). It strikes us that these benefits do not seem as substantial as the negative impacts, but since we do not analyze the economic impact of these benefits, we cannot assess the degree of the offset with any degree of certainty.

High water levels—identified risks and vulnerabilities

Table 23 summarizes risks and vulnerabilities posed by high water levels as identified in our research.

The most significant risk posed by high water levels, repeatedly flagged in the literature, is the risk of flooding. Flood impacts can affect interests in all five of our case studies. Primarily, floods can damage loading/unloading facilities used by commercial shipping, boat launches and parking lots used by boaters and anglers, piers, beaches and properties, various facility infrastructure in hydroelectric plants and other power and industrial facilities, wells and farmland, and both municipal and industrial water systems. Floods can also result in rapid flows or floating ice and debris that could further damage infrastructure as well as endanger water users such as boats, cruise ships, or commercial vessels.

Another adverse effect frequently associated with high water levels is coastal erosion. Coastal erosion could increase damage to shore protection structures as well as other coastal structures and infrastructure, reduce the aesthetic appeal of private and public beaches which, in the case of public beaches, could reduce their tourist appeal.

In addition, high water levels could endanger the safe operation of navigation locks, force the more frequent operation of the gates of a dam to release surplus water, and risk unexpected downstream flooding when surplus water is released. Hydroelectric generation facilities could face lost-opportunity costs when they are forced to release water without using it to generate electricity.

Flooding and erosion impacts on residential waterfront properties could have secondary impacts that may in fact prove more significant than damage repair and clean up. Diminished waterfront access or view could result in declines in property values. Repeated damage or increased risk of recurring damage could increase insurance costs and thereby further depress property values. Declining property values, in turn, could translate into declines in municipal property tax revenues. With seasonal waterfront properties, should access and view concerns reduce usage of the properties, local economies could lose the secondary revenues that come with such uses.

Given that we do not analyze economic impacts under a high water levels scenario in the present study, we cannot assess with certainty the weight of these impacts and whether they would outweigh the adverse impacts of the worst-case low water levels scenario we analyze in the present study. This represents a major area where additional study is needed.

TABLE 23

Potential risks and vulnerabilities of high water levels as identified in our research

Commercial shipping and harbours	Tourism and recreational boating and fishing	Residential waterfront properties	Hydroelectric generation	Municipal, industrial, and rural water users
» Damage/disabling of loading/unloading facilities » Risk to safe operation of navigation locks	» Risk of flooding of boat launches and parking lots » Risk of floating debris damaging boats or halting boating/fishing activity » Risk of rapid flows and of floating debris/ice interrupting cruise ship activity » Flood damage, erosion, and debris diminishing the aesthetic and tourist appeal of beaches	» Risk of flooding and reduced access to homes » Reduced waterfront access when piers, boat launches, and sandy beaches are flooded » Diminished aesthetic appeal of waterfront due to beach erosion or storm debris » Erosion and moisture damage to shore protection and beach-use structures » Increased insurance costs » Property value drops as a result of above risks for properties in flood/erosion-risk locations » Reduced municipal property tax revenues as a result of property value drops » Reduced economic activity due to reduced use of affected seasonal properties	» Missed opportunity and suboptimal operations should reservoir levels or river flows increase beyond a facility's capacity or need to use them in generating electricity » Risk of local flooding should surplus water be released from a reservoir/river » Increased risk of erosion in power canals and tailrace » Increased risks to the structural integrity of hydropower infrastructure » More frequent need to operate the gates at a dam to release surplus water	» Flood damages to sewage/drainage infrastructure » Flooding of homes by stormflow or rising waterways » Flooding of homes by overflowing sewage/drainage systems

Nonetheless, it should be recalled that the IUGLSB concluded that low water levels are more of a concern than high water levels for commercial navigation and hydroelectric generation. The magnitude of the economic impacts we estimate under the worst-case low water levels scenario for both interests seem to us to support the IUGLSB's conclusion given the nature of the high water levels impacts on these interests identified in the literature (flood damage to loading facilities and risk to the safe operation of navigation locks in the case of commercial shipping, flood and erosion damage, increased use of dam gates, and lost opportunity to produce electricity in the case of hydroelectric generation).

In the case of tourism, insofar as coastal and infrastructure damage would cause coastal tourists to vacation elsewhere, and insofar as floating ice and debris, rapid flow, or damage to infrastructure, would cause boaters and anglers to relocate or cease their activity, high water levels could have a significant impact on the tourism industry.

The big question is whether this impact would outweigh the impacts of low water levels on the industry, which in our analysis are the most significant of all five case studies. While we cannot answer this question with confidence, we find it telling that, according to the IUGLSB, tourism businesses themselves seem more concerned about low water levels than about high water levels. Insofar as the industry has already taken effective measures to adapt to high water levels during the three high water levels decades from the late 1960s to the late 1990s, those measures could also help it reduce the impact of a future recurrence of high water levels, at least insofar as water levels do not rise above the historic range.

High water levels pose the most significant concerns in the case of residential waterfront properties and municipal, industrial, and rural water users. In the case of municipal and industrial users, the small impact we project under the worst-case low water levels scenario is likely to be outweighed by the significant cost these users, especially municipalities, are likely to face should vital infrastructure get damaged by flooding. Whether the same is the case with rural groundwater users is less clear, and may depend on factors and conditions specific to each rural home or farm.

TABLE 24

Potential benefits of high water levels as identified in our research

Commercial shipping and harbours	Tourism and recreational boating and fishing	Residential waterfront properties	Hydroelectric generation	Municipal, industrial, and rural water users
» Increased loads reducing number of trips and total costs needed to move same amount of cargo	» None identified	» Strengthening of property values and of resulting property tax revenues for properties in shallowing-risk locations	» Increased generation and resulting revenues (up to a certain point) should reservoir levels or river flows increase	» Benefits to industries providing materials, tools, and services for responses and adaptations to above negative impacts

In the case of residential waterfront properties, it is clear that properties in flood-risk areas are more likely to see potentially significant costs and property value drops from high water levels than from low water levels, while the reverse is the case for properties in shallowing-risk areas. We do not have the evidence to assess which group may face higher property value drops or higher repair costs.

High Water Levels—Identified Benefits

High water levels could also have some positive impacts on the interests in our five case studies, though most of these positive impacts are limited. Table 24 summarizes potential benefits of high water levels as identified in our research.

High water levels could enable shippers to increase loads on vessels, but only as much as vessel design allows. Similarly, high water levels could increase production in hydroelectric facilities, but only to the extent facility infrastructure allows and the electricity system needs.

As was the case with low water levels, here too businesses and industries that provide flood/erosion damage clean up, repair, or replacement could benefit from high water levels. Insofar as floods and erosion are recurring, this benefit could prove more sustainable than in the case of low water levels, because of the nature of the impacted infrastructure: while boaters may relocate their activity, resulting in marinas closing, GLSL cities, along with their infrastructure and water systems needs, are likely here to stay for the very long term.

In shallowing-risk areas, high water levels could boost residential waterfront property values, thereby also increasing municipal property tax revenues. This is the one benefit that does not have an inherent upper limit, and is limited only by what the market can sustain. We cannot assess, based on our analysis in this study, whether, from a region-wide perspective, this boost outweighs either the boost low water levels would bring to properties in flood-risk areas, or the drops high water levels would bring to properties in such areas.

The literature has not identified high water levels impacts that add value to recreational boating and fishing, increasing the number of annual boating/fishing days and expenditures. It may be that the main benefit high water levels bring this industry is the user confidence that comes from the knowledge that, as long as high water levels persist, the significant negative impacts of low water levels are being averted.

Final remarks

Overall, our findings are in line with the IUGLSB's conclusions that "in general, lower water levels will adversely impact [commercial navigation] interests more than higher levels," and that both conventional and RoR facilities are vulnerable to fluctuations in water levels, though the IUGLSB notes that "low water conditions have more of an impact on hydroelectric generation" than do high water conditions.[292] Our findings also support, albeit more qualifiedly, the indication of tourism industry businesses "that lower water levels were more detrimental to tourism activities than higher water levels."[293]

In these case studies, low water levels presented a distinct measure of vulnerability, and our economic analysis showed this vulnerability could translate into considerable costs to these interests and to the region more broadly. While we do not analyze the economic impacts of high water levels or of positive low water levels impacts, our research makes us doubt they would offset these costs.

On the other hand, our findings suggest that in the case of municipal and industrial water users, industry's higher level of concern with high water levels than with low water levels may be warranted. The low economic impacts projected under the worst-case low water levels scenario, when stacked up against the fact that municipal and industrial water users are highly vulnerable to flood impacts should regular or flash floods occur in their locality, suggests these users are more vulnerable to the risks of high water levels than to those of low water levels. However, water levels drops below the worst-case low water levels scenario, as could happen in the second half of the 21st century, could alter this balance.

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[292] IUGLS, 2012: 27, 29.
[293] IUGLS, 2012: 35.

The picture is less conclusive when it comes to groundwater users and to residential waterfront properties given the fact that we do not analyze high water impacts and did not have access to needed property data outside Ontario. While our estimated low water impacts on groundwater users are relatively small when stacked up against other case studies, they can be quite significant for what often are private households and farms without deep financial pockets. The question we cannot answer is how the risk of those impacts stacks up against the risk of high water levels impacts, primarily flood damage. This would depend on specific conditions and high/low water levels vulnerabilities that differ across farms and households. Further study is required to identify and then aggregate relative vulnerabilities at the individual farm/household level.

The vulnerability of residential waterfront property values to high or low water levels is also a matter of geography, with flood-risk areas more vulnerable to high water levels impacts and shallowing-risk areas more vulnerable to low water levels impacts. In this respect, the present study was only able to provide the low water levels half of the picture. While not all Ontario Great Lakes shores are shallowing-risk, our research nonetheless shows significant adverse impact, linked to low water levels, on residential waterfront properties in Ontario municipalities adjacent to GLSL shores. It is probable that the adverse impact of high water levels on waterfront properties in flood-risk areas could also be significant. However, without access to the relevant non-Ontario property values data it is impossible to assess the extent to which either of these impacts would counterweigh the other.

More broadly, further research into the impacts of high water levels, and particularly of flood and erosion damages, would be an important complement to the present study, as already noted.

The local and sub-regional variability seen in the cases of water users and of property values is also evidenced in the other case studies. While our economic analysis operates at the aggregate and region-wide average levels, none of the impacts are likely to be distributed equally across the region. Areas more dependent on recreational boating and fishing or on shipping are more vulnerable to the adverse impacts of low water levels on those industries than are other areas. Individual shipping lines, ports, marinas, hydroelectric facilities, industrial facilities, properties, rural households, and water systems will differ in the degree of their water levels vulnerabilities depending on multiple factors related to geography and location, infrastructure and maintenance, and operations. Further study is required to assess such local-level impacts in a more nuanced way.

Several regional economic drivers for which insufficient public data was available also merit further study. These include manufacturing, commercial fisheries, public health impacts, and impacts on non-market goods.

The present study has identified several vulnerabilities to extreme water level fluctuations faced by GLSL manufacturers, although the portion of these impacts solely affecting manufacturing could not be disaggregated. Manufacturers who rely on the region's shipping sector to ship product or receive raw materials and components are susceptible to the same impacts on commercial shipping as are other clients of the industry. In the case of low water levels, for example, manufacturers could be vulnerable to losses in ships' carrying capacity, especially if their facilities lack rail connectivity or if their goods cannot be viably transported by rail or truck. Manufacturers who require water as an input, a cooling agent, or to safely discharge or treat byproduct are also susceptible to both high and low water levels similarly to other water users.

In addition, many manufacturers, and in particular advanced and high value-add manufacturers, operate in ongoing global competition for talent. Quality of life can sometimes be an important deciding factor for highly sought innovators, entrepreneurs, and high-skilled workers considering career moves. The opportunity to live, travel, play, and rest in the region's waterways has long been one of the drawing cards of the region's manufacturers in competing for global talent. This may be put at risk by the impacts of fluctuating water levels on the region's waterfront properties and tourism and recreational industries.

Despite several decades of decline and thanks to a recent rebound, commercial fishing remains one of the signature industries of the GLSL region, and has become an example of the economic-environmental integration characteristic of the region. For example, in 2011, Ontario's commercial aquaculture industry produced nearly 3,968 short tons (3,600 metric tons) of fish annually, contributing $60M (CAD) annually to the provincial economy.[294]

However, there is little available data with which to properly identify or assess what impacts fluctuations in water levels may have on this sector, especially given its marked differences from recreational fishing. For example, most aquaculture operations are located in deeper, offshore waters. According to information provided by Ontario government officials consulted by the authors, the Lake Ontario centrachild (sunfish), a comparatively small aquaculture, is

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[294] Data provided to the authors by the Ontario Ministry of Natural Resources.

the only wetland spawner among commercially harvested fish in Ontario. As a result, most commercially-harvested fish species are not impacted by the drying of wetlands other than indirectly, through the broader impact drying wetlands may have on the ecological web and its food chains.

Our research has found several potential risks fluctuating water levels may pose to human health. In the case of low water levels, for example, should water levels drop close to, or below, the current depth of intake pipe inlets, freshwater supplies may be contaminated by sediment or bacteria produced by algae and water plants. Should water shallow near outflow outlets discharging untreated sewage or chemicals, they may not be properly diluted in the water. The dredging of harbours and rivers in response to low water levels could reintroduce heavy metals and other toxins, currently held in sediment beds, or natural minerals in toxic concentration, into the food chain and drinking water supplies, as well as contaminate beaches used for recreation.[295] Further study, however, is needed to quantify the downstream public health risks that these impacts could pose.

In the GLSL, non-market goods, those things we cherish as human beings, but which do not have a market-based value, are essential components of residents' lives and a central part of the region's value proposition. Being water-based, the value residents and visitors place on many of these goods can be put at risk by extreme fluctuations in water levels. As scenic waterfronts, wetlands, and rivers dry up or give way to invasive vegetation, or as they flood or get covered with debris, they lose their value as pleasurable to walk or jog beside, to go for a hot summer day swim in, to enjoy the water-based wildlife population of, or simply to observe over a glorious sunset, for example. Of course, this value is highly subjective, and therefore difficult to quantify other than through extensive survey and extrapolation work.

Notably, some of the impact on these values is already factored into our economic analysis. For example, enjoyment of nature is a large part of what attracts boaters to boating, and aesthetic value is a critical component of waterfront property values. Further study, however, is needed to disaggregate the non-market components of these impact values as well as to quantify other impacts high and low water levels may have on such non-market goods in the GLSL.

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[295] Chiotti et al., 2002: 24.

In sum, the key findings of the present study are:

WATER LEVELS

- » Future water levels in the basin are uncertain; whereas most earlier projections expected water levels to drop well below the period of record's historic lows within upcoming decades, current projections suggest both high and low water levels (within the historic range) are possible in upcoming decades.
- » Prudent long-term planning must take this uncertainty into account, and allow for much adaptability in future plans, but also to take stock of risks and vulnerabilities and to prepare for the worst.
- » The science that supports short and long-term water levels projections is evolving thanks to improved data and to methodological and technological advances, but more robust data gathering and research is still needed.

RISKS AND VULNERABILITIES FOR KEY REGIONAL SECTORS AND ECONOMIC DRIVERS

Overall

For just the limited number of sectors we analyzed, under a worst-case low water levels scenario, impacts could amount to **$9.61B through 2030 and $18.82B through 2050** (all values converted to 2012 USD).

Recreational boating and fishing

- » Under a worst-case low water levels scenario, impacts could amount to **$6.65B through 2030 and $12.86B through 2050**.
- » The sector is significantly vulnerable both to lower and to higher water levels, but likely more vulnerable to lower water levels.
- » Major low water levels vulnerabilities include:
  - »» Reduced activity due to difficulty accessing boats or destinations, damage to boats, and in the case fishing reduced catch due to loss of spawning grounds, all resulting in lost annual and boating day expenditures (**$6.59B through 2030 and $12.66B through 2050**).
  - »» Increased maintenance, infrastructure, and dredging costs for marinas to deal with shallowed slips, exposed infrastructure, and narrowed access channels (**$65M through 2030 and $191M through 2050**).

Hydroelectric generation

- » Under a worst-case low water levels scenario, impacts could amount to **$951M through 2030 and $2.93B through 2050.**
- » The sector is more vulnerable to lower than higher water levels.
- » Major low water levels vulnerabilities include:
  - »» Decreased revenue due to decreased or lost generation (**$951M through 2030 and $2.93B through 2050**).
  - »» Increased economic and environmental costs if lost generation is replaced by more expensive and less clean generation.
  - »» Reduced flexibility to respond to fluctuations in demand.

Shipping and commercial harbours

- » Under a worst-case low water levels scenario, impacts could amount to **$1.18B through 2030 and $1.92B through 2050**.
- » More vulnerable to lower than higher water levels.
- » Major low water levels vulnerabilities include:
  - »» Loss of carrying capacity (**$446M through 2030 and $1.17B through 2050**).
  - »» Increased harbour maintenance and dredging expenses (**$730M through 2030 and $750M through 2050**).
  - »» Increased environmental and economic costs should cargo have to be transferred by rail or truck.
  - »» Risk to industries/facilities that cannot shift to rail or truck.

Residential waterfront properties in Ontario municipalities adjacent to GLSL shores

» Under a worst-case low water levels scenario, impacts could amount to **$794M through 2030 and $976M through 2050**.

» Vulnerability varies with local geography and climate, with properties in flood-risk areas more vulnerable to higher water levels and properties in areas susceptible to shallowing more vulnerable to lower water levels.

» Major low water levels vulnerabilities include:

  »» Loss of water access and aesthetic appeal resulting in property values drops (**$794M through 2030 and $976M through 2050 for Ontario waterfront properties**).

  »» Loss of tax revenues as a result of property values drops.

  »» Lower usage of seasonal properties resulting in lower inputs into local economies.

Rural, municipal, and industrial water users

» Under a worst-case low water levels scenario, impacts could amount to **$34M through 2030 and $39B through 2050**.

» Significant vulnerability to higher water levels include flooding and erosion, with significant vulnerability to low water levels only beyond extreme threshold.

» Major low water levels vulnerabilities include:

  »» Need to deepen or replace dried up rural groundwater wells (**$28M through 2030 and $35M through 2050**).

  »» Need to extend or replace intakes and outflows in municipal and industrial water systems should water levels drop below current inlets or outlets (**$6M through 2030 and $4M through 2050**).

  »» Risk of contamination due to exposed intakes/outflows.

RISKS AND VULNERABILITIES FOR LOCAL AND SUB-REGIONAL ECONOMIES

» The impacts of high and low water levels will be felt primarily by local economies, some of which could be severely impacted.

» Most vulnerable are local economies that rely on:

  »» **Hydroelectric power generated around Lake Ontario and between Lakes Erie and Ontario, especially Niagara River**
  Facilities in those areas could face generation losses valued at **$951M through 2030 and $2.83B through 2050**.

  »» **Property taxes from waterfront properties on shoreline areas at risk of shallowing**
  For example, residential waterfront properties in Ontario municipalities adjacent to the shores of Lake Huron could see property value drops of **$403M through 2030 and $612M through 2050**.

  »» **Expenditures by boaters and fishers**
  For example, marinas on Lake Michigan-Huron could see **$410M through 2030 and $1.15B through 2050** in added maintenance and dredging costs.

  »» **Industries dependent of waterborne shipping**
  For example, iron ore shippers and producers, who have a strong presence around Lake Superior, could face losses to shipping capacity estimated at **$220M through 2030 and $465M through 2050**.

OTHER SECTORS AND INTERESTS

Future low water levels could have significant impacts on several additional sectors and stakeholders, though sufficient data is lacking for reliable economic impact analysis.

Manufacturing

» Manufacturers who use waterborne shipping to move raw materials and finished products could be significantly impacted by increased shipping costs due to shipping capacity lost to declining water levels.

» Manufacturers without access to rail as an alternative to waterborne shipping could face risks to viability if shipping cost increases become prohibitive.

» Under extreme water level drops, manufacturers using water as an input may be forced to extend pipes or relocate inlets/outlets should water levels drop below the present location of inlets/outlets.

Agriculture

» Commercial farmers who rely on waterborne shipping or on groundwater may be similarly vulnerable to low water levels.

Ecosystems

» Wetland ecosystems may be rendered ineffective in providing typical ecological services (breeding and habitat for fish and waterfowl, cleaning of contaminants, etc.) due to drying up or shallowing, or due to changes to species mix and invasion from alien species.

» This risk may be more potent when low water levels are accompanied by warming water temperatures and/or changes to seasonal flows.

First Nations

» First Nations and Native American tribes are culturally as well as economically bound to the GLSL.

» Low water levels could affect critical subsistence and commercial wild rice crops and fish catch.

» A diminishing GLSL could pose a significant cultural threat to First Nations and Native American tribes.

AREAS FOR FUTURE ACTION

» Better scientific data collection and improved accessibility to this data.

» Significant investment in new equipment and technology to provide more extensive and sensitive monitoring of climate factors affecting GLSL water levels.

» Enhanced partnership, collaboration, and exchange between government, the scientific community, and the private sector in driving required data collection and monitoring as well as co-ordinated solutions.

» Deepening the GLSL's stock of economic impact data through new research that assesses impacts based on recent projections and especially of a realistic worst-case high water levels scenario, and through research into additional key sectors such as manufacturing or commercial fishing.

» Continued consultation and planning on the part of decision-makers that takes account of future water levels uncertainty by planning for increased adjustability and for worst-case scenarios.

» Further analysis of potential responses to water level fluctuations, and especially an analysis of the costs and benefits of different options for action.

» Private sector participation and leadership in robust contingency planning and in the implementation of adaptive behaviours in the various potentially affected sectors.

Appendices: Economic Methodology

APPENDIX 1:

General Remarks

We base our case study analyses on the best publicly available data, complemented by property value data purchased from MPAC. Where several sources were found, we combine complementary sources, and otherwise draw on the most reliable source available.

For each sector we identify at least one key low water levels impact that lends itself to reliable quantification and economic analysis. For each impact, we ascertain marginal economic losses on the basis of a worst-case low water levels scenario for two projection periods: present through 2030 and present through 2050. We aggregate the losses for each identified impact into total impact estimates for each case study, and further aggregate impacts for each case study into overall region-wide impact estimates. Where data makes it possible, we also present sub-regional impacts, usually on a lake-by-lake basis.

We developed a specific methodology to calculate impacts for each case study, based on the available data. We discuss these methodologies in Appendices 2-6. In this Appendix we discuss several methodological issues common across our case studies.

Climate Change Models and Scenarios

As explained earlier, because this report relies primarily on available economic impact data, we have to use the water levels projections employed in generating this economic impact data. This meant drawing upon projections made public in the early 2000s, drawn from earlier climate change models developed by EC for the IPCC's first two assessments.[296]

We had initially considered the two future water levels scenarios most commonly used in this economic impact literature. We drew these scenarios from the work of Frank Millerd,[297] though they recur in other economic impact analyses as well.

Millerd labeled these scenarios as *CCCma* and *CCC GCM1*. For *CCCma*, Millerd provided two variants of the scenario, for 2030 (averaging out projections for 2021-2040) and for 2050 (averaging out projections for 2041-2060).[298]

In comparing these scenarios against more recent projections of future GLSL water levels, derived through more advanced modelling and methodology (see Figure 10 on p. 17 above), it became clear the projections derived from the scenario Millerd labeled *CCC GCM1* are well below both current projections and historic lows. We have therefore deemed this scenario too extreme to be considered realistic any more, and refrained from using it in the present report.

Projections based on the scenario Millerd labeled *CCCma* are less extreme, remaining within the historical range for the entire basin through 2030 and for all but Lake Michigan-Huron through 2050. We therefore use both of Millerd's variants of this scenario in the present report, labeling them *SC 2030* and *SC 2050* for clarity.

SC2030 and *SC2050* are variants on a transient scenario based on an EC AOGCM that coupled an ocean model with an earlier atmospheric/land surface model. As explained by Millerd, these variants "are developed from global climate change model runs that simulate the response of the climate system to a gradual increase in greenhouse gases and sulphate aerosols. Greenhouse gases increase at past rates up to the present and then are increased by 1 per cent a year until 2100. The cooling effects of sulphate aerosols are included. The period 1961-1990 is the base climate, 2030 represents an average of 2021 to 2040, and 2050 an average of 2041 to 2060."[299]

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[296] Mortsch and Quinn, 1996; Boer et al., 2000; Flato et al., 2000; Mortsch et al., 2000; Lofgren et al., 2002.
[297] Millerd, 2005: 272.
[298] Millerd draws both variants of this scenario from Mortsch et al., 2000.
[299] Millerd, 2005: 272.

The above model runs projected "a drier and warmer climate is indicated with runoff and outflow decreasing and evapotranspiration and lake evaporation increasing, resulting in lower lake levels. The mean annual water level changes on the Great Lakes for the selected climate change scenarios were used to develop monthly water level estimates from 1900 to 1989 at 12 locations from Lake Superior to Montreal harbour for [the] climate change scenario. The 1900 to 1989 monthly data include natural annual and seasonal variations in water levels. The base of comparison data are levels above a datum in the Gulf of St. Lawrence, not depths."[300]

While more moderate than other projections from the period and largely within historical lows, this scenario still projects water levels that in many cases are lower than those projected by more recent projections (see Figure 10 on p. 17 above). The more recent projections use more advanced physics as well as better scaling to the regional level—as noted by one expert consulted for this report, the atmospheric/land surface model used in generating *SC 2030* and *SC 2050* has a coarser horizontal resolution (about 3.75 degrees latitude by 3.75 degrees longitude) without representation of the Great Lakes themselves because of the relative small size of the watershed under such a resolution (nine gridcells at most). For this reason, we treat this scenario as a worst-case scenario for future GLSL low water levels.

Currency and Value Point Conversion

Our findings are expressed in total impacts for the projection period, discounted to 2012 values and converted to USD. To convert estimated future values to 2012 USD, we use a discount rate of 0.04 (4 per cent). When converting Canadian dollars to USD we use a conversion rate of 1 CAD = 0.9 USD, which represents a recent average of the Canadian currency conversion. In converting past dollar figures, we use US inflation over the elapsed period of time.

Because not all researchers whose findings are cited in this report have noted their currency or value-point, we cannot convert all values in the report to a single currency or value-point. We state other researchers' findings in the narrative in the authors' original currency, without a value-point. When such findings are also used as inputs in our economic analysis, we convert them accordingly for the purpose of our calculations, but retain original currency in the narrative so as to remain consistent across citations.

Present Value Analysis

Future economic impact findings can be expressed as either per-year values for the final year in the projection period ('$x per year in year y') or total-over-period values ('total $x by year y'). Our case studies differ as to whether the available data allowed impacts to be initially calculated in per-year or total-over-period values. Findings for residential waterfront property values, harbour dredging and adaptation repairs, and water users, were initially calculated as total-over-period. Findings for shipping capacity losses, recreational water activities, and hydroelectric generation were initially calculated as impacts per-year for final year in period.

To allow for consistency and meaningful comparison across case studies, we use present value analysis to convert per-year values into total-over-period values where initial calculations were expressed in per-year terms. Notably, present value analysis (or other economic tools at our disposal) does not enable the opposite conversion, from total-over-period to per-year.

Conversion to present values allows us to understand future costs in today's dollars. To give an example, a dollar one year from now is worth less than one dollar today because of the lost opportunity to gain a year's interest on that dollar had it been invested today (this is known as opportunity cost). The process of conversion to present values also incorporates and therefore compensates for some measure of the risk factor inherent in any future projection.

The rate at which it is assumed future values will decrease relative present values is known as the discount rate. There are accepted methodological guidelines in economics for the selection of the discount rate in a given analysis.

To calculate the present value of a future impact we divide that future impact by one plus the discount rate for each year in which we are moving backwards in time. That is, an impact in the year 2050 would need to be divided by one plus the discount rate to the power of thirty-eight, because there are thirty eight periods between the years 2050 and 2012 (our baseline year).

Where impacts were expressed in values per-final-year of projection period, we estimate impact values in the preceding years in the projection period, then sum them up into a total value for the projection period. To facilitate this calculation we use the mathematically reasonable technique of using a hypothetical linearity assumption. That is, we assume the given per-final-year impact value would be the largest per-year impact value in the projection period, and that annual impacts throughout the projection period would increase linearly

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[300] Millerd, 2005; 272.

up to the given per-final-year value. We then divide the given per-final-year impact by 38 (for the through 2050 projection period) or 18 (for the through 2030 projection period). This value is used as the increment by which the impact grew each year up to the final year in the projection period, allowing us to calculate the total impact for the projection period.

Notably, the hypothetical linearity assumption used in this calculation is merely a mathematical tool employed strictly in the context of this calculation. It does not entail an assumption that economic impacts or water levels will in fact be distributed in a linear fashion throughout a projection period.

Performing this calculation enabled us to express all impact values for all case studies in total-over-period values. We then use present value analysis to convert these values to 2012 USD values, using an economically conservative discount rate of 4 per cent. We have chosen 2012 as our baseline year because it was the closest to present year for which relevant data was available. Being a particularly low water levels year also made this a conservative choice in the context of the present study.

Using present value analysis imposes certain methodological limitations. Most importantly, this analysis means impact values in the distant future become very small in comparison to impact values in the near future. For example, A $1M impact next year, using a 4 per cent discount rate, is $961,500 in today's dollars. A $1M dollar impact in 38 years using a 4 per cent discount rate is merely $225,200 in today's value. This is the reason that impact estimates for the period from the present through 2050 are lower than impact estimates from the present through 2030 in the case of impacts on harbour infrastructure repair and maintenance and on municipal/industrial water intakes and outflows. This is also the reason we do not analyze projection periods beyond 2050.

The discount rate puts a negative value on time, factoring into a multiyear calculation the fact that any present value depreciates over time such that $100 a year from now is worth less than $100 today. A net present value calculation totals up the latter conversion (future value into today's values) for a succession of future years. These calculations thereby also factor risk and uncertainty into the calculation of future values.

A criticism that is sometimes applied to this approach in environmental debates is that it represents a "live for today" attitude, and values the welfare of future generations less than that of the present. An alternative way to view this is that a dollar invested in a trust fund today will grow to a higher value in the future, and such an investment is an alternative to direct policy expenditures aimed at improving future welfare.

Present value calculations are heavily dependent on the chosen discount factor. A slight change in the discount factor can have a dramatic change on resulting values. We stay on the conservative side of estimation, using a 4 per cent real discount rate to be inclusive of opportunity cost and risk factors involved. This 4 per cent rate builds in a substantial risk margin compared to the risk-free government bond interest rate, for example. By comparison, over the past ten years, the Government of Canada real return bond yield, as reported by the Bank of Canada, had an average value of only 1.5 per cent.

Present value calculation is a very helpful tool for policymakers to allow weighting both benefits and costs over time, as it puts more weight on earlier costs and benefits than on later costs and benefits.

Indirect Macroeconomic Impacts

Because our impact values are calculated as totals over the entire projection period and are converted into 2012 values using a present value analysis, we are not methodologically able to reliably ascertain indirect and induced macroeconomic impacts using sectoral input-output multipliers.

Input-output multipliers are based on intra-industry relationships that exist in the region. If a shock hits one industry, these multipliers allow us to estimate the effects this exogenous impact will have on other sectors, known as indirect and induced effects. In practice, these values can change considerably from year to year as new innovations and changes in operating environments and economic conditions force economic sectors to evolve. Moreover, the relationship between industries today may not exist in the future. Therefore it is methodologically questionable to apply these multipliers to impact values totaling 38 or even 18 future years of annual impacts.

APPENDIX 2:
Commercial Shipping and Harbours

Existing literature on the economic impacts of low water levels on commercial shipping and harbours focuses on two types of costs: costs related to losses in ships' carrying capacity, and costs related to harbour maintenance.

Shipping

Table 25 outlines our step-by-step methodology, assumptions, and proxies, in calculating impact estimates due to shipping capacity losses.

TABLE 25
Impact estimate methodology: Loss of shipping capacity

ASCERTAIN THE REGION-WIDE ECONOMIC IMPACTS OF LOW WATER LEVELS ON: Loss of shipping capacity	
STEP 1	Ascertain loss in carrying capacity per every inch of water drop for the median ship in the Great Lakes fleet While ship-by-ship carrying capacity data was available from Greenwood's, 2013, ship-by-ship ton miles data was not publicly available, forcing us to use aggregate ton miles data in Step 2. To remain consistent with Step 2, we use size of median vessel in Step 1.
STEP 1.1	Ascertain loss in carrying capacity per every inch of water drop based on ship size This data is collected from Quinn, 2002.
STEP 1.2	Ascertain size of a median ship in the Great Lakes fleet We draw the median ship size from Greenwood's, 2013.
STEP 1.3	Calculate loss in carrying capacity per every inch of water drop for the median ship in the Great Lakes fleet Combining these values with the fleet's median ship size allowed us to calculate the per inch median loss of carrying capacity in each fleet.
STEP 1.4	Carry out Steps 1.1-1.3 for both US and Canadian Great Lakes fleets
STEP 2	Ascertain estimated total regional impact per inch of water on the shipping sector in the region
STEP 2.1	Ascertain the percentage decline in total carrying capacity based on the decline in water levels projected by our water levels scenario. Following standard methodology, we are making a no-change assumption, namely that the amount of goods that need to be shipped will remain constant, such that additional trips will be required to make up for carrying capacity losses.
STEP 2.1.1	Ascertain ton-miles traveled for each of the two Great Lakes fleets For the US, we obtain this data from United States Department of Transportation Maritime Administration, 2013. For Canada, we obtain this data from English and Hackston, 2013.
STEP 2.1.2	Ascertain loss of ton-miles carried in the region based on the decline in water levels projected by our water levels scenario. For each of the two Great Lakes fleets, we multiply ton-miles traveled (Step 2.1.1) by the decline in carrying capacity of the median ship in each fleet (Step 1.4).
STEP 2.2	Calculate estimated total regional impact on the shipping sector in the region For each of the two Great Lakes fleets, we multiply the loss of ton-miles value (Step 2.1.2) by the cost of each ton-mile, based on Cambridge Systematic Inc., 1995, Dager, 1997, and industry sources. The value we have chosen is five cents per ton-mile, a conservative estimate. This estimate accounts for the variable costs that factor into cost per ton-mile, for example additional capital costs, seaway and port fees, or fuel. We add up the values for both Great Lakes fleets.

It should be noted that while the best sources available for estimating ton-mile costs date back to the 1990s, the regulatory and operating environment for the shipping sector has changed dramatically since that time, resulting in costs increases beyond the rate of inflation. As explained to the authors by industry sources, many new environmental regulations related to air emissions and water discharges as well as security requirements have resulted in cumulative increases to the cost structure for GLSL short sea shipping. New regulations require new technologies which not only cost up front but also require maintenance and training, and can take space that had previously been used for cargo.

In addition, operating costs (e.g., crew, lubes, maintenance and repair, insurance and overhead) have likely increased with inflation. Voyage costs (e.g, fuel, port charges) have increased well above the inflation rate. Fuel costs are the single largest expense that a vessel incurs while engaged in commercial activity and account for 47 per cent of voyage costs.[301] Since the 1990s, the overall price of fossil fuels has almost quadrupled[302]. Emissions control areas on US coastal waters implemented by the US Environmental Protection Agency mean ships operating in those areas are required to burn fuel with a lower sulphur content, which is more expensive. Seaway tolls have also increased at a rate above inflation to compensate for ongoing infrastructure projects.

Because the sector requires transportation to occur between lakes, it is impossible to determine the exact shipping industry impact on a lake-by-lake basis on the basis of publicly available data. Instead, we provide a partial breakdown of costs per industry, specifically, of costs for raw commodities industries. We cannot further estimate the extent to which these costs would be transferred by shippers to client industries.

Ascertaining raw commodities industry costs required a separate methodology. Table 26 outlines our step-by-step methodology, assumptions, and proxies, in calculating impact estimates due to shipping capacity losses for raw commodities industries.

TABLE 26

Impact estimate methodology: Loss of shipping capacity (costs to raw commodities industries)

ASCERTAIN THE REGION-WIDE ECONOMIC IMPACTS OF LOW WATER LEVELS ON: Loss of shipping capacity (costs to raw commodities industries)	
STEP 1	Ascertain the current Canadian-side per-ton increase in cost by commodity (iron ore, coal, grain, other bulk/general cargo) as a result of low water levels
STEP 1.1	Ascertain the Canadian-side total tons shipped by commodity for 2001 This is provided for each commodity in Millerd, 2005.
STEP 1.2	Ascertain the 2001 total Canadian-side estimated increase in cost by commodity (iron ore, coal, grain, other bulk/general cargo) as a result of low water levels These estimates are provided for each commodity in Millerd, 2005.
STEP 1.3	Calculate the 2001 Canadian-side per-ton increase in cost by commodity (iron ore, coal, grain, other bulk/general cargo) as a result of low water levels For each commodity, we divide the estimated cost increases for each commodity industry under our water levels scenario (Step 1.2) by the Canadian-side total tons shipped by commodity for 2001 (Step 1.1).
STEP 1.4	Calculate the current Canadian-side total increase in cost by commodity (iron ore, coal, grain, other bulk/general cargo) as a result of low water levels For each commodity, we apply the ratio from Step 1.3 to the Canadian-side total tons shipped by commodity for 2010, obtained from English and Hackston, 2013. We convert these values to 2012 USD.
STEP 2	Ascertain the current US-side total increase in cost by commodity (iron ore, coal, grain, other bulk/general cargo) as a result of low water levels For each commodity, we apply the ratio from Step 1.3 to the US-side total tons shipped by commodity for 2010, obtained from English and Hackston, 2013. We convert these values to 2012 USD.
STEP 3	Ascertain the current region-wide total increase in cost by commodity (iron ore, coal, grain, other bulk/general cargo) as a result of low water levels We add the values calculated in Steps 1.4 and 2.

Harbour Maintenance

To measure the impact of low water levels on harbours, we calculate the added costs of harbour infrastructure repair and upgrade and of the dredging of slips and harbour channels that result from low water levels. Our approach draws, with some modifications, on models developed by Bergeron and Clark in their work on the costs of climate change on harbours.[303]

Bergeron and Clark created a universal matrix of repair and adaptation costs that harbours must incur due to low water levels. Using a case study approach focused on the ports of Duluth-Superior and Toledo, Bergeron and Clark estimated the costs of dredging both individual slips and federal channels. They also estimate the costs associated with dock repairs as a result of low water levels.

We are including in this analysis only GLSL Seaway System ports and harbours upstream of Trois-Rivieres, QC.

Tables 27-29 outline our step-by-step methodology, assumptions, and proxies, in calculating harbour maintenance impacts.

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[301] Stopford, 2009: 226.
[302] Stopford, 2009: 226.
[303] Bergeron and Clark, 2011.

TABLE 27

Impact estimate methodology: Harbour maintenance (dock repair and replacement costs)

ASCERTAIN THE REGION-WIDE AND LAKE-BY-LAKE ECONOMIC IMPACTS OF LOW WATER LEVELS ON: Harbour maintenance (dock repair and replacement costs)	
STEP 1	Ascertain the per-foot cost of dock repair and replacement We adopt the calculations of Bergeron and Clark, 2011: $3000 per one dock foot for repairs, and $5000 per one dock foot for replacement.
STEP 2	Ascertain the cut-off point at which repair is no longer feasible and replacement becomes the only alternative We adopt the finding of Bergeron and Clark that docks with water depth at their face of 30 ft (9.14 m) or greater will likely require replacement rather than repair.
STEP 3	Identify the number and length of docks in the region We collect these numbers from the data provided in Greenwood's, 2013.
STEP 4	Determine how many docks require replacement as opposed to repair Depth data for docks is taken from Greenwood's, 2013.
STEP 5	Sum up the total dock length in each category
STEP 6	Multiply the relevant per-foot costs by the total dock length in each category in each lake to arrive at a lake-by-lake estimate.
STEP 6.1	Perform this calculation for both projection periods in our water levels scenario.
STEP 7	Add up the lake-by-lake totals (Step 6) to arrive at a region-wide estimate.
STEP 7.1	Perform this calculation for both projection periods in our water levels scenario.

TABLE 28

Impact estimate methodology: Harbour maintenance (slip dredging)

ASCERTAIN THE REGION-WIDE AND LAKE-BY-LAKE ECONOMIC IMPACTS OF LOW WATER LEVELS ON: Harbour maintenance (slip dredging)	
STEP 1	Ascertain cost per cubic yard of dredging a slip by one foot We follow Bergeron and Clark in estimating an average cost of $10 per cubic yard for dredging a slip by one foot. We find this estimate to be reasonable given other available data.
STEP 2	Ascertain number of cubic yards per slip Bergeron and Clark did this through actual measuring, which we cannot carry out. For a conservative estimation, we assume an average slip would be able to handle a ship of medium size, and use the size of a medium sized vessel as proxy. Notably, Bergeron and Clark used ship length of 1000 ft in their analysis as this size ships are common in both the ports they studied. We adjust to medium-sized length to be more on the conservative side.
STEP 2.1	Ascertain Size of Medium Sized Vessel Drawing on Bergeron and Clark, we peg a medium size ship in the GLSL Seaway System at 730 ft (222.5 m) in length and 75 ft (22.86 m) in width. We multiply the length by the width, and then by a factor used to accommodate maneuverability of the vessel, which we draw from Bergeron and Clark.
STEP 3	Calculate average cost of dredging one slip by one foot We multiply the size of a medium sized vessel (Step 2) by the average cost per cubic yard of dredging a slip by one foot (Step 1)
STEP 4	Calculate average cost of dredging one dock by one foot Because data regarding number of slips per dock for all commercial ports in the region is not available, we assume for the sake of a conservative estimate one slip per dock.
STEP 5	Ascertain lake-by-lake total added cost of dock dredging as result of low water levels
STEP 5.1	Ascertain number of docks in each of the Great Lakes We derive this number from Greenwood's, 2013.
STEP 5.2	Calculate lake-by-lake total added cost of dock dredging as result of low water levels For each of the Great Lakes, we multiply the average cost of dredging one dock by one foot (Step 4) by the number of docks in that lake (Step 5.1), and multiply that by the number of feet by which water levels are forecast to drop in that lake by our water levels scenario.
STEP 6	Ascertain regional total of added cost of dock dredging for region as result of low water levels We add up the lake-by-lake added costs from Step 5 to arrive at a regional total.

TABLE 29
Impact estimate methodology: Harbour maintenance (dredging remainder of harbour outside of docks)

ASCERTAIN THE REGION-WIDE AND LAKE-BY-LAKE ECONOMIC IMPACTS OF LOW WATER LEVELS ON: **Harbour maintenance (dredging remainder of harbour outside of docks)**	
STEP 1	Ascertain lake-by-lake total added cost of dredging rest of harbour (other than docks) as result of low water levels Since we cannot follow Bergeron and Clark's methodology to make this calculation, we use some of their findings to estimate these cost.
STEP 1.1	Ascertain average ratio of dock dredging cost to rest-of-harbour dredging costs Bergeron and Clark found that the costs of dredging harbour docks by one foot accounted for 7 per cent of total costs incurred by harbours for a one-foot dredge. In other words, the ratio between the cost to dredge docks by one foot and the costs to dredge the rest of the harbour by one foot is 7:93.
STEP 1.2	Calculate lake-by-lake total added cost of dredging rest of harbour (other than docks) as result of low water levels We apply the ratio from Step 1.1 to the lake-by-lake total added cost of dock dredging as result of low water levels (Harbour Maintenance: Dock Dredging Step 5) to arrive at the lake-by-lake total added cost of dredging the remaining (non-docks) portions of harbours.
STEP 2	Ascertain regional total of added cost of dock dredging for region as result of low water levels We add up the lake-by-lake added costs from Step 1.2 to arrive at regional total

As noted in Table 29, we found that we cannot follow Bergeron and Clark's methodology to break the impact on dredging the rest of the harbour (other than docks) on a lake-by-lake basis (step 1). To do this we would need to multiply the average number of cubic yards to be dredged in harbours by the one-foot dredging cost per cubic yards, and multiply that by the number of harbours on each lake and the projected by-foot water levels drop. While we have the latter three pieces, the number of cubic yards to be dredged was ascertained by Bergeron and Clark through actual physical measuring, which we cannot replicate.

APPENDIX 3:
Tourism and Recreational Activities

The economic literature regarding climate change impacts on tourism is relatively thin. It is particularly difficult to draw a direct link between climate change impacts and choice of recreational destination, let alone put dollar values on this impact.

A successful tourist destination uses its appeal to convince tourists to come to it and spend. The key studies that are available focus on tourist expenditures, and especially on the expenditures of boaters and anglers, an important segment of tourism in the GLSL. There is also useful data available regarding marina dredging and maintenance. Our analysis therefore focuses on these subsectors.

Combining data from separate sources that focus on boaters, anglers, and harbours, respectively, risks double counting certain costs. For example, the same boat maintenance and repair costs recur both in literature regarding recreational boating and in literature regarding sport fishing.

Furthermore, if adaptations to one loss factor are made in a timely matter, other loss factors may be somewhat remedied. For example, marina adaptations made in timely fashion could reduce boating revenue losses.

While we separate impacts on boaters, anglers, and harbours as best we can on the basis of the available data, some risk of double counting is unavoidable.

Boating

In the recreational boating activity, the impacts of low water levels are felt most strongly in consumer expenditure. To avoid double counting expenditures, we distinguish between two categories of consumer expenditures: trip expenditures and annual operating expenses.

Trip spending includes everything that boaters purchase for a day out on the lake. This includes, but is not limited to, food and beverages, gas, travel costs, gear, equipment, maintenance, clothing, boat rentals, facility rentals, restaurants, hotels and other similar expenses.

Annual operating expenses include all expenses to maintain and operate one's boat. This includes boat purchases and financing, insurance, boat storage, repairs, membership dues and other similar associated expenses. To avoid double counting, we exclude boat slip rental costs from annual boating expenditures, counting these among losses incurred by marinas.

Table 30 outlines our step-by-step methodologies, assumptions, and proxies, in calculating boating expenditure impacts.

TABLE 30

Impact estimate methodology: Boating expenditures (trip spending + annual operating expenses)

ASCERTAIN THE REGION-WIDE ECONOMIC IMPACTS OF LOW WATER LEVELS ON: **Boating expenditures (trip spending + annual operating expenses)**	
STEP 1	Ascertain region-wide impacts on trip spending
STEP 1.1	Ascertain US-side total trip spending for the region This data is provided in USACE, 2008.
STEP 1.2	Ascertain Canada-side total trip spending estimate for the region Canadian-side trip spending data is available on a province-wide basis for the provinces of Ontario and Quebec from Genesis Public Opinion Research Inc. and Smith Gunther Associates, 2007 and from Hickling Arthurs Low, 2013. We therefore have to separate out GLSL spending from non-GLSL spending for both provinces.
STEP 1.2.1	Ascertain the percentage of boats registered in the GLSL region out of the overall number of boats registered in each of the provinces This data is provided in Genesis Public Opinion Research Inc. and Smith Gunther Associates, 2007 and in Hickling Arthurs Low, 2013.
STEP 1.2.2	Ascertain the percentage of GLSL trip spending out of the total trip spending for each province We use the provincial percentages from step 1.2.1 as a proxy for this.
STEP 1.2.3	Calculate Canada-side total trip spending for the region We apply the provincial percentages from step 1.2.2 to the provincial total spending data from Genesis Public Opinion Research Inc. and Smith Gunther Associates, 2007 and from Hickling Arthurs Low, 2013.
STEP 1.3	Calculate region-wide total trip spending estimate We add up the US-side data (step 1.1) and the Canada-side estimates (step 1.2.3).
STEP 1.4	Ascertain average spending per boating day
STEP 1.4.1	Ascertain total number of boating days in the region We use an estimate provided in GLC, 2005.
STEP 1.4.2	Calculate average spending per boating day estimate Divide the region-wide total trip spending estimate (step 1.3) by the total number of boating days in the region estimate (step 1.4.1).
STEP 1.5	Ascertain overall estimated region-wide impacts on trip spending
STEP 1.5.1	Ascertain overall number of boating days lost to the region due to low water levels We set as a benchmark the number of days in the boating season that an average boater would lose due to low water levels.
STEP 1.5.1.1	Ascertain average number of boating days lost per boater per boating season in the region We use an estimate of this number from ILOSLRSB, 2006b to estimate the loss of boating days in the season due to low water levels.
STEP 1.5.1.2	Ascertain average number of overall boating days per boater per boating season in the region We use an estimate provided in GLC, 2005.
STEP 1.5.1.3	Calculate overall proportion of boating days lost per boater per boating season out of overall boating days per boater per season We divide the average number of boating days lost per boater per boating season (Step 1.5.1.1) by the average number of overall boating days per boater per boating seasons (Step 1.5.1.2).
STEP 1.5.1.4	Calculate estimated overall number of boating days lost to the region due to low water levels We multiply the total boating days for the region (Step 1.4.1) by the ratio calculated in Step 1.5.1.3.
STEP 1.5.2	Calculate overall estimated region-wide impacts on trip spending We multiply the estimated overall number of boating days lost in the boating season (step 1.5.1.4) by the estimated average per day trip spending (step 1.4.2).
STEP 2	Ascertain region-wide impacts on annual operating expenditures
STEP 2.1	Estimate how many boaters would leave the activity or take it to an out-of-region location over the projection period as a result of low water levels We estimate that, all else constant, by the end of the projection year the region will see an annual boater attrition rate of ten per cent. We explain this below.

STEP 2.2	Ascertain per year total spending on annual boating expenditures in the GLSL region For Canada, we draw this information from Genesis Public Opinion Research Inc. and Smith Gunther Associates, 2007, and from Hickling Arthurs Low, 2013. For the US we draw this information from USACE, 2008.
STEP 2.3	Calculate region-wide impacts on annual operating expenditures Multiply total spending over projection period (Step 2.2) by attrition rate estimated in Step 2.1.
STEP 3	Ascertain the region-wide economic impact of low water levels on boating expenditures We add up the impacts on trip spending (Step 1.5.2) and operating expenditures (Step 2.3).
STEP 4	We multiply the calculated impact values by a factor calculated on the basis of the ratios between water level predictions in the scenarios used by Bergeron and Clark, 2011 We do this to account for the fact that Bergeron and Clark's analysis is based, in part, on scenarios predicting more extreme drops than our worst-case low water levels scenario.

Notably, the estimated average number of boating days lost per boater per boating season in the region ascertained in Step 1.5.1.1 is based on survey data collected in 2001 and 2002 and pertains specifically to 1999-2001, the first years of the recent low water levels period. Given that the water levels recorded during that period are generally higher than those projected by the worst-case low water levels scenario, we believe the loss of eight boating days per boater to be a sufficiently conservative estimate for our purposes.

Our actual calculation of loss of boating days as proportion of total days (Step 1.5.1.3) has yielded a number representing roughly one third of the boating season. At this rate, it is safe to assume that some boaters would leave the sport altogether or relocate their activity to alternative out-of-region locations, resulting in the loss in annual boating expenditures we seek to ascertain in Step 2.

This attrition rate has to be assumed (rather than calculated) because disaggregated data regarding the reasons that lead boaters to leave boating or the GLSL region is not available. We therefore assume an annual attrition rate of ten per cent by the end of the longer projection period (2050). We feel this assumption is conservative given the average loss of days calculated as well as the overall rates of attrition in the sector over the past 20 or so years.[304]

It is realistic to expect some of these impacts would be mitigated, at least to some degree, as boaters adapt their behaviour to new conditions, for example by switching to boats designed for low draft. As explained earlier, there is too much variability and unpredictability inherent in predicting the future impacts of these adaptive behaviours to calculate them with sufficient reliability within the confines of the present report.

We cannot provide lake-by-lake impact breakdowns for impacts on boating expenditure because lake-by-lake breakdowns of expenditures and trip data were not available.

Recreational Fishing

The economic impacts of low water levels on recreational fishing fall into two categories: lower catch rates and loss of fishing days. Lower catch rates result from decreases in fish populations due to loss of wetland spawning grounds, which either dry up or become inaccessible to fish.[305] As fish populations decrease, so does the number of trips anglers choose to take. Fishing days are also lost due to anglers' inability to take their boats in and out of docks or marinas. Fewer trips mean less downstream expenditures.

Several studies have covered these impacts and drawing on these studies, we estimate the value of each percentage point decrease in fish population to quantify decreases in trip expenditure by anglers.[306] We make the assumption that only anglers that use boats would lose fishing days due to low water levels, as land-based anglers usually can simply move closer to the water.

To quantify the loss of fishing days we must calculate the spending on fishing by boats on GLSL waters. In doing this it is important to differentiate anglers' boating expenditures from those of recreational boaters, to avoid double counting. We do this by separating out the boating expenses that are strictly related to fishing.

It may be suggested that anglers would attempt a variety of adaptive behaviours in response to drops in catch rates—for example, increasing the number of trips to find alternative fishing locations or picking alternative species to fish—before stopping to fish

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[304] United States Department of the Interior Fish and Wildlife Service, and United States Department of Commerce United States Census Bureau, 2006.
[305] Fracz and Chow-Frazer, 2013.
[306] Austin et al., 2007.

altogether. To the extent that these behaviours prove successful, low water level impacts may be averted. However, the available evidence suggests that drops in fish populations do in fact lead to drops in participation in fishing activities.[307]

Table 31 outlines our step-by-step methodologies, assumptions, and proxies, in calculating sport fishing impacts.

TABLE 31

Impact estimate methodology: Sport fishing (lower catch rates + loss of fishing days)

ASCERTAIN THE REGION-WIDE ECONOMIC IMPACTS OF LOW WATER LEVELS ON: Sport fishing (lower catch rates + loss of fishing days)	
STEP 1	Ascertain annual decrease in angler expenditures (boaters and land based) as a result of lower catch rates to be expected at the end of the projection period under each of our climate change scenarios
STEP 1.1	Estimate percentage of decrease in fish populations to be expected at the end of the projection period under our climate change scenario Estimates regarding wetland declines to be expected at each projection period end under our water levels scenario are taken from Fracz and Chow-Fraser, 2013. We conservatively assume that a 1 per cent decrease in wetland spawning grounds would, over time, lead to at least a 1 per cent decline in fish populations, and use this as a proxy for fish population decline.
STEP 1.2	Estimate decrease in angler expenditures (boaters and land based) per each percentage point decrease in fish populations We use the estimate provided by Austin et al., 2007.
STEP 1.3	Calculate annual decrease in angler expenditures (boaters and land based) as a result of lower catch rates to be expected at the end of the projection period under each of our climate change scenarios We multiply the projected rates of fish population decreases under each variant of our climate change scenario (Step 1.1) by the estimated decrease in angler expenditures (Step 1.2).
STEP 2	Ascertain annual impact on angler expenditures (boaters only) as a result of lost fishing days for projection period under each of our climate change scenarios As noted earlier, we assume that only anglers that use boats might lose fishing days as a result of low water levels, as land-based anglers usually can simply move closer to the water.
STEP 2.1	Ascertain Canada-side annual angler expenditures in the GLSL region Since, as explained above, we are focusing on anglers who use boats, we are assuming that for those anglers number of fishing days equals their number of boating days.
STEP 2.1.1	Ascertain annual province-wide boating expenses that are strictly related to the fishing activity in Ontario and Quebec Genesis Public Opinion Research Inc. and Smith Gunther Associates, 2007 provided this data for both provinces.
STEP 2.1.2	Ascertain the proportion of fishing trips taken specifically in the GLSL out of the province–wide overall number of fishing trip taken per year for each of Ontario and Quebec Genesis Public Opinion Research Inc. and Smith Gunther Associates, 2007 provided this data for both provinces.
STEP 2.1.3	Calculate Canada-side annual angler expenditures in the GLSL region We multiply the expenditure ascertained in Step 2.1.1 by the proportion calculated in Step 2.1.2.
STEP 2.2	Ascertain US-side annual boater-angler expenditures in the GLSL region Since, as explained above, we are focusing on anglers who use boats, we are assuming that those anglers' number of fishing days equals their number of boating days. Since the US-side data is for all anglers, boater-anglers must be separated out of this total.
STEP 2.2.1	Ascertain overall annual angler expenditures (boater + land based) in the Great Lake states Data provided by United States Department of the Interior Fish and Wildlife Service and United States Department of Commerce United States Census Bureau, 2006
STEP 2.2.2	Ascertain the proportion of boater anglers out of overall anglers on the US side of the GLSL region Data provided by United States Department of the Interior Fish and Wildlife Service and United States Department of Commerce United States Census Bureau, 2006
STEP 2.2.3	Calculate US-side annual boater-angler expenditures in the GLSL region We multiply overall angler expenditures (Step 2.2.1) by the proportion of anglers that use boats for their fishing activities (Step 2.2.2).
STEP 2.3	Calculate GLSL specific annual boating expenses that are strictly related to the fishing activity in the entire region We add the values calculated in Steps 2.1.3 and 2.2.3.
STEP 2.4	Ascertain annual estimated region-wide decrease in angler boating expenditures due to loss of fishing/boating days Since, as explained above, we are focusing on anglers who use boats, we are assuming that those anglers' number of fishing days equals their number of boating days.

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[307] Austin et al., 2007; Marbec, 2010

STEP 2.4.1	Ascertain overall number of boating days lost to the region due to low water levels We set as a benchmark the number of days in the boating season that an average boater would lose due to low water levels.
STEP 2.4.1.1	Ascertain average number of boating days lost per boater per boating season in the region We use an estimate of the average number of boating days lost from ILOSLRSB, 2006a to estimate the loss of boating days in the season due to low water levels.
STEP 2.4.1.2	Ascertain average number of overall boating days per boater per boating season in the region We use an estimate provided in GLC, 2005.
STEP 2.4.1.3	Calculate overall proportion of boating days lost per boater per boating season out of overall boating days per boater per season We calculate the proportion of the number calculated in Step 2.4.1.1 out of the number calculated in Step 2.4.1.2.
STEP 2.4.2	Calculate annual estimated region-wide decrease in angler boating expenditures due to loss of fishing days We multiply the proportion calculated in Step 2.4.1.3 by the number calculated in Step 2.3. The average per boater proportion of lost boating days out of overall boating days (Step 2.4.1.3) is used as a proxy for the average per boater-angler proportion of lost fishing days out of overall fishing days because, as noted earlier, for boater –anglers fishing days = boating days.
STEP 2.5	Calculate annual impact on angler expenditures (boaters only) as a result of lost fishing days by end of projection period under our water levels scenario The calculations in steps 2.1-2.4 were made on the basis of actual data from past low water level years. These therefore need to be converted into forecast losses for each projection period in our water levels scenario. This move could not be based on available data since, as explained earlier, the water levels scenario cannot be taken as accurately forecasting any given year in the projection period.
STEP 2.5.1	We multiply the calculated impact values by a factor calculated on the basis of the ratios between water level predictions in the scenarios used by Bergeron and Clark, 2011 We do this to account for the fact that Bergeron and Clark's analysis is based, in part, on scenarios predicting more extreme drops than our worst-case low water levels scenario.
STEP 3	Ascertain total-period estimated region-wide impacts on angler expenditures We add the values calculated in Steps 1.3 and 2.5.1.

Notably, there are multiple factors that may affect changes to fishing practices other than those related to low water level impacts. Data parsing out the different factors affecting changes to fishing practices or decisions to abandon sport fishing in the region is not available.

We are not providing lake-by-lake breakdowns of impacts on recreational fishing because the data on which we rely is not disaggregated sub-regionally.

Marinas

The economic impacts of low water levels on marinas fall into two categories: slip revenue losses and adaptation costs. Slip revenue losses are incurred when boat slips become inaccessible but boaters remain committed to the boating activity. These losses are thus distinguished from participation drop losses—losses incurred when boaters give up on boating in the region or altogether—which were already accounted for earlier. Adaptation costs include repairs, maintenance, and marina dredging required due to low water levels.

Ideally, this calculation would be carried out at the individual marina level, accounting for the variability among marinas in the region. The available data does not extend to this level. For the upper Great Lakes, impact estimates that combine US and Canadian marinas on a lake-by-lake basis are available.[308] Data specific to Lake Ontario and the St. Lawrence River was only available for the US.[309] For the Canadian side, only province-wide data is available.[310] The available data does not disaggregate overall marina impacts estimates into slip revenue losses and adaptation costs, and we therefore follow suit in our analysis.

The Canadian-side data for Lake Ontario and the St. Lawrence River dates back to 1999 and 2001-2002, whereas the rest of the data is more recent. As already noted, water levels in these years were generally higher than those projected by the worst-case low water levels scenario. These years can therefore serve as conservative estimates for the impact period we are analyzing.

Table 32 outlines our step-by-step methodologies, assumptions, and proxies, in calculating marina impacts.

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[308] Ontario Centre for Climate Impacts and Adaptation Resources, 2010.
[309] USACE, 2008.
[310] Genesis Public Opinion Research Inc. and Smith Gunther Associates, 2007.

TABLE 32

Impact estimate methodology: Marinas (slip revenue losses + increased adaptation costs)

ASCERTAIN THE REGION-WIDE AND LAKE-BY-LAKE ECONOMIC IMPACTS OF LOW WATER LEVELS ON: Marinas (slip revenue losses + increased adaptation costs)	
STEP 1	Ascertain region-wide average per-marina impacts (slip revenue losses+adaptation costs) In the absence of additional data, we use the Upper Great Lakes data from Ontario Centre for Climate Impacts and Adaptation Resources, 2010, as proxy for rest of the region.
STEP 2	Ascertain the number of marinas on each lake This data is provided in USACE, 2008.
STEP 3	Calculate lake-by-lake impacts (slip revenue losses+adaptation costs) We multiply the average per-marina impact (Step 1) by the number of marinas on each lake (Step 2).
STEP 4	Calculate region-wide impacts (slip revenue losses+adaptation costs) We add up the lake-by-lake impacts calculated in Step 3.
STEP 5	Calculate region-wide impacts by end of each projection period Following our data sources, Steps 1-4 yield calculations for three standardized water level drop scenarios: one-foot drop, two-foot drop, and three-foot drop. We use the one-foot drop findings as proxy for SC2030 and the two-foot drop findings as proxy for SC2050.

APPENDIX 4:
Methodology: Waterfront Properties

Assessing the economic impact of low GLSL water levels on waterfront properties in the region is more complex than other case studies in this report. This is because subjectivity plays a large role in placing an individual price on a given property, and because of the typically dynamic nature of the housing market.

It is already well established in the economic impact literature that the value of a waterfront property is greatly determined by the waterfront itself.[311] When comparing waterfront properties to otherwise similar inland properties, the value placed on waterfront-related amenities (visual aesthetics, boat access, beach frontage, etc.) can be upwards of 50 per cent of the value of the property, depending on the type of waterfront property and amenities.[312]

However, this literature draws on case studies from regions other than the GLSL. There is very little research or publicly available data related to property value changes as linked with declines in water levels in the GLSL.

In the present study, we analyze data collected by Ontario's Municipal Property Assessment Corporation (MPAC), an independent body established by law to conduct property assessments throughout the province.[313] MPAC provided data for 105 municipalities adjacent to the Great Lakes and the St. Lawrence River as well as the Ontario 'cottage country' municipalities of Dysart et al., Minden Hills, Lake of Bays, and Muskoka Lakes, consisting of 70,764 waterfront properties in 2003 and 98,014 waterfront properties in 2012.

For each municipality, MPAC provided counts and mean property valuations, separated into waterfront and non-waterfront properties. Price observations were provided for three time points: 2003, 2008, and 2012. We have chosen these dates so that we can identify price changes in properties both before and after the 2008 recession. Notably, MPAC revised the way they coded data from 2003 onwards, and we were advised by MPAC that under our data needs comparisons between the data from 2003 onwards and pre-2003 data points would not be reliable.

In order to isolate water-level impacts from other impacts, we compare waterfront properties in Ontario municipalities adjacent to GLSL shores to non-waterfront properties in the same municipality as well as to waterfront properties in Ontario's 'cottage country' that are not on the Great Lakes. Our assumption is that any impacts other than those related to low GLSL water levels would affect both waterfront and non-waterfront properties in the same municipality, and recreational properties both on Ontario GLSL shores and inland.

Table 33 outlines our step-by-step methodologies, assumptions, and proxies, in calculating impacts on residential waterfront property values in Ontario municipalities adjacent to GLSL shores.

TABLE 33

Impact estimate methodology: Residential waterfront property values in Ontario municipalities adjacent to GLSL shores

ASCERTAIN THE REGION-WIDE AND LAKE-BY-LAKE ECONOMIC IMPACTS OF LOW WATER LEVELS ON: **Property values for residential waterfront properties in Ontario municipalities adjacent to GLSL shores**	
STEP 1	Ascertain total value of waterfront properties in the sub-region of study
STEP 1.1	Ascertain number of waterfront properties per municipality We derive this from the data obtained from MPAC. We perform this for every municipality in the study population.
STEP 1.2	Ascertain average value of waterfront properties per municipality This data is provided by MPAC. We perform this for every municipality in the study population.
STEP 1.3	Calculate total value of waterfront properties per municipality We multiply the average value of waterfront properties in the municipality (Step 1.2) by the number of waterfront properties in that municipality (Step 1.1). We perform this for every municipality in the study population.

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311 Bourassa et al., 2004; Pompe, 2008; Wyman and Sperry, 2010; Wyman et al., 2013.
312 Marbek, 2010
313 MPAC, n.d.

STEP 1.4	Ascertain total value of waterfront properties in sub-region of study We add up all the per municipality totals calculated in Step 1.3.
STEP 2	Ascertain percentage and direction of change in property values per one-foot drop in water levels To ascertain this, we employ the regression analysis that is described in detail below. Notably, during the initial regression analysis, municipalities with no properties classified by MPAC as “seasonal/recreationa”l were identified as statistical outliers. We re-performed Steps 1.1-1.4 for a new study population that excluded these municipalities.
STEP 3	Calculate the projected lake-by-lake losses in property values associated with projected water levels declines We multiply the percentage loss calculated in Step 2 by the per-foot decline in water levels on each lake as projected by our water levels scenario.
STEP 4	Calculate the projected region-wide losses in property values associated with projected water levels declines We add up the lake-by-lake numbers from Step 3.

To analyze the impact of low water levels on residential waterfront property values in Ontario municipalities adjacent to GLSL shores, we needed to ascertain whether water level changes would impact the value of a waterfront property to a statistically significant degree, keeping other factors constant. Should such statistical significance be found, we would need to ascertain the percentage and direction of change in property values for a one foot drop in water levels.

A powerful statistical tool for estimating the relationship between variables is a regression analysis. We identify the marginal effect declining water levels have on the mean waterfront housing prices in the GLSL region. Using projected water levels for each lake we then estimate the impact that even lower lake levels would have on waterfront properties in the region. See Table 34 for our regression analysis output.

Since the number of observations in our study population was relatively low for an analysis of this kind, we faced possible time series data constraints. Time series data is the recorded observation of a variable, in our case, property price, over time. To overcome these constraints we create two new variables to represent housing price changes from 2003-2008 and housing price changes from 2008-2012. We match these variables to the change in water level of the adjacent lake over the same time frame.

Our regression analysis has identified municipalities that have residential waterfront properties designated by MPAC as “seasonal/recreational” as a subgroup of the initial 105 municipalities that is impacted by changes in water levels over both time frames to a statistically significant degree. The exclusion of municipalities with no recreational residential waterfront properties is reasonable because seasonal residences are more likely to be priced according to the availability of waterfront amenities.

We therefore exclude municipalities in which there were no residential waterfront properties designated as “seasonal/recreational”, and perform the regression analysis on the new subgroup. This exclusion left us with 84 municipalities consisting of 54,532 waterfront properties in 2003 and 74,813 waterfront properties in 2012.

We perform several tests to determine whether our assumptions and exclusions are valid within the context of the proposed regression model. Multicollinearity is not a significant factor in our model. The distributions of the predicted residuals vs studentized residuals for the water level parameter in our model deviated from normal, but we believe this is simply because of a lack of observations. With more observations, we believe that the above residual plot would have a normal distribution. Heteroskedasticity was determined to not be an issue between the observed data. Autocorrelation is not detectable in the data, and the assumption of a linear relationship between the variables is not violated.

TABLE 34

Regression output for residential waterfront property values in Ontario municipalities adjacent to GLSL shores

Summary Output

Regression statistics

Multiple R	0.785245
R-squared	0.616609
Adjusted R-squared	0.611962
Standard error	20.27082
Observations	168

ANOVA

	df	SS	MS	F	Significance F	
Regression	2	109042.2	54521.11	132.6851	4.47E-35	
Residual	165	67799.52	410.9062			
Total	167	176841.7				

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	16.18734	2.996112	5.402784	2.26E-07	10.27168	22.103
X Variable 1	0.722783	0.060988	11.85126	7.81E-24	0.602366	0.843201
X Variable 2	14.14775	4.024009	3.515835	0.000566	6.202566	22.09294

In a preliminary examination of our data, we noted that there may be a very strong correlation between waterfront and non-waterfront properties, as well as a correlation between waterfront property prices and water levels. The regression results show that we do in fact have significance for the coefficients of both non-waterfront properties and waterfront properties.

The coefficient for the impact of water levels on waterfront properties is 14.14, which represents a 14 per cent decline in property values for each foot of water level declines during the observation period. This value seems to us too high to assume a continued property values decline of this magnitude due to water levels heading into the future. We therefore prefer to remain more conservative and use a 6 per cent decline, representing two standard deviations below the value of the coefficient, in calculating the impact of future water levels projected under the worst-case low water levels scenario.

Notably, this calculation isolates the effect water levels have in driving down the value of waterfront properties from the value of other market impacts that affect housing prices over time. We do use non-waterfront properties as a parameter in the regression in order to encompass all other market variations happening during the time frame of the observations.

When interpreting the results we must also look at the confidence interval for the coefficient of water levels. This indicates that the percentage change in property values per foot would vary anywhere between 6-22 per cent, 95 per cent of the time in the data. This is a fairly wide range and therefore must indicate that subsections in the data show variability in the impact water levels have on waterfront properties. This agrees with our assumption that some properties will be impacted more than others based on the amenities that the waterfront provides.

We must note that this regression model only explains 78 per cent of the variation in the data, and only 61 per cent once it has been adjusted to the parameters. Part of the discrepancy between R-squared and the Adjusted R-squared comes from the small number of observations in the data. This means that although our model is statistically significant, in the real world there is more going on than this model accounts for. However, for simplicity sake, we can use this model to indicate the importance water levels have on waterfront property pricing.

Notably, our regression analysis also showed that, while there may be other considerations that affect subjective valuations of property values, water level fluctuation is by far the most significant such consideration.

Data comparable to MPAC's for other jurisdictions in the GLSL region is not publicly available. This is important because different price drivers are at play in the Ontario, Quebec, and various US-side residential property markets—for example, several US-side markets are vulnerable to flooding, such that higher water levels rather than lower water levels would drive property values down. As a result, extrapolating from the Ontario market to non-Ontario markets would be methodologically incorrect. We therefore provide an impact estimate for Ontario-side properties rather than for the entire region, and have been particularly cautious and conservative in deriving this estimate, as already explained.

MPAC's individual assessments may not always capture the actual market value of a given property at a given point in time. MPAC's aggregate data is nonetheless reliable, since aggregation balances out discrepancies between assessed and actual prices. When taken in comparison with similar properties or with properties in the same municipality, and when considered over time, MPAC's data is a telling indicator of actual property value trends.

In this report we only analyze the impact of low water levels on residential waterfront properties. We have not been able to find available research that identifies what impacts low water levels may have on commercial properties.

APPENDIX 5:
Hydroelectric Generation

Literature on the economic impacts of water levels on revenue from hydroelectric generation in the GLSL is limited. The main source available is the work of Buttle and his colleagues, who analyzed the impact of climate change on hydroelectric production in Ontario.[314]

Buttle and his colleagues use two water levels scenarios—the one we employ as our worst-case low water levels scenario and another projecting more extreme water level lows—to project water flows corresponding to projected future water levels and the resulting loss of production. They then quantify this loss of production into dollar values using the cost of replacing lost production with the next best alternative power generation source, namely natural gas.

Buttle and his colleagues conducted facility-level studies on selected facilities in Ontario to ascertain the flows needed to ensure maximum plant output. Specifically, they studied Adam Beck 1 (Niagara River, RoR), Adam Beck 2 (Niagara River, RoR), Adam Beck PSG (Niagara River, pumped storage), Cascade (Sequin River, RoR), Clergue (St. Marys River, RoR), Decew Falls (Welland River, RoR), and Saunders (St. Lawrence River, RoR).

Within the scope of the present study we cannot replicate these facility-level analyses on a region-wide scale. Rather, we apply the revenue losses as a result of climate change estimated by Buttle and his colleagues to the total capacity of a selection of other hydroelectric generation facilities in the region. We then quantify the resulting revenue loss figures in a similar way to Buttle and his colleagues. We treat this dollar figure as a conservative proxy for the region-wide impact. We also update some values used by Buttle and his colleagues, such as price, to more recent ones.

Because losses in revenues from hydroelectric production may be affected by multiple local factors, there is significant variability in these losses across hydroelectric generation facilities across the region. To reliably account for this variability, we make two conservative adjustments.

First, where US facilities are located nearby Canadian facilities studied by Buttle and his colleagues, and are therefore likely to face similar physical and hydrological conditions, we make sure to include those in our analysis. These facilities include: Edison Sault (St. Marys River, RoR), Saint Marys Falls (St. Marys River, RoR), Robert Moses (Niagara River, RoR), Lewiston (Niagara River, pumped storage), and Franklin D Roosevelt Power Project (St. Lawrence River, RoR).

To complete our sample we add Beauharnois (St. Lawrence River, RoR), Les Cèdres (St. Lawrence River, RoR), Rivière-des-Praries (Rivière-des-Praries, RoR), Varrick (Lake Ontario/Oswego River, RoR), and RG&E (Lake Ontario, RoR). We assume that production losses relative to capacity for these facilities will be, on average, similar to those in the rest of our study sample.

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[314] Buttle et al., 2004.

Notably, many of these facilities are located on connecting channels in between lakes. As a result, we provide, instead of a lake-by-lake breakdown of impacts, a breakdown of impacts by larger sub-regions that encompass two lakes.

Second, we only extrapolate Buttle's data to facilities drawing water directly from the Lakes, connecting channels, and the St. Lawrence River. This removes facilities drawing their waters from tributaries, where low water levels impacts are more indirect, while keeping all of the region's major facilities within our sample to ensure it represents a more than significant chunk of the region's hydroelectric production. The only two facilities in the study sample that are on tributaries, Cascade and Decew Falls, were both in the original Buttle sample and could not be disaggregated from it.

This has the added advantage that none of the facilities added to our study sample are conventional, only RoR and pumped storage, similarly to Buttle and his colleagues. This removes the variability that would otherwise have been introduced by differences between conventional and RoR facilities.

Table 35 outlines our step-by-step methodologies, assumptions, and proxies, in calculating hydroelectric generation revenue impacts.

TABLE 35

Impact estimate methodology: Hydroelectric generation revenues

ASCERTAIN THE REGION-WIDE AND PER CONNECTOR CHANNEL ECONOMIC IMPACTS OF LOW WATER LEVELS ON: Hydroelectric generation revenues	
STEP 1	Ascertain estimated sub-regional hydroelectric loss in revenue as a result of low water levels / climate change
STEP 1.1	Ascertain overall hydroelectric capacity for the sub-regions For reasons noted above, we use overall capacity of the facilities located on the lakes, connecting channels, and St. Lawrence River as a proxy for region-wide production. This number was compiled from data collected from the relevant utility/company websites and lists aggregated on Wikipedia.
STEP 1.2	Ascertain the hydroelectric revenue losses to the specific sub-regional facilities as a result of low water levels / climate change We use the revenue losses from a water levelsscenario used by Buttle et al., 2004. as a proxy for our broader sample.
STEP 1.3	Calculate estimated sub-regional hydroelectric revenue losses as a result of low water levels / climate change We divide the revenue losses for each facility by its given capacity. We then multiply this ratio of revenue losses per MW by the total capacity for all facilities in sub-region. We treat this as a conservative proxy for the region-wide loss since Step 1.1 did not capture the entire capacity of the region, as already noted.
STEP 1.4	Adjust the loss in revenue to the new baseline water year of 2012 We divide the 2012 water level per lake by the historical water level per lake used in Buttle et al., 2004. We then multiply this ratio by the revenue losses calculated in step 1.3 to get the 2012 adjusted losses for the climate change scenarios.
STEP 2	Ascertain the 2012 value of sub-regional loss of revenue as a result of low water levels / climate change We use added costs accrued in replacing lost production with the next best alternative source of electricity as a conservative proxy for this value.
STEP 2.1	Ascertain added costs accrued in replacing lost production with the next best alternative source of electricity Following Buttle et al., 2004. we use natural gas as the next best replacement source of power—a likely (and common) assumption given the region's energy mix. However, we update the natural gas generation price levels used by Buttle et al., 2004. to the levelized cost of $67 (USD) per MWh provided in United States Energy Information Administration, 2013. Notably, the levelized cost factors in both the market price and the construction costs of what new natural gas facilities would be needed to compensate for lost hydropower generation over a 30-year span.
STEP 2.2	Calculate the 2012 value of sub-regional loss in revenue for a each facility as a result of low water levels / climate change We divide the new cost of replacement power of 67$ (USD) per MWh by the cost of $52 (CAD) per MWh ($46.8 (USD) per MWh after currency conversion) given in Buttle et al., 2004. We then multiply the ratio of power replacement by the calculated losses from step 1.4 to get the 2012 value of those losses.
STEP 3	Ascertain region wide impacts We sum the revenue losses from step 2.2 for the entire GLSL region.

We do not include in our analysis costs such as reallocation of employees, potentially higher production costs in thermal plants that use Great Lakes water for cooling, productivity costs associated with brownouts, blackouts, and/or price changes in every sector that are dependent on electricity, and trade considerations if increased GHG emissions from thermal plants need to be offset by carbon offset purchases.

APPENDIX 6:
Municipal, Industrial, and Rural Water Users

Impacts on municipal, industrial, and rural water users are measured by the additional costs incurred by those withdrawing water from the basin (e.g., public utilities, power plants, manufacturing plants, and well users) to continue satisfying the same level of demand. It is likely that some of these costs would be transferred downstream to users and consumers, but this will not add to the overall costs, just redistribute existing costs.

Of the various factors contributing to these additional costs, the most studied are costs related to intake facilities (such as drinking water treatment plants) and outflow facilities (such as wastewater treatment plants). These costs pertain to inlets and outlets used by these facilities (in many cases, the same facility would have both inlets and outlets), and may include repairs, replacement, extension, and cleanup (e.g., removing obstructing plants and algae). Of these costs, extension costs are the only ones for which there is relevant publicly available data. Notably, extension is an adaptation that obviates the need to expend at least some of the costs noted above.

Costs related to groundwater use (residential, agricultural, and industrial) have also been studied, if to a lesser degree. Basic data—for example, aquifer levels—is not consistently available for the GLSL basin. In this report we therefore augment relevant available data by using the costs of extending/redrilling residential wells as a proxy for overall costs related to groundwater use.

Inlets and Outlets

Inlets rely on withdrawing water from a fixed depth. If water levels drop below that fixed depth and the inlet becomes above-water, it will not be able to withdraw the required amount of water. When water is used for cooling, it may also need to be at a specific temperature and therefore must come from a specific depth. Outlets need to be below a certain fixed depth if the untreated water flowing out of the outlet is to dilute safely and effectively in the water.

Our analysis draws on two technical studies submitted to the IUGLSB[315] and the ILOSLRSB[316], respectively. Between them, these studies sent surveys to all facilities with inlets or outlets in the GLSL, asking them to identify the critical water levels at which each of their inlets/outlets would be above-water. Notably, both surveys garnered relatively low response rates, weakening their results. They nonetheless remain the best available source of data for the kind of analysis needed for the present report.

There are some methodological differences between the two studies that force us into some assumptions and proxies in our own work. First, while both studies considered a scenario of water levels dropping to historic lows (we refer to this scenario as ECT2), only the study conducted by ECT and Veritas for the IUGLSB considered a second scenario, namely water levels dropping one meter below historic lows (we refer to this scenario as ECT1).

In our study we use the more conservative *ECT2* (water levels dropping to historic lows) as a proxy for our worst-case low water levels scenario, since water levels projected for the two projection periods provided by this scenario are closely above or below *ECT2*.

Second, while both studies report the number of facilities that were surveyed, the number that had sent any response, and the number that provided the required critical water levels information, only ECT and Veritas also reported the number of inlets and outlets in all categories. The ILOSLRSB only reported facility numbers, without a breakdown of numbers of inlets and outlets.

Table 36 outlines our step-by-step methodologies, assumptions, and proxies, in calculating impacts on municipal and industrial inflow and outflow systems.

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[315] ECT and Veritas, 2011.
[316] ILOSLRSB, 2006a.

TABLE 36

Impact estimate methodology: Municipal and industrial inflow and outflow systems

ASCERTAIN THE REGION-WIDE ECONOMIC IMPACTS OF LOW WATER LEVELS ON: Municipal and industrial inflow and outflow systems	
STEP 1	Ascertain estimated number of inlets and outlets that would be above water under projected low water levels
STEP 1.1	Estimate number of upper Great Lakes inlets that would be above water under projected low water levels
STEP 1.1.1	Estimate ratio of upper Great Lakes inlets at risk of being above-water under the low water levels scenario ECT and Veritas report that out of 55 inlets for which critical water level information was provided, two inlets would be above-water under ECT2.We assume these ratios would hold for inlets for which critical water level information was not provided, and therefore to the overall number of inlet in the upper Great Lakes.
STEP 1.1.2	Calculate estimated number of upper Great Lakes inlets that would be above water under projected low water levels ECT and Veritas reported that there are 683 inlets in the upper Great Lakes. We apply the ratios calculated in Step 1.1.1 to this number.
STEP 1.2	Estimate number of Lake Ontario-upper St. Lawrence River inlets that would be above water under projected low water levels
STEP 1.2.1	Estimate average number of inlets per facility in Lake Ontario-upper St. Lawrence River Since the ILOSLRSB did not provide this information, we use the ratio of inlets per facility in the upper Great Lakes as a proxy. ECT and Veritas reported 683 inlets in 555 facilities in the upper Great Lakes, a ratio of 1.23:1.
STEP 1.2.2	Estimate ratio of Lake Ontario-upper St. Lawrence River intake facilities (facilities with inlets) at risk of being above-water under ECT2 The ILOSLRSB reported that out of 10 facilities with inlets that provided critical water level information for their inlets, one was at risk under ECT2. We assume this ratio would hold for inlets for which critical water level information was not provided, and therefore to the overall number of inlet in Lake Ontario-upper St. Lawrence River.
STEP 1.2.3	Calculate estimated number of Lake Ontario-upper St. Lawrence River inlets that would be above water under projected low water levels We apply the ratio calculated in Step 1.2.1 to the number calculated in Step 1.2.2.
STEP 1.3	Ascertain estimated number of outlets in the region that would be above water under projected low water levels
STEP 1.3.1	Ascertain estimated number of facilities with outlets in Lake Ontario-upper St. Lawrence River that would be above water under projected low water levels We apply the ratio of outflow facilities reporting low water levels impacts out of all facilities that responded to the ILOSLRSB (2 out of 32) to the entire number of outflow facilities in the Lake Ontario-upper St. Lawrence River sub region reported by the ILOSLRSB (79). This yields an estimate of 5 facilities to be impacted.
STEP 1.3.2	Ascertain estimated number of facilities with outlets in the region that would be above water under projected low water levels We use the estimate from step 1.3.1 as a proxy for the entire region. From the ECT and Veritas and the ILOSLRSB studies it seems that a concern with outflow facilities exists only for facilities on the St. Lawrence River. On the lakes themselves, outlets are placed at such a depth that they do not risk being exposed above-water. However, neither study disaggregates lake or river outlets from overall outlets in their findings. Notably, there were no at risk outlets identified among facilities that responded to ECT and Veritas.
STEP 1.3.3	Ascertain estimated number of outlets in the region that would be above water under projected low water levels In the absence of data regarding number of outlets per facility, we assume, conservatively, that each of those facilities would have at least one outlet, and estimate the number of outlets in the region that would be above water under ECT2 at 5.
STEP 1.4	Estimate the overall number of inlets and outlets in the region that would be above water under projected low water levels We add the ECT2 estimate from Step 1.1.2 and the estimates from Steps 1.2.3 and 1.3.3.
STEP 2	Ascertain the average cost of water inlet/outlet extension We use pipe extension costs provided by ECT and Veritas, 2011.
STEP 3	Ascertain the region-wide economic impacts of low water levels on municipal and industrial Inflow and Outflow Systems We multiply the estimated number of inflow and outflow facilities that would be above water under projected low water levels (Step 1.3.3) by the average cost of water inlet/outlet extension (Step 2) for ECT2.

In Step 2, we use pipe extension costs as a proxy for adaptation costs in general. Drawing on their survey responses, ECT and Veritas considered several adaptation measures that withdrawal facilities may adopt, such as relocation, finding a different water source, and others. However, comparing the cost estimates ECT and Veritas provided for various adaptation measures, pipe extension emerges as the most realistic adaptation measure available for both inlets and outlets affected by low water levels. Notably, this move assumes, for the sake of calculation, that pipe extension is an adaptation measure available to all facilities, even though this may not always the case.

We have not calculated lake-by-lake impacts since neither source study disaggregates its findings to the degree needed for such a calculation.

Rural Groundwater Use

Research has shown a strong relationship between groundwater levels and water levels in the Great Lakes and their tributaries. It is therefore not surprising that recent drops in lake levels were echoed in the region's groundwater. This affects rural residents and businesses that use wells as their primary source of water.

Ideally, calculating this impact would require identifying the number of the region's wells that would require deepening and the percentage where deepening is impossible and a new well is the only option, as well as the average cost per well of both deepening and replacement. In an interview with the authors, an industry insider put the cost of deepening a well by ten linear feet at roughly $3000 per well (including set up charges, environmental rehabilitation fees, charges for actual digging, and other typical expenses). The cost of digging a new well would be even higher.

Even if a well needs to be deepened by less than ten linear feet to adjust to low water levels, the marginal costs to the user of additional depth are minor in comparison to well-digging costs that do not depend on depth. It is therefore likely that once a user has decided to deepen their well, they will do so by significantly more than needed, allowing them to withstand additional declines in water levels.

Data regarding the number of affected wells and the percentage that would need replacement rather than deepening is not publicly available, requiring the workarounds outlined in Table 37.

Table 37 outlines our step-by-step methodologies, assumptions, and proxies, in calculating rural groundwater use impacts.

TABLE 37

Impact estimate methodology: Rural groundwater use

ASCERTAIN THE REGION-WIDE ECONOMIC IMPACTS OF LOW WATER LEVELS ON: **Rural groundwater use**	
STEP 1	Ascertain the average expected groundwater drop as a result of low water levels forecast by our water levels scenario
STEP 1.1	Ascertain the average expected groundwater drop as a result of low water levels forecast by our water levels scenario We estimate a one-foot drop for the region under our water levels scenario. See below for explanation.
STEP 2	Ascertain percentage of the GLSL region's wells to require deepening and the percentage of the GLSL region's wells where deepening is impossible and a new well is required In the absence of available data, we conservatively assume one in every four hundred wells would need deepening or replacement under SC2030 and one in every two hundred under SC2050
STEP 3	Ascertain costs of deepening or replacing a well
STEP 3.1	Ascertain well deepening costs In an interview with the authors, an industry insider estimated the cost of deepening a well up to ten linear feet at roughly $3000 per well (including set up charges, environmental rehabilitation fees, charges for actual digging, and other typical expenses).
STEP 3.2	Ascertain pump replacement costs A deeper well (deepened or new) would often require a new pump. Using the common online estimation service rsmeansonline.com, we estimate the cost of pump replacement and installation at $2950.
STEP 3.3	Ascertain costs of digging new well A cost estimate for digging new wells was not available. Since it stands to reason digging a new well would usually be more expensive than extending an existing well, we use deepening costs as proxy and therefore do not distinguish deepened and new wells in our calculations.
STEP 3.4	Calculate overall cost of deepening or replacing well (including pump replacement) We add the values calculated in Steps 3.1 and 3.2.
STEP 4	Ascertain the number of households in the region using wells We divide the overall rural population using groundwater number by the average number of people per household in the rural areas of the region. Both values are obtained from Great Lakes Science Advisory Board, 2010. We use a conservative estimate of one well per household.
STEP 5	Calculate region-wide estimated expenditure on well deepening and replacement. We multiply the number of households in the region using wells (Step 4) by the ratio of wells needing repair (one out of 400 for SC2030 and one out of 200 for SC2050; Step 2), then multiply this number by the estimated cost per well (Step 3.4).

Notably, the only estimate of groundwater levels drops as a result of climate change impacts in the publicly available literature comes from work by Lofgren and his colleagues.[317] Lofgren and his colleagues drew on a water levels scenario projecting more extreme drops than our worst-case low water levels scenario to estimate a two-foot drop in groundwater levels in the Lake Ontario-upper St. Lawrence River sub-region.

No comparable data is available for the rest of the region or under our water levels scenario, forcing us to use the two-foot drop estimate by Lofgren and his colleagues. However, to account for the more extreme scenario used by Lofgren and his colleagues, we adjust their findings to a half-foot drop estimate for *SC2030* and a one-foot drop estimate for *SC2050*.

We cannot provide lake-by-lake impact breakdowns for impacts on rural groundwater use because lake-by-lake breakdowns of number of rural wells and forecasts of groundwater level drops were not available.

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[317] Lofgren et al., 2002.

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List of Acronyms

AOGCM	Atmosphere-ocean general circulation models
EC	Environment Canada
GHG	Greenhouse Gases
GIA	Global Isostatic Adjustment
GLEAM	Great Lakes Environmental Assessment and Mapping project
GLERL	Great Lakes Environmental Research Laboratory
GLSL	Great Lakes and St. Lawrence River
GLWLD	Great Lakes Water Levels Dashboard
IJC	International Joint Commission
ILOSLRSB	International Lake Ontario-St. Lawrence River Study Board
IPCC	Intergovernmental Panel on Climate Change
ISLRBC	International St. Lawrence River Board of Control
IUGLSB	International Upper Great Lakes Study Board
LBRM	Large Basin Runoff Model
MPAC	(Ontario) Municipal Property Assessment Corporation
NBS	Net Basin Supply
NOAA	(United States) National Oceanic and Atmospheric Administration
RoR	Run of the river
USACE	United States Army Corps of Engineers
WSP	Water Supply Plant

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The Council of the Great Lakes Region (CGLR) is a member-based organization with a mandate to collaborate with the many successful organizations already working in the region to highlight, enhance and support their projects. The Council also looks to inform state, provincial and federal decision makers in both countries about the region's long-term economic, social, and environmental goals. Finally, the Council is also working to play a leadership role in connecting private, public, and not-for-profit actors across the region, cultivating a strong regional voice to promote shared interests and solutions to our common challenges.

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