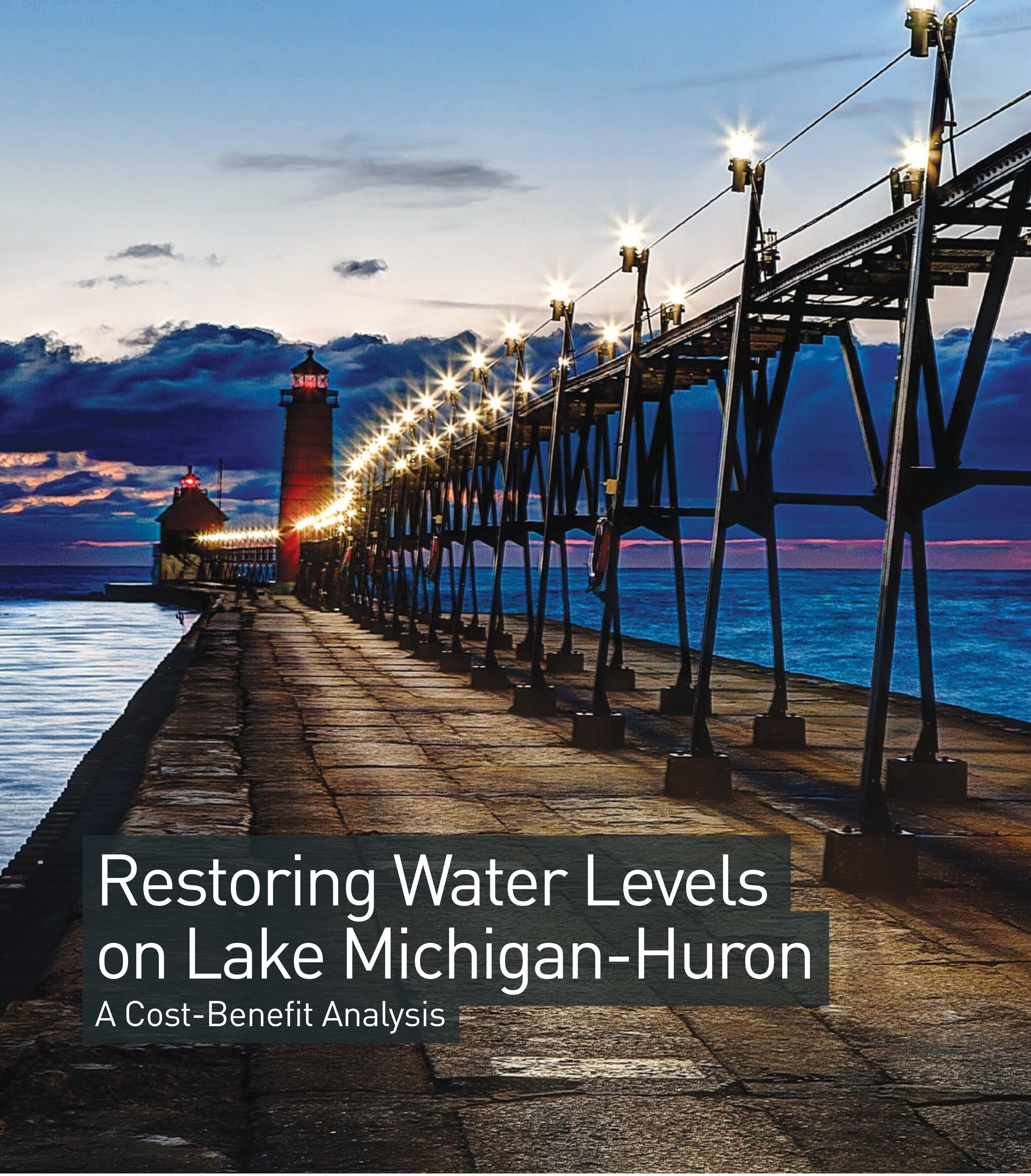

Restoring Water Levels on Lake Michigan-Huron

A Cost-Benefit Analysis

CGLR
COUNCIL OF THE GREAT LAKES REGION

Mowat Centre
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Contents

Executive Summary

Water levels in the Great Lakes are in a constant state of flux. This is good; natural fluctuations are essential to a healthy ecosystem. But sustained periods of extreme water levels are potentially costly, both for the economy and the environment. In June 2014's *Low Water Blues*, we estimated the direct economic costs of an extreme low water level scenario on selected sectors in the Great Lakes and St. Lawrence River System (GLSLS). The results were revealing and, given missing data on a wide range of sectors and impacts, may prove conservative.

This report builds on this research by assessing previously identified mitigation strategies under a similar extreme low water level scenario. We assess the costs and benefits of these approaches under this water level scenario for four key Great Lakes sectors:

» Commercial shipping and harbours

» Tourism and recreational water activities

» Waterfront properties

» Hydroelectric generation

Although the International Joint Commission (IJC) has noted the capacity of key GLSLS interest to adapt to water levels within historical upper and lower ranges, it warns that levels outside of these ranges would require certain interests to adopt more systematic responses than they have undertaken to date. In this regard, experts have advanced three broad approaches:

» Raising water levels in Lake Michigan-Huron by installing fixed structures in and around the St. Clair River, a process known as restoration.

» Raising or lowering water levels, as conditions dictate, on the entire GLSLS using new and existing dam-like structures, channel excavations and region-wide regulation plans, a process known as multi-lake regulation.

» Creating a structured, iterative and bi-national process of improving responses to changing water levels through long-term monitoring, modelling and assessment of hydrological trends and their impacts, a process known as adaptive management (AM).

Data and methodological constraints preclude a cost-benefit analysis (CBA) of all of these approaches. Instead, we attempt to provide the first comprehensive economic CBA of existing proposals to restore water levels on Lake Michigan-Huron using previously-studied structural options. We also provide qualitative analyses of the two remaining approaches — multi-lake regulation and AM — and assess the political viability of all three approaches.

We assess mitigation strategies with a focus on water levels in Lake Michigan-Huron. Our focus on Lake Michigan-Huron is not arbitrary; it was the hardest hit of the Great Lakes during the low-water spell of 1999 to 2013, and remains highly vulnerable to extreme lows, which is critical given the region's massive shipping, tourism, hydroelectric and cottage industries.

We identify a number of previously-studied structures that are capable of generating positive economic net benefits under our worst-case low water level scenario. The most promising of these interventions, according to our analysis, is a series of sills in the upper St. Clair River. But we stop short of recommending specific interventions for three reasons.

First, our estimates are modest. In our best-case scenario, restoration could yield almost $250 million USD in benefits from now to 2064. It is possible these estimates are conservative: they apply a four per cent discount rate, incorporate conservative estimates of several impacts and exclude costs that our structures would mitigate. However, it is also possible that our estimates are liberal: they exclude costs associated with restoration and assume a worst-case low water level scenario. This is of course problematic: if restorative structures, which are only capable of raising water levels, are not viable under our low water level scenario, then they are not viable at all.

The politics of adapting to and mitigating the impacts of climate change in the Great Lakes and St. Lawrence Region means identifying policies and structures capable of eliminating or limiting redistributive conflicts and environmental risks.

Second, our estimates are limited by the same uncertainties associated with any analysis of this nature: uncertainty about fluctuations in water levels; uncertainty about the impacts of water levels on ecological and economic outcomes; and uncertainty about the costs and benefits of interventions.

Finally, restoring water levels — no matter what the net regional benefit may be — faces formidable political obstacles. Virtually any effort to raise or lower water levels is likely to benefit some groups at the expense of others. This is a major constraint, as policymakers are reluctant to adopt structures that harm major interests. This does not preclude intervention if policymakers can find ways of resolving redistributive conflicts. But as we will argue, these solutions may be difficult to find.

These challenges have raised interest in multi-lake regulation — raising or lowering water levels, as conditions dictate, on the entire GLSLS using dam-like structures, channel excavations and region-wide regulation plans. This approach would allow the region to better cope with sudden and dramatic changes in water supplies and could ease tensions between stakeholders in flood- and non-flood prone regions. It could also present opportunities for habitat enhancement and restoration. But multi-lake regulation is no panacea. It is ecologically risky; would not eliminate the risks of extreme water levels; and would involve billions of dollars in excavation, construction and operation and maintenance costs.

This brings us to our third approach: adaptive management (AM). AM does not involve managing or raising water levels (though it can be combined with these approaches). Rather it is a structured, iterative process of improving responses to changing water levels through long-term monitoring, modelling and assessment of hydrological trends and impacts. It was recently endorsed by the International Upper Great Lakes Study as the most economical and politically practical means of adapting to the uncertainties and costs surrounding water levels, which explains the IJC's recent efforts to strengthen bi-national cooperation in this area.

We draw two conclusions from our analysis. First, the economic viability of restoration requires further research. Future CBAs ought to build on our work by including ecological impacts; additional economic impacts; more sophisticated modelling of economic outcomes; a wider range of hydraulic scenarios; better cost estimates of engineering structures; and, if existing proposals are incapable of redressing political and environmental hurdles, promising proposals for new engineering structures (indeed, most of the proposals we analyze were developed several decades ago).

Second, future research needs to grapple with the politics of adapting to and mitigating the impacts of climate change in the Great Lakes and St. Lawrence Region. Decisions over boundary and transboundary water levels today are taken by unofficial consensus, where virtually any group can veto measures expected to significantly harm their interests. Researchers ought to admit this constraint and find ways of redressing it. Ultimately, this means identifying policies and structures capable of eliminating or limiting redistributive conflicts and environmental risks.

The shortcomings of our study limit the recommendations we can make. However, one key recommendation emerges from our research which, if implemented, would help all interests adapt to changing water conditions and improve the quality of future research. We advise the Canadian and US governments to approve the IJC's proposals to strengthen AM on a bi-national basis. Specifically, we advise them to establish a Levels Advisory Board (LAB) capable of facilitating monitoring and modelling of hydrological trends and their impacts. This approach is not without political and administrative costs. But it is the most politically practical means of addressing fluctuating water levels: it is not as controversial as restoration or multi-lake regulation, and would help all actors, regardless of their preferences over water levels, by providing them with more, and better, information on hydrological conditions.

AM is also a necessary, albeit insufficient, condition for structural interventions. Neither restoration nor multi-lake regulation has any chance of approval unless uncertainty over their impacts is reduced. Systematic monitoring and modelling would not eliminate this uncertainty, but it would mitigate it, perhaps opening the door to a more reliable analysis of engineering options.

Résumé

Les niveaux d'eau dans les Grands Lacs sont dans un état d'évolution constante. Et c'est une bonne chose. Les fluctuations naturelles sont essentielles à la santé des écosystèmes. Mais des périodes continues de variations extrêmes de niveaux d'eau sont potentiellement coûteuses, tant pour l'économie que pour l'environnement. En juin 2014, nous avons estimé les coûts économiques directs d'un scénario de niveaux d'eau particulièrement bas dans certains secteurs du réseau des Grands Lacs et de la Voie maritime du Saint-Laurent (GLVMSL). Les conclusions en sont révélatrices étant donné les contraintes de données et la nature prudente de cette estimation. Le présent rapport fait fond sur ces recherches en évaluant les stratégies d'atténuation des coûts d'un pareil scénario dans quatre secteurs :

» Navigation commerciale et ports

» Tourisme et activités nautiques récréatives

» Propriétés riveraines

» Production hydroélectrique

Les experts ont proposé trois moyens de limiter les coûts associés aux variations extrêmes des niveaux d'eau :

» La hausse des niveaux d'eau des lacs Michigan et Huron en installant des structures fixes dans la rivière Sainte-Claire et dans les environs; ce processus est connu sous le nom de restauration.

» La hausse ou l'abaissement des niveaux d'eau, selon les conditions, dans l'ensemble du réseau des GLVMSL en utilisant des structures comme des digues et l'excavation de canaux, un processus appelé régularisation multilac.

» L'adaptation, plutôt que la gestion, des niveaux d'eau et l'amélioration des niveaux d'eau et améliorer les mesures adaptatives par le biais d'une surveillance, d'une modélisation et d'une évaluation des conditions hydrologiques du système complet à long terme, un processus dénommé la gestion adaptative (GA).

Les contraintes méthodologiques et de données excluent l'analyse coût/bénéfice (ACB) de chacune de ces approches. Cependant, nous proposons la première ACB complète des propositions de restauration des niveaux d'eau des lacs Michigan et Huron. Ce choix n'est pas arbitraire. Les lacs Michigan et Huron ont été les plus touchés parmi les Grands Lacs par la période de bas niveau d'eau de 1999 à 2013 et ont, par conséquent, le plus besoin de restauration.

En plus de notre analyse quantitative de la restauration, nous avons proposé des analyses des deux autres approches — la régularisation multilac et la gestion adaptative — nous évaluons la viabilité politique des trois solutions.

Nous avons défini un certain nombre de structures aptes à produire d'importants avantages nets dans le cadre de notre scénario de niveaux d'eau bas le plus défavorable. D'après notre analyse, l'intervention la plus prometteuse est une série de socles en amont de la rivière Sainte-Claire. Mais nous ne sommes pas en mesure de recommander les interventions pour trois raisons.

D'abord, nos estimations sont modestes. Même dans le meilleur des cas, la restauration rapporterait moins de 250 millions de dollars américains d'ici 2064. Il se peut que nos estimations soient prudentes. Toutefois, il est aussi possible qu'elles soient généreuses. Cela pose problème. Si les structures de restauration qui sont uniquement susceptibles de faire augmenter les niveaux d'eau et ne sont pas viables

dans nos scénarios de bas niveaux d'eau, elles ne sont pas viables du tout.

Par ailleurs, nos estimations souffrent de nombreuses incertitudes à l'égard de : l'orientation des fluctuations du niveau d'eau; des conséquences des niveaux d'eau sur les résultats écologiques et économiques; et des coûts et des avantages des interventions.

Enfin, la restauration des niveaux d'eau — peu importe les avantages régionaux nets — est confrontée à de redoutables obstacles politiques. Pratiquement toute initiative visant à hausser ou abaisser les niveaux d'eau aura pour effet d'avantager certains groupes au détriment d'autres. Cela constitue un obstacle de taille. Comme nous l'expliquerons, la Commission mixte internationale (CMI) (l'organisme quasi judiciaire chargé de la résolution et de la prévention des différends sur la gestion du niveau des eaux limitrophes et transfrontalières), ainsi que les gouvernements canadien et américain, sont peu susceptibles de faire monter les niveaux d'eau sans l'approbation d'une grande majorité des intérêts concernés. En conséquence, les décideurs auraient probablement besoin de trouver des moyens de protéger ou d'indemniser les perdants avant l'approbation des projets. Ces solutions pourraient être difficiles à trouver.

Ces défis ont suscité de l'intérêt pour des solutions plus souples en mesure de relever et d'abaisser les niveaux d'eau de tous les Grands Lacs par le biais de digues et des plans de régularisation. Cette approche permettrait à la région de mieux composer avec les changements soudains et dramatiques dans l'approvisionnement en eau et pourrait atténuer les tensions entre les intervenants dans les zones inondables ou non. Mais la régularisation multilac n'est pas une panacée. Elle présente des risques écologiques, n'éliminerait plus les risques de variations extrêmes des niveaux d'eau et mettrait en jeu des milliards de dollars en coûts d'excavation, de construction et de fonctionnement et d'entretien.

Les décisions concernant les eaux limitrophes et transfrontalières sur les niveaux d'eau sont prises officieusement au consensus et pratiquement n'importe quel groupe possède un droit de veto sur les mesures susceptibles de nuire sensiblement à leurs intérêts.

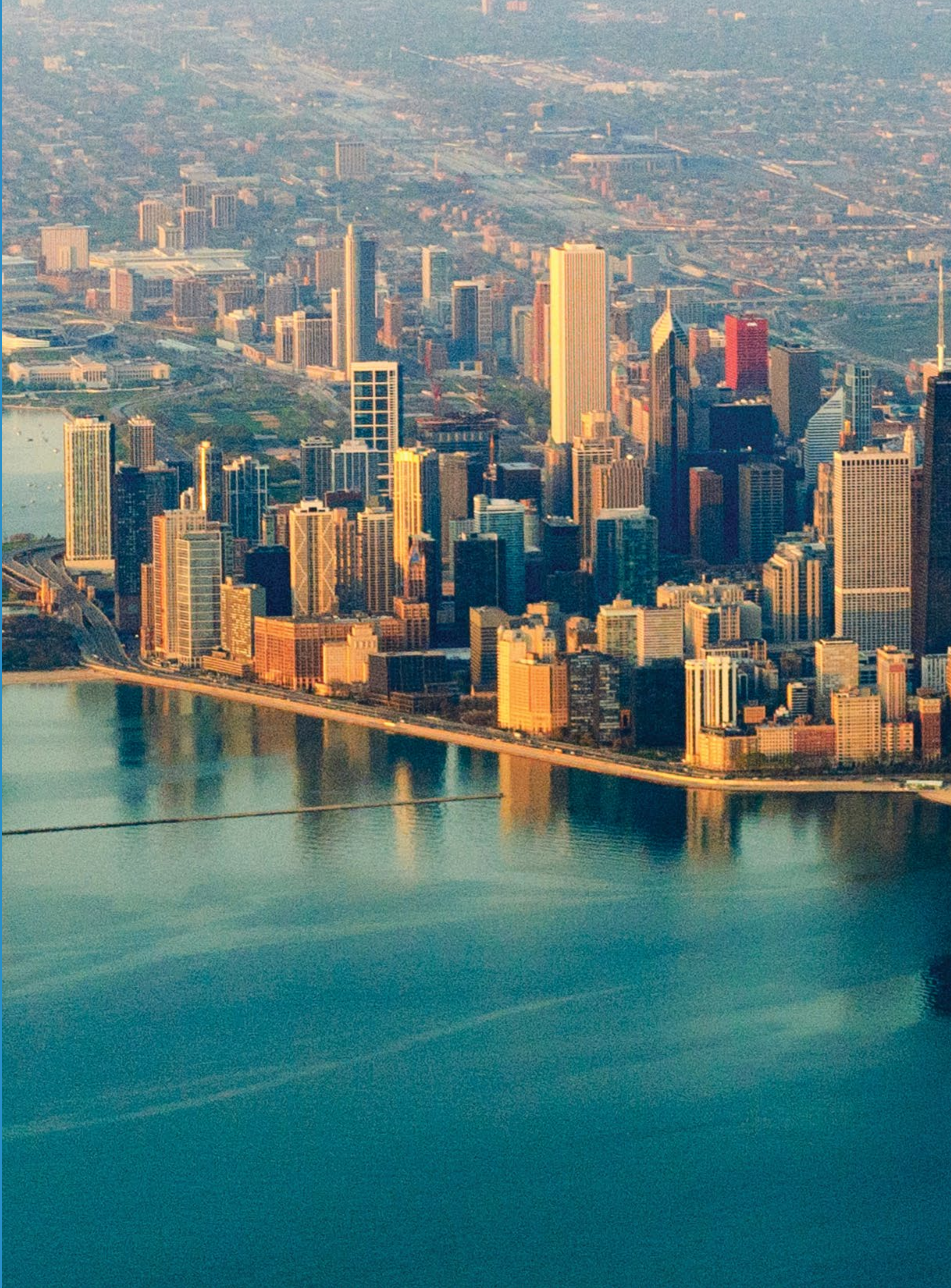
Ce qui nous amène à la troisième voie envisageable : la gestion adaptative. Celle-ci ne consiste pas à gérer les niveaux d'eau, mais à trouver de nouveaux et meilleurs moyens de s'adapter leurs fluctuations. L'adaptation associée à cette approche n'est pas accidentelle, mais éclairée par la surveillance, la modélisation et l'évaluation binationales des tendances hydrologiques et leurs conséquences.

Nous avons tiré deux conclusions. D'abord, la viabilité de la restauration exige des recherches plus approfondies. Les futures ACB devraient faire fond sur nos travaux et comprendre l'incidence écologique; les effets économiques supplémentaires; une modélisation plus sophistiquée des résultats économiques; une plus grande gamme de scénarios hydrauliques; de meilleures estimations des coûts des ouvrages de génie; et si les propositions existantes ne permettent pas de franchir les obstacles politiques et environnementaux, des propositions de nouvelles structures de génie.

Deuxièmement, les recherches doivent se pencher sur les aspects politiques de restauration. Les décisions concernant les eaux limitrophes et transfrontalières sur les niveaux d’eau sont prises officieusement au consensus et pratiquement n’importe quel groupe possède un droit de veto sur les mesures susceptibles de nuire sensiblement à leurs intérêts. Les chercheurs devraient admettre l’existence de ces restrictions et trouver des moyens de les assouplir. En fin de compte, il s’agit de définir des politiques et des structures aptes à éliminer ou à réduire les conflits de redistribution et les risques environnementaux.

Les lacunes de notre étude limitent les recommandations que nous sommes en mesure de formuler. Néanmoins, nous estimons qu’une recommandation aiderait tous les intéressés à s’adapter à l’évolution des conditions de l’eau et à améliorer la qualité des recherches futures. Nous conseillons aux gouvernements canadien et américain d’approuver les propositions du CMI visant à renforcer la gestation adaptative sur une base binationale. En particulier, nous les invitons à mettre sur pied un Comité consultatif sur les niveaux d’eau (CCN) en mesure de faciliter la surveillance et la modélisation des tendances hydrologiques et de leurs impacts. La gestion adaptative est la manière la plus pratique de s’occuper de la fluctuation des niveaux d’eau : elle n’exige pas explicitement de redistribution, aiderait tous les acteurs, peu importe leurs préférences sur les niveaux d’eau, en leur donnant plus de renseignements détaillés sur les conditions hydrologiques.

La gestion adaptative est également une condition nécessaire, bien qu’insuffisante, des interventions structurelles. Ni la restauration ni la régularisation multilac ne risquent d’être approuvées à moins de dissiper l’incertitude entourant leur incidence. La surveillance et la modélisation systématique n’élimineraient pas cette incertitude, mais l’atténueraient et ouvriraient éventuellement la voie à une analyse plus fiable des options de génie.



Part 1: Introduction

In January 2013, water levels on Lake Michigan-Huron[1] hit their lowest level since consistent measurement began in 1918. The record was part of a streak of 186 months in which lake levels were below the lake's long-term monthly averages. Although Michigan-Huron was hit particularly hard, levels were also low, at times, on Lake Superior, where, in 2007, they were at their lowest level since 1926.[2]

By 2014, the situation had changed dramatically. Water levels on Lake Michigan-Huron and Superior surged and, at the time of writing, all lakes exceeded their long-term monthly averages. From January 2013 to December 2014, Lake Superior jumped roughly two feet, a record increase for that 24-month span. Lake Michigan-Huron rose by nearly three feet, just shy of the record for that period.[3]

Water levels are in a constant state of flux. This is good. Natural fluctuations are essential to a healthy ecosystem. But sustained periods of extreme water levels are potentially costly, both for the economy and the environment. Extreme highs can cause flooding, collapsed buildings, and loss of beaches, recreational areas and wetlands. Extreme lows can impede navigation, limit hydroelectric generation, strand wetlands and undermine tourism and property values.[4]

In our June 2014 report,[5] we estimated the direct economic costs of an extreme low water level scenario on the Great Lakes and St. Lawrence River System (GLSLS). Our estimates included selected outcomes in five sectors:

» Commercial shipping and harbours

» Tourism and recreational water activities

» Waterfront properties

» Hydroelectric generation

» Municipal, industrial and rural water users

The estimates were non-trivial and, given missing data on a wide range of sectors and impacts, may prove conservative.

This report assesses strategies for mitigating the costs of low water levels on the first four of these sectors.[6] In general, experts have proposed three broad approaches, all of which are thoroughly described in the International Upper Great Lakes Study (IUGLS):[7]

» Raising water levels in Lake Michigan-Huron by installing fixed structures in and around the St. Clair River to "compensate for past natural and human-induced changes,"[8] a process known as restoration.

» Using region-wide regulation plans to raise or lower water levels, as conditions dictate, on the entire GLSLS using existing and more flexible dam-like structures and channel excavations, a process known as multi-lake regulation.

» Improving responses through long-term, system-wide monitoring, modelling and assessment of hydrological trends and their impacts, a process known as adaptive management (AM).

Data and methodological constraints preclude a cost-benefit analysis (CBA) of each of these approaches. However, we provide the first comprehensive economic CBA of proposals to restore water levels on Lake Michigan-Huron. The focus on Michigan-Huron is not arbitrary. It was the hardest hit of the Great Lakes during the recent low-water spell and is, therefore, arguably in the greatest need of restoration. It has also inspired a number of proposals to raise water levels. These proposals provide most of the data for our analysis.

1 The reference to Lake Michigan-Huron will confuse readers who know lakes Michigan and Huron as separate entities. But the lakes actually share the same surface water elevation (because of their connection at the Straits of Mackinac), which makes them a single lake from a hydraulic and hydrological perspective.
2 For a discussion of water losses during this period, see Gronewold and Stow, 2014. Water levels on Lake Ontario also fell below their long-term averages at various points during this time, but not as often or by as much. Unlike lakes Michigan-Huron and Erie, Ontario is regulated by the Moses-Saunders Dam at Cornwall and Massena on the St. Lawrence River. Lake Superior is also regulated (by dams on the St. Marys River), but this did not prevent it from experiencing record lows, caused by increased evaporation and decreased precipitation, during this period.
3 Gronewold et al., 2015b.
4 IUGLS, 2012: 8.
5 Shlozberg et al., 2014.

6 We were not, for methodological reasons, able to assess the impacts of low water levels on municipal, industrial and rural water users.
7 IUGLS, 2012.
8 IUGLS, 2012: 113.

In addition to our quantitative analysis of restoration, we provide qualitative analyses of the two remaining approaches — multi-lake regulation and AM — and assess the political viability of all three. Our political analysis is crucial. The merits of restoration are highly contested, particularly between those who stand to benefit from higher water levels (including property owners and defenders of wetlands in Georgian Bay) and those who stand to lose (including interests along the heavily populated and flood- and erosion-prone shores of southern Lake Michigan).

We identify a number of previously-studied structures that are capable of generating positive economic net benefits under our worst-case low water level scenario. The most promising of these interventions, according to our analysis, is a series of sills in the upper St. Clair River. These structures would raise water levels on Lake Michigan-Huron by restricting outflows from the outlet of Lake Michigan-Huron. If construction were started immediately and completed in stages, net economic benefits could reach $234 million USD over 50 years. If construction were delayed 20 years (a more realistic scenario), these benefits would fall to $122 million USD from 2015 to 2084.

Despite these benefits, we stop short of recommending interventions for three reasons. First, our estimates are modest. In our best-case scenario, restoration would yield less than $250 million USD from now to 2064. It is possible these estimates are conservative: they apply a four per cent discount rate, incorporate conservative estimates of several impacts and exclude costs that our structures would mitigate. However, it is also possible that our estimates are liberal: they exclude costs associated with restoration, including the costs of temporarily lowering water levels on the St. Lawrence River, and assume a worst-case low water level scenario.

Second, our estimates suffer from uncertainty: uncertainty about the direction of water level fluctuations; uncertainty about the impacts of water levels on ecological and economic outcomes; and uncertainty about the costs and benefits of interventions. This report is the first to systematically quantify the latter. But significant uncertainty remains: data constraints prevent us from quantifying ecological impacts and the full range of economic benefits and we only consider a single hydraulic scenario.[9]

Third, restoration — no matter what the net regional benefits may be — faces formidable political obstacles. Virtually any effort to raise or lower water levels is likely to benefit some groups at the expense of others. This is a major constraint. History shows that the International Joint Commission (IJC), the quasi-judicial body charged with helping resolve and prevent disputes over boundary and transboundary waters,[10] along with the Canadian and US governments, are unlikely to raise water levels without the approval of the vast majority of affected groups. This does not preclude intervention if policymakers find ways of resolving redistributive conflicts. But as we will argue, these solutions may be difficult to find.

These challenges have raised interest in more flexible solutions capable of raising and lowering water levels, on all of the Great Lakes, through dams and regulation plans. This approach — already in place on lakes Ontario and Superior — would allow the region to better cope with sudden and dramatic changes in water supplies and could ease tensions between stakeholders in flood- and non-flood prone regions. But multi-lake regulation is no panacea. As the IUGLS explains,[11] it is ecologically risky; would not eliminate the risks of extreme water levels; and would involve billions of dollars in excavation, construction and operation and maintenance costs. All that said, multi-lake regulation might be viable if extreme water levels were to become the norm. However, the frequency and magnitude of extremes is difficult to forecast.

9 Nonetheless, this scenario provides a useful boundary case. If restorative structures, which are only capable of raising water levels, are not economically viable under a low-water scenario, then they are not viable at all.
10 IJC, 2012: 2
11 IUGLS, 2012: viii.

Causes of water level fluctuations

Water levels in the GLSLS system depend on several factors. This box describes three: climate change, glacial isostatic adjustment and the increased conveyance capacity of the St. Clair River. We highlight these factors because of their technical and political importance.[12]

Climate Change

Climate affects water levels by influencing the lakes' net basin supplies (NBS). NBS values account for water entering each lake basin through precipitation (and runoff) and leaving each lake basin through evapotranspiration.[13]

Historically, changes in precipitation have accounted for most of the long-run variation in water supplies and levels.[14] However, persistent lows on Superior and Michigan-Huron from 1999 to 2013 were primarily the result of increased evaporation — not decreased rain and snowfall. It is believed that higher evaporation rates were caused, in turn, by warmer surface water temperatures and decreased ice coverage (note, however, that this relationship is not entirely clear[15]). In the winter of 2013-2014, climatic conditions changed abruptly. Surface temperatures cooled, evaporation decreased and rain and snowfall increased. Water supplies and levels on Superior and Michigan-Huron rose as a result.

The causes of these abrupt transitions are unclear, but a recent paper by Gronewold and his colleagues[16] suggestively and partially links them to regional climate perturbations. They note that the warm, low-water period from 1999 to 2013 was preceded by an unusually strong El Niño in 1997-98, whereas a cool, high-water period may have taken root with the Arctic Polar Vortex anomaly in 2013-14.[17]

Future water levels remain far from certain and will remain so until our ability to predict precipitation and evaporation is significantly improved. But the growing frequency of extreme climate events suggests that recent and abrupt shifts in the system's thermal and hydrological regime may become more common.[18]

12 Most of the water withdrawn from the basin for human uses, including hydroelectric generation, irrigation and industrial uses, is returned (IUGLS, 2012: 25).
13 Lenters et al., 2013. Water also enters the lakes through runoff from the surrounding drainage basin (IUGLS, 2012: 4, footnote 1).
14 Gronewold and Stow, 2014. Changes in net basin supplies also reflect short-term and seasonal variations. Short-term fluctuations, which can last anywhere from minutes to days, come from sustained high winds and shifts in barometric pressure (IUGLS, 2012: 3). Seasonal variations are more predictable. Water supplies are generally higher in the spring and early summer because of snowmelt and spring rainfall and lower in the fall and early winter because of higher evaporation, a consequence of the "cool, dry air [passing] over the relatively warm water of the lakes" (IUGLS, 2012: 4). There are, however, occasional deviations from these trends. In 2014, for example, water levels on Lake Michigan-Huron actually rose from September to October (Gronewold et al., 2015b).
15 Ice cover lowers evaporation rates by acting as a cap, essentially preventing water vapor from escaping into the air. But recent research shows that high evaporation rates lead to higher ice cover (Lenters et al., 2013). Thus, the relationship between evaporation and ice coverage is complex.
16 Gronewold et al., 2015a.
17 Note, however, that the recent surge began in the spring of 2013.
18 According to a report by the International Great Lakes-St. Lawrence River Adaptive Management Task Team, "in the future, we will likely experience more extreme water levels – both high and low – that are outside the historical range experienced over the past century." (2013: i).

Glacial Isostatic Adjustment (GIA)

GIA refers to the gradual tilting of the earth's crust in response to the retreat of glaciers from the last ice age. The weight of the ice sheets depressed the earth and caused it to bulge beyond the glaciers' edge. As the glacier retreated and the weight decreased, the earth began to rebound and the bulge began to subside. This process is causing shorelines in the northern and eastern sections of the Great Lakes basin to slowly rise and shorelines in the southern and western sections to slowly fall. The upshots are perceived decreases in water levels in rising areas, which include Georgian Bay, and perceived increases in water levels in falling areas, which include Chicago and Milwaukee.[19]

Increased Conveyance Capacity of the St. Clair River

The St. Clair River connects lakes Huron and St. Clair. In 2009, the IJC concluded that the river's conveyance (or water-carrying) capacity had increased since the last dredging of the river in 1962 and that the increase was responsible for a permanent, 7 to 14 centimeter (2.8 to 5.5 inch) drop in water levels on Lake Michigan-Huron (though dredging was not the only factor that affected the river's conveyance capacity during this period).[20] The Canadian and US governments approved works to stem dredging-induced water losses in the 1960s, but water levels surged shortly after. Compensating structures, which would have raised water levels ever further, were never built as a result.[21]

The relative weight of these causes has important policy implications. If large swings in supplies and lake levels are primarily caused by fluctuations in climate, which they are, then a flexible policy response — one capable of managing or adapting to unpredictable shifts in water levels — may be appropriate (though see our reservations about multi-lake regulation in Section 5). If, however, the increased conveyance capacity of the St. Clair River plays a major role, then structures leading to a permanent increase are easier to justify.

Another issue is the role of human activity. Residents of Georgian Bay, who saw their property values and wetlands suffer from the recent low-water spell, can understandably claim that water losses caused by dredging ought to be reversed. But their case is complicated by the fact that permanently raising water levels could exacerbate coastal flooding and property damage downstream when water levels are high, which they were in the mid-1980s.

GIA complicates matters even further. GIA strengthens demand for restoration in Georgian Bay, where shorelines are rising at 17 centimeters to 27 centimeters per century (the precise rise depends on the precise area). But it would increase flood risk along the southern and western sections of Lake Michigan (and to a lesser degree Lake Huron), where shorelines are falling and flooding has occurred in the past.[22]

19 IUGLS, 2012: 6.
20 IUGLS, 2009.
21 See, among others, Georgian Bay Forever, 2012.
22 IUGLS, 2012: 124.

This brings us to our third approach: AM. AM does not involve managing or raising water levels (though it can be combined with these approaches). Rather it is a structured, iterative process of improving responses to changing water levels through long-term monitoring, modelling and assessment of hydrological trends and impacts. It was endorsed by the IUGLS as the most economical and politically practical means of adapting to uncertainties and costs surrounding water levels, which explains the IJC's recent efforts to strengthen and formalize bi-national cooperation in this area.[23]

The economic viability of restorative structures requires further research to collect more fine-grained data and develop better models of individual impacts. Eventually, it would provide a stronger foundation for a broader and deeper analysis of regional impacts.

We draw two conclusions and lessons. First, the economic viability of restorative structures requires further research. Future CBAs ought to build on our work by incorporating ecological impacts; additional economic impacts; more sophisticated modelling of economic outcomes; a wider range of hydraulic scenarios; better cost estimates of engineering structures; and, if existing proposals are incapable of redressing political and environmental hurdles, promising proposals for new engineering options. In the absence of considerable capacity and resources, this research should start small, focusing on specific lakes, sectors or even impacts within them. This would allow researchers to collect more fine-grained data and develop better models of individual impacts. Eventually, it would provide a stronger foundation for a broader and deeper analysis of regional impacts.

Second, future research needs to grapple with the politics of restoration. Decisions over transboundary water levels are taken by unofficial consensus, where virtually any group can veto measures expected to significantly harm their interests. Researchers ought to admit this constraint and identify ways of redressing it. This probably means identifying policies and structures capable of eliminating or limiting redistributive conflicts and environmental risks.

The modesty and uncertainty of our estimates limit the policy recommendations we can make. However, we do make one, which, we believe, will improve the capacity of actors to adapt to fluctuating water levels and provide the foundation for future research. We advise the Canadian and US governments to approve the International Joint Commission's proposals to strengthen AM on a bi-national basis. Specifically, we advise them to establish a Levels Advisory Board (LAB) capable of facilitating monitoring and modelling of hydrological trends and their impacts. AM is the most politically practical means of addressing fluctuating water levels: it is not as controversial as restoration or multi-lake regulation; and it would help all actors, regardless of their preferences over water levels, adapt by providing them with more and better information on hydrological conditions. AM is also a necessary, albeit insufficient, condition for structural interventions. Neither restoration nor multi-lake regulation has any chance of approval unless uncertainty over their impacts is reduced. Systematic monitoring and modelling would not eliminate this uncertainty, but it would mitigate it, perhaps opening the door to a more reliable analysis of engineering options.

23 IUGLS, 2012.

The remainder of the report proceeds as follows:

» Part 2 develops our general methodology.

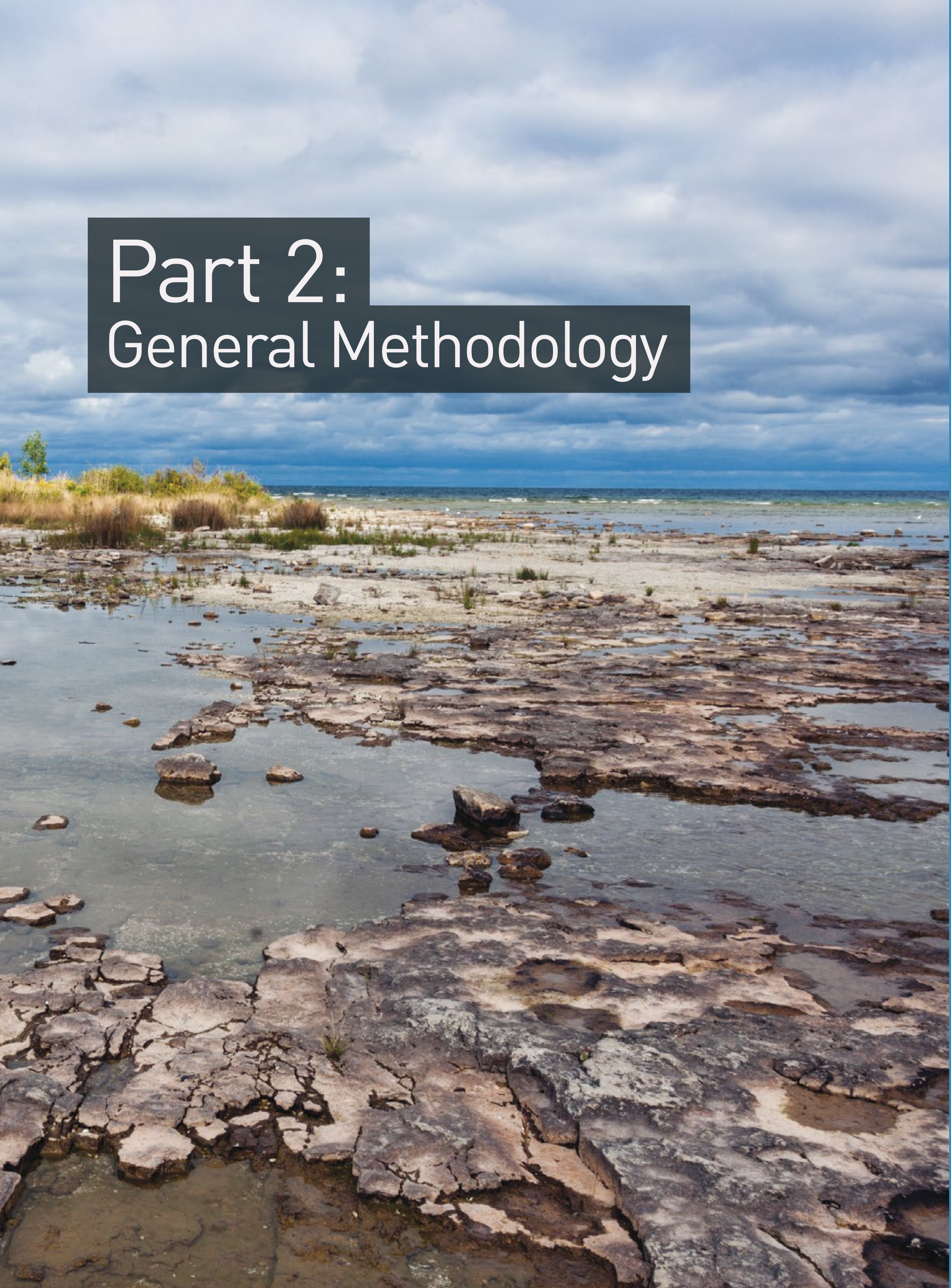
» Part 3 identifies the economic sectors under analysis.

» Part 4 analyzes the costs and benefits of restorative options.

» Part 5 discusses the pros and cons of multi-lake regulation.

» Part 6 discusses the pros and cons of AM.

» Part 7 summarizes our results, their limitations and their research and policy implications.



Part 2: General Methodology

This section outlines the major elements and limitations of our CBA. It also describes our analysis of the political feasibility of engineering structures.

2.1 Overview of quantitative analysis

2.1.1 Sectors analyzed

The first step is to determine which interests to include in our CBA; in other words, which groups have standing. We analyze four:

» Commercial shipping and harbours.

» Tourism and recreational water activities.

» Waterfront properties.

» Hydroelectric generation.

Sectors were chosen on the basis of three criteria: their importance to their local economies and the GLSLS as a whole (the IJC recognizes each as critical);[24] their sensitivity to water levels; and the availability of economic impact data.

These sectors are not homogeneous. They consist of sub-sectors and distinct geographic interests. What is good for property owners in Georgian Bay, for example, is not necessarily good for property owners on Lake Erie. Thus, we disaggregate impacts by lake or region.

There are several sectors or interests — including ecosystem services, First Nations and Native Americans and municipal and industrial users — that our quantitative analysis does not include. We consider these sectors important and omit them only because of methodological or data constraints. We also discuss their importance, at various points, throughout the report.

24 IUGLS, 2012: 23.

2.1.2 Interventions and their costs and benefits

Three broad categories of structures are available to manage water levels: (1) restorative options, such as sills, dikes and weirs, which would raise upstream water levels; (2) regulative options, such as dams and enlarged outlet channels, which would raise and lower water levels as conditions dictate; and (3) semi-restorative options, such as inflatable flap gates and hydrokinetic turbines, which would combine regulative and restorative features. Our quantitative analysis focuses on three restorative and two semi-restorative structures. All five would be located in or around the St. Clair River and all five would raise water levels on Lake Michigan-Huron by restricting the conveyance capacity of the St. Clair River.

As the term suggests, restoration could refer to any effort to raise or lower water levels to what they would have otherwise been in the absence of some natural or human-induced cause. With respect to the GLSLS, it often refers to measures to compensate for dredging of the St. Clair River (see pg. 13). We do not engage in these definitional debates. We merely assess the economic and political feasibility of raising Michigan-Huron levels by fixed amounts.

For each option, we generally consider four costs:

» Materials, labour and other construction costs.

» Engineering and design, real estate purchases, planning and program management and other non-construction costs.

» Operation and maintenance.[25]

» The costs of temporarily lower water levels downstream.

The last item — downstream costs — requires

25 We do not include operation and maintenance costs for all options. They are negligible for one (sills) and unavailable for two others (hydrokinetic turbines and parallel dikes and weirs in Lake Huron).

elaboration. Each of the structures would lower water levels on downstream bodies, including Lake Erie, Lake St. Clair and the St. Lawrence River, by slowing flows through the St. Clair River. The effect would be temporary, however, as the increasing head differential (or difference between upstream and downstream water levels) would eventually increase flows to what they would have been prior to the intervention.[26] We estimate these costs on Lake Erie and the Niagara River, but lack cost data for Lake St. Clair and simulated river flow data (needed to estimate costs) for Lake Ontario and the St. Lawrence River. We exclude these bodies as a result.

2.1.3 Policy scenarios

We also consider the moderating effects of policy scenarios. The impacts of interventions depend on two key decisions. The first is whether construction is staged. Staging reduces benefits on Lake Michigan-Huron by reducing and delaying cumulative increases in water levels, but it lowers costs on Lake Erie by reducing and delaying cumulative decreases downstream. Accordingly, for each option, we analyze two construction outcomes: one in which construction is completed in one stage and another in which it is completed in five, with each stage taking five years to complete and the first stage beginning immediately.

The second policy decision concerns the approval process. The IUGLS[27] estimates that it could take 20 years or more before the necessary environmental, regulatory and other approvals for restorative structures are in place.[28] We consider two regulatory scenarios: one that takes 20 years to obtain approvals and another that takes zero. The immediate construction scenario, while unrealistic, allows us to estimate the structures' maximum potential.

This yields four policy scenarios per structure:

» Construction begins immediately and is completed in one step.

» Construction begins immediately and is completed in five steps.

» Construction begins in 20 years and is completed in one step.

» Construction begins in 20 years and is completed in five steps.

2.1.4 Time horizons and water level assumptions

We employ two time horizons: one from 2015 to 2064 and another from 2015 to 2084. The first is used for scenarios in which construction begins immediately; the second for scenarios in which construction is delayed 20 years. The difference ensures a fair comparison of immediate and delayed construction scenarios. Had we used the same horizon, we would have compared the effects of 50 years of interventions under the immediate scenarios with the impacts of 30 years of interventions under the delayed scenarios. We, and several reviewers, considered this comparison unfair.

We assume a worst-case low water level scenario over these horizons. This decision is data-driven: sufficient economic impact data for high-water conditions are not yet available. To calculate water levels, we use the projected average water level from 2041 to 2060 from the Canadian Centre for Climate Analysis and Modelling's 2050 scenario (CCCma 2050).[29] We then assume this average level is the 2064 level and linearly interpolate values for the remaining years using 2014 and 2064 as our start and end dates. For the delayed construction scenarios, we hold levels constant, at their 2064 level, from 2064 to 2084.

26 IUGLS, 2012: 116-117.

27 IUGLS, 2012: 127.

28 The IUGLS provides a long list of procedures and requirements that would need to precede construction. They include "an assessment of the need for a bi-national study and the scope and nature of the study; required authorizing legislation; the requirement for new IJC Orders of Approval; other required regulatory and environmental approvals; the specific role of the IJC compared to other jurisdictions and how the decision process could function; possible funding mechanisms; an assessment of whether the benefits justify the costs; and a review of past approvals for dredging in the St. Clair River system and related commitments to mitigate" (2012: 127).

29 Millerd, 2005.

TABLE 2.1 Water levels in the Great Lakes

Lake	2014 (in meters)	Historical average (1918-2014 in meters)	2064 projection (in meters)
Superior	183.51	183.4	183.03
Michigan-Huron	176.3	176.42	175.43
Erie	174.21	174.14	173.35
Ontario	74.77	74.75	74.31

Our hydraulic scenario is similar to the one used in our *Low Water Blues* report.[30] However, we make small adjustments to increase consistency with the methodological guidelines developed for a series of regional studies on the economics of climate change. The studies, including this one, are supported by Natural Resources Canada (NRCan) as part of the program of the Economics Working Group of Canada's Adaptation Platform.[31]

Our projected 2064 water levels are roughly one meter (3.2 feet) below the annual average from 1918 to 2014 for Lake Michigan-Huron and roughly 0.8 meters (2.6 feet) below the annual average from 1918 to 2014 for Lake Erie. Projected water levels for lakes Ontario and Superior, which are regulated, are similar to their historical averages (see Table 2.1 for details).

Our approach differs from most forecasts of water levels, which simulate monthly levels based on assumptions about climate variables. Climate assumptions affect water levels by affecting NBS — where NBS refers to the "net amount of water entering each Great Lake resulting from precipitation falling directly on the lake surface, runoff to the lake from the surrounding drainage basin and evaporation from the lake."[32] Together with the inflow received from an upper great lake, NBS drives water levels and lake outflows. Increases in NBS correspond to wetter climate scenarios and higher water levels, while decreases in NBS correspond to drier climate scenarios and lower water levels. Although we do not simulate water levels, our scenario most closely corresponds to the two driest sequences simulated in the IUGLS[33] and the International Lake Ontario-St. Lawrence River Study.[34] See Appendix 4 for details.

2.1.5 Discounting

Most cost-benefit analyses discount future costs and benefits. Discounting is generally advised for two reasons. First, people value current over future outcomes and second, the future is less certain than the present. Our discount rate is four per cent. We also conduct sensitivity analyses using two per cent and six per cent rates. As with our time horizon, these values were used for consistency among the series of regional studies supported by NRCan.

2.1.6 Currency

All values in our analysis have been converted to 2012 US dollars and factor out the effects of general inflation. Thus, our discount rate is a real rate of four per cent.

30 Shlozberg et al., 2014.
31 The guidelines were developed by the Cross-Region Integration Group. The group was convened by NRCan and consisted of the regional study leads and members of the Economics Working Group. The regional studies include this study and three others: one on the St Lawrence region, one on the coastal region of Quebec and another on the coastal zones of the Atlantic Provinces. For further information on the Adaptation Platform and Economics Working Group, see: http://www.nrcan.gc.ca/environment/impacts-adaptation/adaptation-platform/10027.
32 IUGLS, 2012: 4, footnote 1.

33 IUGLS, 2012.
34 ILOSLRSB, 2006. The study labels these sequences as T1 and T2. In both, the effects of climate change become more pronounced over time.

2.1.7 Study limitations

Our analysis has several limitations. First, we focus on direct economic costs and ignore effects on secondary markets.

Second, we do not quantify the full range of direct economic costs and benefits. We do not, for example, estimate the impacts of interventions on recreational boaters and fishers or municipal and industrial water users. We also omit impacts on lakes St. Clair and Ontario and the St. Lawrence River. Section 3 explains these omissions in detail.

Third, we exclude environmental impacts. These impacts, while vitally important, are difficult to quantify. We do, however, discuss their importance throughout the report.

Fourth, our cost data are arguably dated. We rely on estimates from the secondary literature, but a number of proposals were developed several years or even decades ago.

Fifth, our cost estimates have been adjusted for general inflation, but not to possible changes in the relative prices of labour, construction materials and other inputs.

Finally, our expectations about future water levels are contested. We assume a worst-case low water level scenario and model water levels as a decreasing linear trend over time. However, we appreciate that a range of scenarios are plausible and that outcomes are stochastic and unlikely, therefore, to follow a linear trend. We would have preferred to simulate economic impacts under a variety of scenarios (the key policy challenge is not, after all, to plan for persistently low water levels, but to cope with variability and uncertainty). But this would have generated estimates of extremely high levels, an outcome for which credible economic impact data are lacking.[35]

35 For a discussion of data constraints, see Shlozberg et al., 2014: 14.

Despite these weaknesses, our low water scenario provides a useful boundary case. Restorative structures are designed to increase water levels by a fixed amount. If these structures (which are not capable of lowering water levels) are not economically viable under our low water level scenario, then they are not viable under higher water level scenarios either. In fact, restoration could create serious costs under such a scenario, particularly to the densely populated southern shores of Lake Michigan and the southeastern shores of Lake Huron.[36]

2.2 Overview of qualitative analysis: Pareto optimality and political feasibility

The conceptual foundation of CBA is Pareto efficiency. A Pareto efficient outcome is one in which it is impossible to find another policy that makes everyone better off without making at least one person worse off. As attractive as this principle is, it is generally impossible (in the absence of transfers) to identify Pareto-improving outcomes when dealing with policies affecting large numbers of diverse interests. Managing water levels falls under this category. Great Lakes water levels affect a wide range of interests, including domestic, municipal and industrial water users; hydroelectric producers; recreational boaters and tourists; commercial shippers and harbours; and property owners. To complicate matters, these interests are spread across two countries; two Canadian provinces and eight US states; thousands of units of local government; and more than 100 Native American tribes and First Nations.

Does the inability to please all groups inevitably wed cost-benefit analysts to the status quo? Not necessarily. If projects generate positive net benefits, the winners can, in theory at least, transfer a portion of their gains to the losers, such that everyone is better off — or at least no worse off — under the new policy.

36 IUGLS, 2012: 125.

Plan 2014: A new proposal to regulate water levels on Lake Ontario

New efforts to restore or regulate water levels face a number of political obstacles, as do measures to alter existing regulation plans. Consider recent efforts to revise the regulation of Lake Ontario. The existing plan, which was designed to meet objectives set in 1956, narrows the range of likely Lake Ontario water levels by releasing or withholding water at the Moses Saunders dam near Cornwall. This has reduced the variability of water levels significantly, benefiting shoreline homeowners, shippers, recreational boaters and other interests as a result. But it has also caused significant environmental harm. The IJC blames the current plan for damaging 26,000 hectares (64,000 acres) of coastal wetlands.[37]

The IJC recently proposed Plan 2014, which would continue to compress Lake Ontario water levels, but within a wider range. The plan is the product of 14 years of analysis and public consultation and is expected to have neutral or minor impacts on most groups, but to provide major benefits to wetlands[38] and animal habitats. It has been sent to the Canadian and US governments for concurrence and while it is generally popular in Canada and with some US groups, it is opposed by lakeshore property owner communities in New York State. The latter worry that the plan will increase flooding and erosion. That may be true, but its most likely effect, argues the IJC, is to increase the costs of maintaining sea walls, revetments and other shoreline protections.[39]

37 IJC, 2014.
38 In the words of the IJC (2014), wetlands "act as the kidneys of the Great Lakes by filtering pollutants, and by providing critical habitat to many species of amphibians, birds, mammals and fish."
39 This is less of a concern in Canada, where the government prohibited construction on flood plains after Hurricane Hazel in 1954.

Unfortunately, a net surplus does not mean that all or even a lot of that surplus is available for redistribution. A number of tricky political and technical issues can get in the way. How, for example, do the beneficiaries of higher water levels compensate the losers from increased flood risk?

The problem is not merely normative. It is a political constraint as well. Barring a special agreement between the Canadian and U.S. governments, any application for a new obstruction, use or diversion of shared waters requires IJC approval. And if the obstruction is expected to raise waters beyond natural levels, the IJC must, pursuant to the Boundary Waters Treaty, ensure "suitable and adequate protection" of any interests potentially harmed across the border.[40]

This does not mean that the IJC cannot approve projects harmful to certain groups.[41] But the IJC and the Canadian and US governments are clearly reluctant, in their dealings with water levels and flows, to create significant losers.[42] Recent efforts to revise the regulation of Lake Ontario provide a case in point (see sidebar). Indeed, it would appear decisions over GLSLS water levels are taken by unofficial consensus, where virtually every major group exercises a de facto veto over measures expected to significantly harm their interests. In other words, it would seem that Pareto optimality is a quasi-political — and not merely a normative — constraint.[43]

40 IJC 2012.
41 IJC 2012.
42 A good example of this is the "balancing principle" underlying the regulation of Lake Superior: the IJC tries to provide benefits and relief to groups affected by water levels without causing undue harm to other groups (IUGLS, 2012: 23).
43 We emphasize the quasi-political nature of this constraint, because the IJC and both governments are not, from a strictly legal perspective, prohibited from approving projects that inflict harm. We simply believe they are extremely reluctant to do so.

The IJC and the Canadian and US governments are clearly reluctant, in their dealings with water levels and flows, to create significant losers. Virtually every major group exercises a de facto veto over measures expected to significantly harm their interests.

Granted, these constraints have not prevented the IJC or either government from undertaking socially and environmentally disruptive projects. The St. Lawrence Seaway and Power Project, for example, flooded 38,000 acres of land and forced seven villages, three hamlets and 225 farms to relocate.[44] Importantly, affected parties were compensated in this instance. But public acceptance for disruptions of this scale has clearly declined. No engineering project faces an easy road. They all require extensive public consultation and economic, regulatory and environmental review.

2.3 A note on data sources

We rely on a range of data sources, including published data, publicly available datasets and data from academic researchers, government and industry. Data on water levels and their benefits come, by and large, from our *Low Water Blues* report.

44 For a detailed history of this project, see Macfarlane (2014).

Part 3: Economic Sectors and Impacts

Our study examines the effects of low water levels and mitigating structures on four sectors:

» Commercial shipping and harbours
» Tourism and recreational water activities
» Waterfront properties
» Hydroelectric generation

This section briefly describes these sectors (see our *Low Water Blues* report for more details[45]). It also estimates the costs that these sectors would bear in the event our low water level scenario is realized.

Our estimates are mostly limited to lakes Michigan-Huron and Erie. An exception is hydroelectric generation. Here, we focus on plants located on the Niagara River, the facilities most likely to be affected by a temporary decrease in Lake Erie levels.[46]

We focus on these bodies for three reasons. First, Michigan-Huron and Erie are the only Great Lakes not subject to regulation of their outlet flows (lake Michigan-Huron levels are moderated in an indirect and limited way by dams on the St. Marys River,[47] while Lake Erie is not regulated at all). Second, our data comes from public cost estimates and these estimates are limited to structures targeting Lake Michigan-Huron. Third, restoration on Michigan-Huron would temporarily lower water levels downstream, creating costs on several bodies, including Lake Erie and the Niagara River.

We should, in theory, extend our analysis to other lakes and rivers downstream, including the St. Lawrence River, as restoration would affect these bodies as well. However, we lack the economic impact and simulated river flow data to do so.

Note that while our sectoral analysis largely follows *Low Water Blues*, sectoral impact values in the present report differ from those in that earlier report for two reasons. One, sectoral impact values in *Low Water Blues* were calculated at a region-wide level in part by using region-level data that cannot be separated at the lake-by-lake level. Since we need this separation to capture the differential effects of restoration on lakes Michigan-Huron and Erie, the present report calculates only those adaptation costs that can be separated at the lake-by-lake level.

Two, the necessary methodological adjustments described in section 2.1.4 also affected impact values in the present report. These adjustments increased the total impacts in sectors for which impact calculations were estimated on a yearly basis (e.g. for hydroelectric producers) as each additional year of low water levels increases the total impact to the sector. However, it decreased total impacts in sectors for which impact calculations were estimated over the entire time horizon based on the final year's water level (e.g. residential property owners.[48]

45 Shlozberg et al., 2014.
46 Plants on the St. Lawrence River would also be affected, but we lack the data necessary to study these effects.
47 Since 1979, plans to regulate Lake Superior have incorporated interests both upstream and downstream from key regulatory structures (these structures are located on the St. Marys River, the channel connecting lakes Superior and Michigan-Huron). Before making a decision to release water from Lake Superior, regulators observe, at the start of each month, water levels on Superior and Michigan-Huron. If levels on Superior are slightly above their long-term average and levels on Michigan-Huron are slightly below, then regulators release more water from Lake Superior than they otherwise would to bring levels on both lakes closer to their long-term averages. Michigan-Huron flows are not, however, regulated downstream at the St. Clair River, which explains why it is more vulnerable to extreme lows than lakes regulated both upstream and downstream (i.e., Superior and Ontario).

48 By keeping the same water level projection and adding 12 years to the time horizon, the average annual impacts decline for sectors that calculate impacts for the entire timeframe, which leads to a significantly lower NPV. When the impact calculations are estimated yearly, this simply means 12 more years of additional impacts.

3.1 Commercial shipping and harbours

Valued at $5.8 trillion USD in 2014, the Great Lakes and St. Lawrence Region would, if it were a country, constitute the third largest economy in the world behind the United States and China.[49] It is hard to imagine this level of economic activity if not for the 2,300 miles (3,700 kilometers) of marine highway stretching from the Atlantic Ocean to the far shores of Lake Superior. According to the St. Lawrence Seaway Corporation, the seaway sustains annually 227,000 jobs in the US and Canada and saves $3.6 billion in transportation costs compared to the next least expensive mode of transportation.[50]

In general, lower water levels harm shipping interests. Most ships in the region are designed to carry as much cargo as possible at existing depths. A sharp decline in water levels would increase the risk of vessels running aground. Shippers would have to take measures — including reducing speeds and cargo loads — to keep under-keel clearances (or the distance between the lowest part of the hull and the bottom of the river or lake) above legal minimums. In the short term, this would mean more and longer trips to ship a given amount of cargo. In the long term, it could require modifications and expansions of existing fleets.[51]

49 Kavcic, 2015.

50 Saint Lawrence Seaway Development Corporation, 2011.

51 IUGLS, 2012: 27.

Data constraints prevent us from estimating the full range of costs of low water levels for this sector. Accordingly, we focus on two outcomes: (1) the costs of lost carrying capacity, which are borne by shippers and (2) infrastructure and maintenance costs, which are borne by ports, taxpayers and the maritime industry.[52]

In keeping with our focus on direct impacts, we do not consider the potential benefits of higher shipping costs for the rail and trucking industries. We do not see this as a problem, however, as it is still cheaper to transport bulk commodities by water, even under our low water level scenario.

Ports and harbours would also suffer. Shallow waters expose wooden dock supports to air and cause dry rot, increasing maintenance costs. They also slow or obstruct traffic in and out of harbours, necessitating maintenance and, in some cases, capital dredging. Busier ports could cause additional delays for shippers, though they could also boost short-term revenues for ports.[53]

Assuming a 50-year time horizon, the total estimated cost of our low water level scenario for shipping and harbours is roughly $2 billion. That estimate comes from an estimated $42.9 million in harbour maintenance costs on Lake Michigan-Huron; $48 million in harbour maintenance costs on Lake Erie; $1 billion to replace lost carrying capacity on Lake Michigan-Huron; and $839 million to replace lost carrying capacity on Lake Erie.

52 In Canada, 19 ports are managed and maintained by federal authorities. The remaining facilities are managed by private companies and provincial and municipal governments. The maritime industry pays for maintenance and dredging on the St. Lawrence River. Governments cover, through general revenues, the remaining costs along the GLSL Seaway. In the US, private companies manage some commercial ports, but most are managed by public port authorities established by state and local governments. Maintenance and dredging is the responsibility of the United States Army Corps of Engineers. Funding for 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 (Marine Delivers, n.d.; Shlozberg et al., 2014).

53 Shlozberg et al., 2014. Extremely high water levels are also costly (they can disable loading facilities and make it harder to safely operate navigation locks) but low levels are – generally speaking – costlier.

3.2 Tourism and recreational water activities (marinas)

Coastal tourism is a major component of the GLSLS economy. According to the IUGLS, in the areas bordering the Upper Great Lakes alone, visitor tourism in 2007 was responsible for $55 billion to $60 billion USD in direct spending and supported over 650,000 jobs.[54]

In *Low Water Blues*, we estimated the impacts of low water levels on three outcomes: (1) spending on sport fishing; (2) lost revenues to marinas from lost slips; and (3) boating days, which affects spending on trips, equipment, boats and boat maintenance.

We are unable to estimate the costs of lost boating and fishing days in this report. The first report used aggregated data for the GLSLS and calculated the costs of lost days as a linear function of water levels (we assumed each lake would experience the same decline in levels at any given point). This approach is not viable in this report, however, because we want to capture the variable impacts of restorative structures on two lakes: Michigan-Huron and Erie.

As a result, our calculations here are restricted to those adaptation costs that can be separated on a lake-by-lake level, namely additional harbour dredging and lost rental income from stranded slips. Notably, this represents a small segment of the region-wide impact values reported for this sector in *Low Water Blues*, the bulk of which came from lost boating and fishing days.[55]

We do not think the effect of these changes alters our general conclusions regarding the viability of restoration options. In *Low Water Blues* we estimated the cost of low water levels on GLSLS recreational boating trips and spending at roughly $11 billion 2012 USD (Shlozberg et al., 2014). This is not a trivial value, but it is not a massive value either given our 38-year, 2012 to 2050, time horizon. Also note that restoration would mitigate some — but not all — of these costs under our worst-case low water level scenario.

Assuming a 50-year time horizon, the total estimated cost of additional dredging and lost rental income from stranded slips under our low water level scenario is roughly $5.5 million ($4.1 million for Lake Michigan-Huron and $1.4 million for Lake Erie).

3.3 Hydroelectric generation

The GLSLS is a major producer of hydroelectric power. Hydroelectricity accounts for about a seventh of the region's net generation, but it is a more prominent source of power in Ontario (25 per cent), New York State (19 per cent) and Quebec (98 per cent) (though most of Quebec's hydroelectric generation comes from Northern Quebec and Labrador, not the St. Lawrence River).[56] It is also an important source of power for northern Michigan and northeastern Wisconsin.

Although hydroelectric dams can have negative ecological and social impacts, those impacts are usually subject to environmental assessment and screening by regulators. Hydroelectric generation also has a number of advantages over other energy sources. Hydroelectric stations do not emit carbon dioxide, generally last much longer than other generation sources[57] and do not require any fuel inputs other than water. They can also be dispatched in periods of high electricity demand and backed off in periods of low demand.

54 IUGLS, 2012: 34.

55 In addition, we refined our *Low Water Blues* methodology to enable us to estimate the potential benefits of different restoration options, as explained in Appendix 2 section A2.2. This change further lowered the adaptation costs and impact values calculated in the present report from those calculated in *Low Water Blues*.

56 These figures are averages for 2008 to 2014. American data come from the US Energy Information Administration and the authors' calculations. The Canadian data come from Statistics Canada (Cansim Table 127-0002) and the authors' calculations. The data were downloaded on March 16, 2015.

57 A hydroelectric dam can last as long as a century (IEA, 2010).

Future demand for hydroelectricity, and for that matter electricity, is uncertain. Population growth and public opposition to greenhouse gas emissions may increase demand for renewable non-emitting sources.[58] However, more efficient energy consumption may reduce the overall demand for electricity and hydroelectricity along with it.

Low river flows and water levels impose potentially serious costs on hydroelectric producers and customers. Production depends on the amount of water available for reservoirs and rivers and the head — or difference between upstream and downstream water levels — at hydro dams. Generally, lower water levels mean less head, which results in less hydroelectric generation. According to the IUGLS, "drought, or any event that threatens the long-term, reliable supply of water, is the greatest risk to hydroelectric generation interests."[59]

Extremely high water levels are also costly, though not nearly as costly as low water levels.[60] They can cause flooding by forcing producers to spill excess water from rivers and reservoirs;[61] increasing the need to open and close gates; threatening the structural integrity of dams (though dams are generally designed to withstand floods); and increasing the risk of erosion of power canals and the channels that carry water away from turbines.[62]

We calculate — for every foot drop in water levels — the cost of replacing hydroelectric production with natural gas, the most commonly used source of comparably dispatchable electricity. Our analysis is limited to facilities on the Niagara River. We use water levels on Lake Erie as a proxy. We use data from Buttle and his colleagues[63] to estimate the replacement costs per foot loss in water levels for the three Adam Beck facilities (Adam Beck 1 and 2 and the Adam Beck Pump Generation Station) and extrapolate this estimate to the US facilities on the Niagara River, namely the Robert Moses and Lewiston plants.

Assuming a 50-year time horizon, the total estimated cost of replacing lost hydroelectric generation on the Niagara River under our low water level scenario is $6.2 billion.

58 IUGLS, 2012: 28.
59 IUGLS, 2012: 29.
60 IUGLS, 2012: 29.
61 High water levels only increase production up to a certain threshold determined, among other things, by the size of reservoirs (in conventional facilities) and demand for energy. Beyond that threshold, the facility must spill surplus water from the reservoir (IUGLS, 2012: 29).
62 These channels are known as tailraces.
63 Buttle et al., 2004.

Low water levels undermine property values in several ways: they limit access to piers, boat launches and beaches; diminish properties' aesthetic appeal; expose piers and boat launches to dry rot; and undermine tourist and other economic activities in surrounding areas.[64] High water levels also cost property owners: they erode shorelines; damage shoreline structures; limit access to boat launches, piers and beaches; flood homes and cottages; and increase the costs of flood insurance.

64 Georgian Bay Forever estimates that the 10,000 cottages along the eastern and northern shores of Georgian Bay contribute over $100 million CAD to the region's local economies (these estimates were provided to us by Georgian Bay Forever).

3.4 Waterfront properties

In the spring of 2013, *The Globe and Mail* published a series of then-and-now photos of shoreline properties in the Georgian Bay area.[65] The photos revealed sharp declines in water levels from the 1970s, 1980s and 1990s and the rock, mud and stranded docks and shorelines left in their wake. The effects on property values were unmistakable: these were clearly less desirable places to vacation and live (though their desirability may have increased with the recent rise in water levels).

But the threat of low water levels to Great Lake properties is uneven. It is highest for property with relatively flat foreshore slopes on Georgian Bay, where water levels have — on account of isostatic rebound and the increased conveyance capacity of the St. Clair River — seen the sharpest declines.[66] It is lowest along the southern shores of lakes Michigan and Ontario where high — not low — levels are the biggest threat.[67] Indeed, it is possible that property values on the sandy, erodible shore of Lake Michigan benefited from low levels from 1999 to 2013.

We estimate the impact of water levels on property values using data on residential waterfront properties in Ontario municipalities located on Great Lake shores (Section A2.4 in Appendix 2 describes our regression analysis). It is possible our estimates are conservative. Our regression sample does not include negatively affected properties outside of Ontario.[68] Nor do we include future waterfront developments, which, according to the IUGLS, are likely to be extensive.[69] But it is also possible that our estimates are liberal. Our regression does not include property values along the southern shores of Lake Michigan, which may actually benefit from low water levels.

Assuming a 50-year time horizon, the total estimated cost of our low water level scenario for property values is $535 million: roughly $412 million for Lake Michigan-Huron and roughly $123 million for Lake Erie.

65 Baic and Whetstone, 2013.
66 A report commissioned by municipalities in the Georgian Bay area estimates that property values dropped 25 per cent during the recent low-water period (Case Brook, 2013: 44).
67 Shlozberg et al. 2014.
68 Of the roughly 90,000 properties along the shores of the upper great lakes, only 29,700 are located in Canada (IUGLS, 2012: 31).
69 The IUGLS expects private and public-sector interests to develop the entire shoreline of Lake Michigan-Huron, with the exception of Georgian Bay, over the next 50 years (2012: 31).

3.5 What we do not quantify

Our analysis does not capture the full range of actors or sectors affected by water levels. Omissions reflect data and methodological constraints, not a lack of concern for these outcomes. Notably, our analysis neglects:

- Municipal and industrial water users
- Recreational boaters and fishers
- Native Americans and First Nations
- Ecological services
- Hydroelectric generation on the St. Lawrence River

Note that the first two groups — municipal and industrial water users and recreational boaters and fishers — were included in our first report. They are excluded here because we were unable to separate their adaptation costs on a lake-by-lake basis, as explained earlier. For the reasons noted in section 3.2, we do not think the effect of these changes alters our general conclusions regarding the viability of restoration options.

Ideally, we would also include First Nations and Native American Tribes, but we lack data on revenues from wild rice harvests, tourism, commercial and subsistence fishing and other sectors of indigenous economies.[70] We also recognize that indigenous concerns transcend simple economic analysis and cannot, therefore, be fully captured by our quantitative approach.[71]

The GLSLS also provides a number of ecological services. Many of these — including fish for commercial and recreational sport fisheries, waterfowl and ecotourism — serve vital economic functions. Others — including clean drinking water, biodiversity and air and water filtration — are not strictly economic. Ideally, we would assign dollar values to these impacts, but we cannot do so for two reasons. First, the relationship between water levels and ecological services is more complicated than the linear relationship we assume for other sectors. Sustained highs and lows have negative consequences,[72] but so do narrow fluctuations (recall the consequences of Lake Ontario's aggressive regulation plan). This makes our standard approach — estimating a constant cost per foot drop in water levels — absurd. A more complex cost function — one capable of capturing the benefits of cyclical fluctuations — is needed.

Second, many, if not most, ecological services are not bought and sold in markets, leaving us without prices to measure their effects. Granted, methods of valuating nonmarket effects are available. We could, for example, have asked people how much they are willing to pay to protect various services under various conditions. But this approach, known as a contingent valuation surveying, was beyond the scope of our analysis.[73]

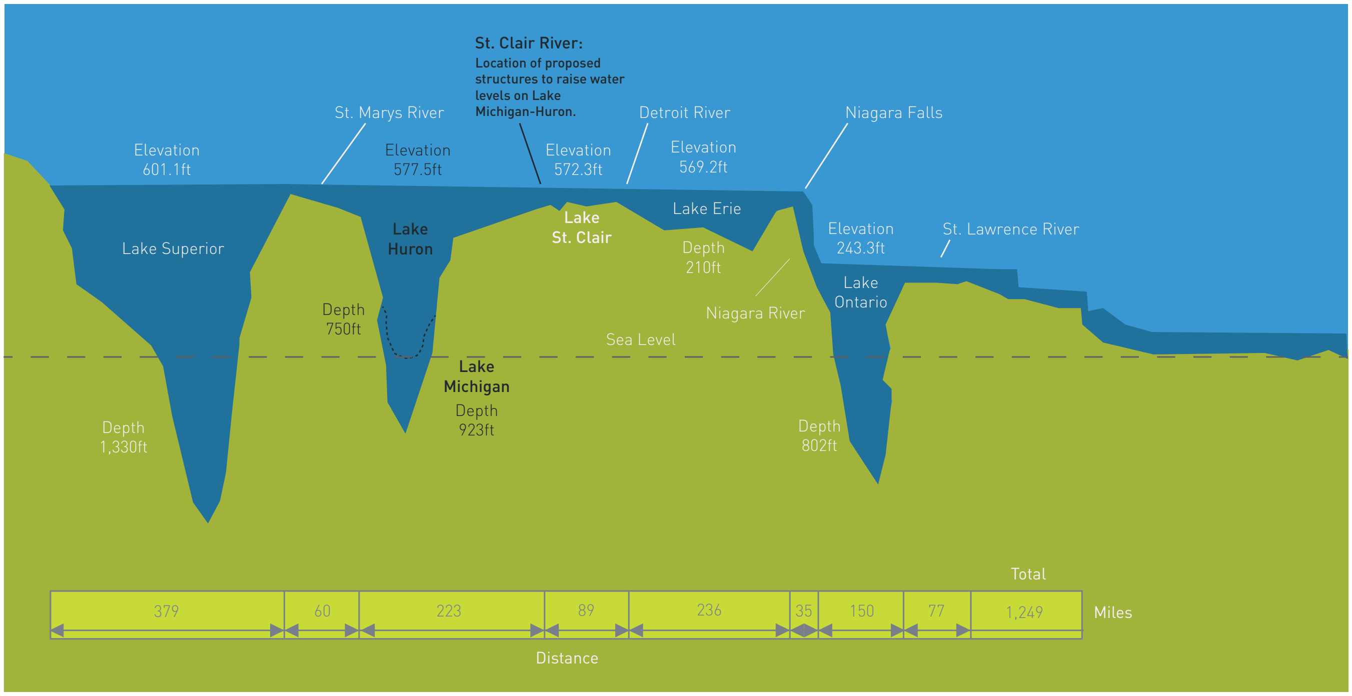
Assuming a 50-year time horizon, the total estimated cost of our low water level scenario for shipping and harbours is roughly $2 billion.

70 The impacts of low water levels on deep-water fishing are unknown. They would, however, have costs for groups reliant on wetland-spawning and shallow-water species (Shlozberg et al., 2014).
71 First nations and tribal groups use the region's natural resources to meet a variety of economic, cultural and spiritual needs. They also view the earth, including its water resources, "as an interconnected ecosystem, where human life is part of and not separate from that ecosystem, and where people have strong intergenerational connections both to the past and the future" (IUGLS, 2012: 36). This relationship belies quantification.

72 Extreme lows, for example, increase green algae growth in shallow waters (Cattaneo et al., 2013); threaten wetland vegetation and the fish species that feed on it (Mortsch, 1998); and make GLSLS waterways more susceptible to invasive species, such as phragmites (Kling et al., 2003).
73 It is clear that residents of the GLSLS value ecological services. It is evident in the advocacy of ecological groups, including The National Wildlife Federation, Ducks Unlimited, Great Lakes United, the Nature Conservancy and the Nature Conservancy of Canada. It is also evident in environmental laws and regulation.

Part 4: Restoration

FIGURE 4.1 Cross-section of Great Lakes-St. Lawrence River System



Note: Diagram adapted from Michigan Sea Grant

Low water levels impose a number of costs. It is possible to alleviate these costs by adjusting water levels with engineering structures. These options fall under three categories: restorative options designed to permanently increase water levels; regulative structures designed to raise and lower water levels, within limits, according to regulation plans; and hybrid or semi-restorative structures that combine restorative and regulative features. Our quantitative analysis focuses on restorative and hybrid options.

In theory, restoration could refer to any effort to raise or lower water levels to what they would have been in the absence of human intervention or natural events.[74] But among GLSLS observers, it typically refers to proposals to raise Lake Michigan-Huron levels.

As section 2.1.2 explains, the focus on Lake Michigan-Huron is partly technical. It was the hardest hit of the Great Lakes during the latest low-water spell and arguably in the greatest need, therefore, of restoration. But the focus is also political. Water levels would not have fallen as low as they had if not for dredging of the St. Clair River in the 1930s and 1960s.[75] This increased the river's navigability, but at the expense of property owners and ecological interests in Georgian Bay. Not surprisingly, residents in this area have been vocal proponents of restoration, though some groups, including Georgian Bay Forever, prefer multi-lake regulation. Restoration also has its fair share of critics, however, including residents of the flood-prone shores of southern Lake Michigan.

Figures 4.1 and 4.2 visualize the location and effects of the interventions. Figure 4.1 is a cross-section of the GLSLS, showing water flowing downstream from Lake Superior to the Atlantic Ocean. Although unique, each option would affect water levels in the same basic way: they would raise levels in Michigan-Huron by impeding water as it flows downstream from Lake Huron and through the St. Clair River. The structures would also temporarily restrict flows into lakes Erie, St.

74 IUGLS, 2012: 8.

75 IUGLS, 2009.

FIGURE 4.2 Location of restoration options

1 Submerged sills in the upper St. Clair River

2 Parallel dikes and weirs extending into Lake Huron

3 Fixed rock-filled dikes and adjustable inflatable flap gates across east channel at Stag Island

4 Fixed rock-filled dikes and adjustable inflatable flap gates across east channel at Fawn Island

Note: Diagram adapted from Bruxer (2011)

Clair and Ontario and the Niagara and St. Lawrence rivers. This would temporarily low water levels, creating costs on these bodies. Figure 4.2 shows where four of the five structures would be located. We discuss each in more detail below.

The goal of this section is twofold: to assess whether these options are economically and politically viable. The economic analysis is largely quantitative. It compares the benefits of raising water levels on Michigan-Huron against two sets of costs: the costs of temporarily lowering water levels on Lake Erie and the Niagara River and the costs of building, maintaining and operating engineering structures. The political analysis is qualitative. It identifies the redistributive tensions surrounding these options and whether these tensions, which decrease the likelihood of intervention, can be eased.

4.1 Quantitative analysis

We estimate the impacts of five sets of options: (1) sills, (2) fixed rock-filled dikes, (3) parallel dikes and weirs, (4) inflatable flap gates and (5) hydrokinetic turbines. All five would be located in or near the St. Clair River — the channel connecting lakes Huron and St. Clair — and all five would raise water levels on Lake Michigan-Huron by restricting the conveyance capacity of the St. Clair River (see Figure 4.2). These options are not new: all have been studied in the IUGLS[76] and elsewhere. But our study is the first to quantify their direct economic impacts across a wide range of sectors.

76 IUGLS, 2012.

TABLE 4.1 Estimated costs and restoration levels for sills (figures expressed in millions of 2012 USD)

Cost/Benefits	Option A	Option B	Option C	Option D
Restoration level	6 cm	21 cm	8 cm	23 cm
Construction	10.74	57.90	34.30	182.80
Non-construction	1.57	7.43	3.94	20.03
Construction time	18 months (our assumption)	18 months	18 months (our assumption)	31 months

Note: Options A and B use type 4 sills, whereas options C and D use type 11 sills. See Bruxer (2011) for descriptions of these types.

TABLE 4.2 Estimated net present value for sills (figures expressed in millions of 2012 USD)

Adaptation option	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
6cm	3.46	70.85	-5.21	31.84
21cm	190.94	233.51	50.82	121.83
8cm	-16.39	80.54	-31.86	38.36
23cm	85.00	173.51	-61.71	96.54

Note: 4 per cent discount rate.

Before proceeding, a caveat: readers ought to pay particular attention to our analysis of sills. It is more extensive than our analysis of other options for two reasons. First, sills are, according to our estimates, the most viable option. Second, their impacts do not differ significantly from those of other structures (most options have similar effects across lakes, sectors and policy scenarios).

4.1.1 Sills[77]

Sills are simple stone or stone and concrete structures that operate as “speed bumps” on the bottom of the connecting channel. Sills would raise water levels in Michigan-Huron by obstructing flows as they head downstream.[78]

The ideal location for sills is the upper St. Clair River. This is the narrowest and fastest portion of the river and is, therefore, where sills would exert their maximum effect. It is also the deepest portion of the channel, ensuring they would not interfere with shipping and other forms of navigation.

The level of restoration depends on the size, number and location of sills. Any number of combinations could be analyzed. We analyze four of eleven promising combinations studied by Franco and Glover.[79] Their simulation is still considered the most comprehensive[80] and Frost and Merte[81] recently estimated the costs of building their proposals.

The combinations and their estimated costs and restoration levels appear in Table 4.1. The full or eventual impacts on Michigan-Huron water levels range from 6 centimeters for combination A to 23 centimeters for combination D. Option A would cost $10.7 million to build. Option D would cost $182.8 million.[82]

77 The sections on sills and other options draw heavily on Bruxer (2011) and Froste and Merte (2011).

78 More technically, they would raise water levels by “restricting channel conveyance and raising upstream water levels by reducing the channel cross-sectional area and increasing the river bed roughness” (Bruxer, 2011: 5).

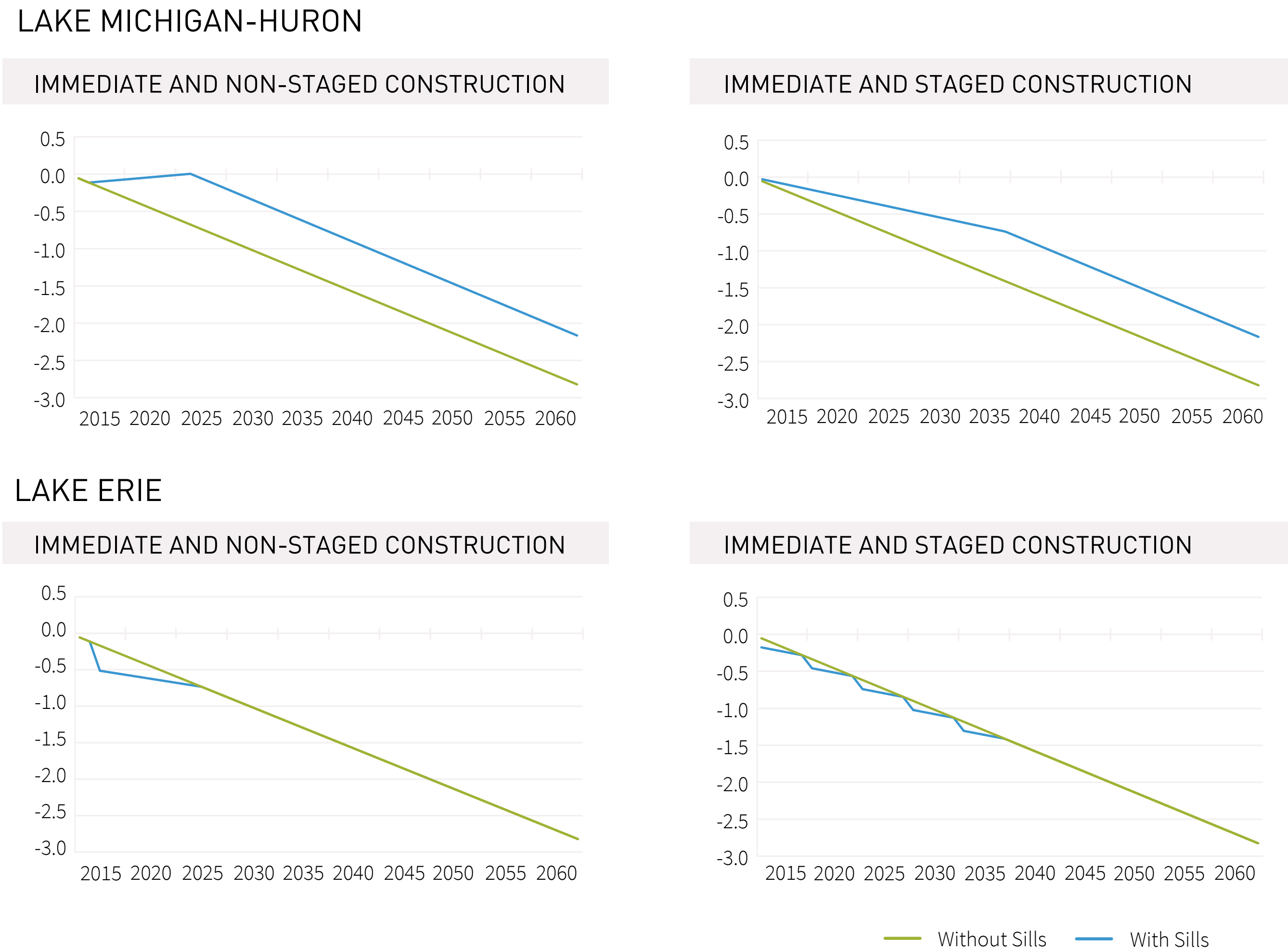
79 Franco and Glover, 1972.

80 Bruxer, 2011.

81 Frost and Merte, 2011.

82 CAD values for tables 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 and 4.10 are provided in Appendix 1.

FIGURE 4.3 Impact of sill combination B on Michigan-Huron and Erie water levels



Note: The blue line refers to water levels under our base-case low-water level scenario.

The literature[83] estimates construction times for options B and D, but not options A and C. We assume options A and C, like option B, would take 18 months to build.

As with all of our restoration scenarios, we consider four policy scenarios (immediate construction in stages; delayed construction in stages; immediate construction in one stage; and delayed construction in one stage).

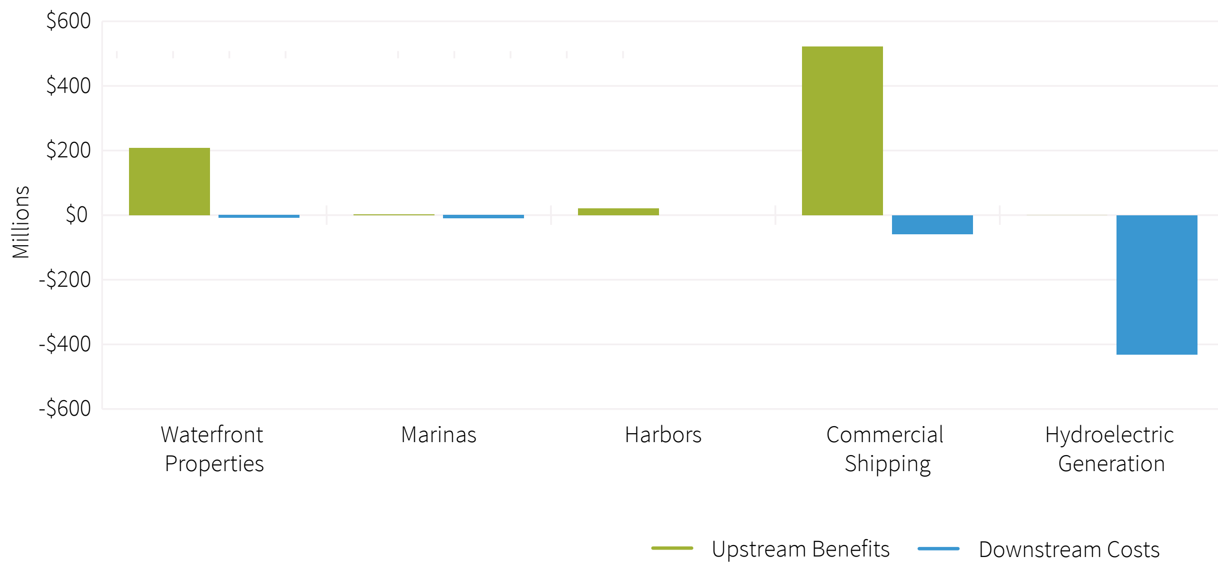
The structures involve a mix of costs and benefits. They would raise water levels on Michigan-Huron, thus benefiting interests on this lake. But they would temporarily lower water levels on downstream bodies, including Lake Erie, thus costing interests on these bodies.

83 Frost and Merte, 2011.

The plots in Figure 4.3 display the impacts of sill combination B on both lakes. In each plot, construction begins immediately. However, in the plots on the left, it occurs in a single stage. In the plots on the right, it occurs in five. In both cases, effects take time to ramp up. In the staged scenario, this ramping-up process begins immediately and proceeds, in a linear fashion, over five years for each of the five stages. In the non-staged-scenario, it is delayed and proceeds, in a linear fashion, over 10 years.[84] Non-staged effects take longer to begin and ramp up, because of the additional time required to build, and realize the effects of, a larger numbers of sills.

84 We assume small stages take no time to build. We could have assumed a small number of months for construction, but this would have had virtually no impact on our overall results.

FIGURE 4.4 Costs and benefits for sill combination B (21 cm) if construction is not staged and begins immediately (figures expressed in millions of 2012 USD)



Note: Bars do not account for the full range of costs and benefits for a given sector. See section 3 and Appendix 2 for details.

Two other differences between staged and non-staged construction deserve mention. First, staging reduces the cumulative difference between sill and non-sill projected water levels on Michigan-Huron, thereby reducing potential benefits upstream. The total difference, over 50 years, is 3.8 feet. Second, staging also reduces the cumulative difference between sill and non-sill projected water levels on Erie, thereby reducing potential costs downstream. The total difference, over 50 years, is about 0.5 feet.

Recall that delaying construction does not, under our analysis, affect the number of years structures are in place. That is because we extend the time horizon of our delayed scenario by 20 years. The delay does, however, affect our estimates. It pushes the costs and benefits of restoration into the future, where they are more heavily discounted.

We now turn to dollar impacts. Table 4.2 contains results for 16 scenarios (four sill combinations by four construction scenarios). Two findings stand out. First, the optimal scenario, according to our estimates, is staged and immediate construction of combination B, which would eventually raise water levels by 21 centimeters or 8.27 inches a year.[85] This would yield a positive net benefit of $234 million. The value falls to $122 million, however, if construction is delayed by 20 years. Tables A5.1 and A5.2, which appear in Appendix 5, report the results of our sensitivity analyses. If we apply a more conservative discount rate of 6 per cent, then the impacts of combination B fall to $78 million in the staged-immediate scenario. It is $33 million if construction is staged and delayed. If we use a 2 per cent discount rate, then these figures increase to $552 million and $396 million, respectively.

The second major finding is that it is better to build in stages. This is, perhaps, surprising, as staging reduces gains for interests on Lake Michigan-Huron. But this reduction is more than offset by gains to hydroelectric producers on the Niagara River. The dollar loss per foot drop in water levels is higher for hydroelectricity than it is for major sectors (e.g., commercial shipping) on Lake Michigan-Huron.

85 Combination D would increase water levels more, but its construction costs are considerably higher.

TABLE 4.3 Estimated costs and restoration levels for fixed rock-filled dikes (figures expressed in millions of 2012 USD)

Cost/Benefits	Option A: Stag Island	Option B: Fawn Island
Restoration level	16cm	5cm
Construction	105.20	71.78
Non-construction	13.33	9.19
Construction time	34 months	23 months
Operation and maintenance	0.80	0.80
Sill costs	52.52	52.52
Sill construction time	16 months	16 months

Source: Bruxer, 2011.

TABLE 4.4 Estimated net present value for fixed rock-filled dikes (figures expressed in millions of 2012 USD)

Adaptation option	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
16cm	99.99	224.52	40.31	109.14
5cm	-113.39	-13.59	-56.75	-6.28

Note: 4 per cent discount rate.

Figure 4.4 provides a breakdown of impacts by lake and sector for the immediate, non-staged construction scenario. Benefits (or the green bars) refer exclusively to Michigan-Huron. Costs (or the blue bars) refer exclusively to Lake Erie and the Niagara River (the channel connecting lakes Erie and Ontario). As Figure 4.4 reveals, the cost-benefit equation is dominated by benefits to shippers ($522 million) and property owners ($208 million) on Michigan-Huron and costs to hydroelectric producers ($431 million) on the Niagara River.

4.1.2 Fixed rock-filled dikes in the eastern channels of Stag Island and Fawn Island

Our second restoration option is laying fixed rock-filled dikes across the eastern channels of two islands — Stag and Fawn — in the St. Clair River. These structures would raise water levels by limiting downstream flows to the islands' western channels.

Table 4.3 displays the estimated costs and restoration levels of the Stag and Fawn structures. We analyze the structures individually. The Stag Island structure would cost $105.2 million to build, with an additional $13.3 million in non-construction costs. The Fawn Island structure would cost $71.8 million to build, with an additional $9.2 million in non-construction costs.

The Stag option is expected to take 34 months to complete. The Fawn option is expected to take 23 months.

In contrast to sills, dikes involve operation and maintenance costs. These costs are estimated at $0.8 million per year for both structures.

The weirs would increase the velocity of flows along the islands' western channels. As Bruxer notes, this may result in erosion and expansion of the channels, which would necessitate sills or other structures to mitigate these effects. Thus, following Bruxer, we include costs and

TABLE 4.5 Estimated costs and restoration levels for dikes and weirs (figures expressed in millions of 2012 USD)

Cost/Benefits	
Restoration level	16cm
Construction	138.70
Non-construction	17.55
Operation and maintenance	NA
Construction time	30 months

Sources: Bruxer, 2011; Frost and Merte, 2011.

TABLE 4.6 Estimated net present values for parallel dikes and weirs (figures expressed in millions of 2012 USD)

Adaptation option	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
16cm	32.44	177.29	9.75	87.53

Note: 4 per cent discount rate.

construction times for 150 rock sills.[86] These sills are expected to cost $52.5 million and to take 16 months to install.

The Stag Island structure is expected to raise water levels the most: 16 centimeters or 6.23 inches compared to five centimeters or 1.97 inches for the Fawn Island structure. As with sills, weirs are also expected to have negative downstream effects on Lake Erie.

The main results appear in Table 4.4. Additional details appear in Table A3.2 of Appendix 3. All of the Stag structures generate positive net benefits. As with sills, the highest estimated benefits come from staged construction beginning immediately, which yields an estimated $225 million, just $9 million shy of the estimate for sills. If staged construction is delayed 20 years, this figure falls to $109 million. None of the Fawn Island structures are viable.

The distribution of impacts across groups and lakes does not differ significantly from the distributions for sills (or any other intervention): property owners and shippers on Lake Michigan-Huron would benefit most; hydroelectric generators on the Niagara River would lose the most.

4.1.3 Parallel dikes and weirs in Lake Huron

A third restorative option is dikes and weirs in Lake Huron. These structures would raise water levels by narrowing the lake's outlet at the St. Clair River and extending this narrowed passage into the lake (see Figure 4.2).[87] The proposed structures would be approximately a mile (1,500 meters) in length and would be made of cement. Moore's proposal, described by Bruxer, calls for weirs to connect the dikes to the land surrounding the St. Clair outlet.

As Bruxer notes, Moore's proposals, which were developed in the 1930s, were not designed to deal with a number of changes in the channel, including the increased probability of structures increasing flow velocities.[88] Unfortunately, we do not have cost estimates of structures to mitigate these effects.

Table 4.5 reports estimated restoration levels and construction costs. There is no simulated estimate of the structure's effect on water levels.

86 Bruxer, 2011: 18, 20.

87 Bruxer, 2011: 11.

88 Bruxer, 2011: 11.

TABLE 4.7 Estimated costs and restoration levels for inflatable flap gates (figures expressed in millions of 2012 USD)

Cost/Benefits	Low estimate	High estimate
Restoration level	16cm	16cm
Construction	119.27	151.99
Non-construction	15.08	19.14
Operation and maintenance	0.80	1.00
Construction time	Unknown	Unknown
Sill costs	Not necessary	52.52
Sill construction time	Not necessary	16 months

Source: Bruxer, 2011.

TABLE 4.8 Estimated net present values for inflatable flap gates (figures expressed in millions of 2012 USD)

Adaptation option	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
16cm high cost	52.82	189.74	9.85	87.64
5cm	-30.30	134.33	4.65	75.15

Note: 4 per cent discount rate.

Moore assumed, however, it would be roughly 16 centimeters or about 6 inches. Like Bruxer, we use this assumption. The United States Army Corps of Engineers Detroit District[89] estimated total construction and non-construction costs at approximately $156 million USD. It also estimated that the structures would take 30 months to build.

The results appear in Table 4.6 and, in more detailed form, in Table A3.3 in Appendix 3. When we apply a four per cent discount rate, positive net benefits range from $10 million in the non-staged and delayed construction scenario to $177 million in the immediate and staged scenario.

4.1.4 Inflatable flap gates at Stag Island and Fawn Island

We now turn to hybrid options. But before we do, a caveat: it is possible our low water level scenario underestimates the benefits of these interventions. The main advantage of these options over strictly restorative structures is the ability to reverse restoration in the event of high water levels. But this benefit is potentially offset by two factors: the effects of hybrids are not immediately reversible (they take time to fully dissipate) and the very necessity of reversals — while beneficial to flood-prone areas — negates much of their positive impact.

The first hybrid structures are inflatable flap gates in the eastern channels of Stag Island and Fawn Island. The proposed gates would consist of metal and would rest on concrete foundations until raised by compressed air. The raised structures would increase water levels by obstructing water as it flows downstream. Regulators could deflate the gates to reverse their effects. It would take several years, however, for inflated gates to realize their full impact, just as it would take several years for the effects to dissipate once gates are deflated.

Table 4.7 contains costs and restoration estimates under low- and high-cost scenarios. Estimated construction times are unavailable.

The scenarios are expected to exert identical restorative effects: 16 centimeters or roughly 6 inches. However, option B involves higher construction, non-construction and operation and maintenance costs.

89 Frost and Merte, 2011.

TABLE 4.9 Estimated costs and restoration levels for hydrokinetic turbines (figures expressed in millions of 2012 USD)

Costs/Benefits	56 Turbines	151 Turbines
Restoration level	9cm	19cm
Construction	179.60	345.4
Non-construction		
Operation and maintenance	Unknown	Unknown
Construction time	Unknown	Unknown
Power Production	1.3MW	2.5MW

Note: Option A refers to the 56-turbine scenario. Option B refers to the 151-turbine scenario. Construction values were estimated from Kumar and Saini and are based on projects comparable to the Verdant RITE project, which uses turbines similar to those proposed in the IUGLS. No currency or year were given for construction cost estimates. The authors assumed they were priced in 2012 USD.

Source: IUGLS, 2012; Kumar and Saini, 2014; authors' calculations.

TABLE 4.10 Estimated net present values for hydrokinetic turbines (figures expressed in millions of 2012 USD)

Adaptation option	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
19cm	-54.30	125.16	-27.59	68.57
9cm	-124.79	9.73	-58.41	12.43

Source: IUGLS, 2012; Kumar and Saini, 2014; authors' calculations.

Like certain fixed structures, flap gates could also increase velocities in the islands' western channels. This is only likely true of option B, however. Accordingly, we only include costs for mitigating sills for this option.

As with all interventions, we consider staged and non-staged and delayed and non-delayed scenarios, giving us a total of four construction scenarios.

The scenarios and their estimated costs appear in Table 4.8. Full results are reported in Table A3.4 in Appendix 3. Each of the low-cost scenarios generates positive net benefits. They range from $10 million for non-staged construction with a 20-year policy delay to $190 million for immediate and staged construction.

4.1.5 Hydrokinetic turbines

The second hybrid option is hydrokinetic turbines. In addition to raising water levels, turbines have the added benefit of generating hydroelectric power. Hydrokinetic turbines are similar to large freestanding windmills, but harness the current of the river, rather than wind, to generate electricity. It is possible to halt the turbines if water levels rise, but as with flag gates, it would take time for their effects to dissipate.

The ideal location for turbines is the upper St. Clair River, where they can take advantage of strong currents to raise water levels and generate power.

We measure the value of electricity by multiplying the number of megawatt-hours (MWh) the turbines produce by the replacement cost of producing the energy. We use a natural gas plant producing power at levelized costs of $67 per MWh, the same figure we use to calculate the replacement cost of lost hydroelectric production in the Niagara region.[90]

90 This figure, which comes from the United States Energy Information Administration (2014), is the cost of replacing hydroelectric generation with natural gas generation over a 30-year period. It includes both the market price of producing natural gas and the costs of building new natural gas facilities.

Table 4.9 contains restoration estimates for two combinations of turbines in the upper St. Clair River. Unfortunately, we lack data on operation and maintenance costs, but we were able to estimate construction costs using figures for comparable projects from Kumar and Saini.[91] Note, however, that these estimates come from a demonstration project and may, therefore, be inflated.

We assume the structures would take five years to build. This estimate is based on construction times for Verdant Power's Roosevelt Island Tidal Energy (RITE) Project in New York State.

The results are summarized in Table 4.10 and, in more detailed form, in Table A3.5 in Appendix 3. If construction is staged and started immediately, combination A would yield $125 million in positive net benefits. Combination B performs significantly worse. It appears hydrokinetic turbines are the least viable of our five interventions.

4.1.6 Summary of quantitative findings

We identify a number of previously-studied structures that are capable of generating positive economic net benefits under our model assumptions. The most promising of these interventions, from a simple net benefits perspective, is a series of sills in the upper St. Clair River. If construction is staged and begun immediately, net benefits could reach $234 million over our 50-year time horizon. If, however, construction is staged and delayed 20 years (a more likely scenario), then net benefits would fall to $122 million from 2015 to 2084.

The least viable option appears to be hydrokinetic turbines. At a four per cent discount rate, they would generate $125 million if construction were staged and started immediately. This figure falls to $69 million if construction is delayed.

91 Kumar and Saini, 2014.

In general, benefits are maximized when construction is staged. As we have noted, staging reduces the cumulative annual water level increases on Michigan-Huron, limiting benefits to property owners, commercial shippers and other interest on this lake. However, it also reduces cumulative annual decreases in water losses on Lake Erie, supporting hydroelectric production on the Niagara River. Hydroelectricity is more sensitive to water level decreases than property values and shipping costs, which explains why staging is preferable.

4.2 Political feasibility

Our analysis suggests that certain restorative options would generate positive net benefits. The next question is whether cost-beneficial projects are politically viable. We think there is good reason to be skeptical. Barring a special international agreement between Canada and the United States, any application to affect water levels or flows requires the approval of the IJC, but the IJC and both governments are unlikely — for legal and political reasons — to approve projects that inflict significant harm on key interests, even if they would benefit the region as a whole.

This is a serious constraint. Water levels in the GLSLS affect countless groups. Any solution is bound to leave at least one geographic or economic interest worse off. This does not, however, mean we are stuck with the status quo, at least not in theory. If projects generate sufficient net gains, the winners can transfer a portion of their gains to losers, such that everyone is no worse off.

These payments work well in certain policy areas, including international trade negotiations. But they are not an effective means of facilitating agreements over water levels. Consider, for example, threats to flood-prone areas: all of our restorative options would permanently increase water levels on Michigan-Huron. Property owners and defenders of wetlands in Georgian Bay would welcome this outcome, but residents on the southwestern shores of Lake Michigan — who were victims of flooding in the 1980s — would not. Theoretically, interests in Georgian Bay could compensate losers for assuming added flood risk. But what would these transfers look like? And would potential losers accept such a deal?

We identify a number of previously-studied structures that are capable of generating positive economic net benefits under our model assumptions. The most promising of these interventions, from a simple net benefits perspective, is a series of sills in the upper St. Clair River. If construction is staged and begun immediately, net benefits could reach $234 million over our 50-year time horizon.

This is why hybrid options are appealing. Flap gates and hydrokinetic turbines would increase water levels — thus mitigating risks for low-water areas. But their effects are partially or fully reversible — thus mitigating risks to flood-prone areas. It would seem, therefore, that redistributive conflict is avoided.

But three problems arise. First, hybrids are partially regulative and would require regulation plans. This would involve additional planning and delays, factors that would quickly eat into the modest benefits these structures are expected to provide. Second, although their effects are reversible, they are slow to dissipate, meaning they may not provide regulators with the flexibility needed to cope with climate change.

Finally, hybrids, like strictly restorative options, pose ecological risks. They would potentially disrupt sediment transport and disturb and re-suspend contaminated sediments along the St. Clair River. What is more, the upper St. Clair River — the ideal location for sills and hydrokinetic turbines — is a spawning ground for lake sturgeon, an endangered species. The eastern channels of Stag Island and Fawn Island, the proposed sites of our remaining options, have also been identified as potential sturgeon spawning grounds.[92]

Ecological risks are even harder to manage than economic ones, because it is impossible, even in theory, to design compensating measures. Fish cannot negotiate transfers and environmental laws prevent both countries from endangering fish habitats. Proponents would likely need, therefore, to convince governments that structures pose little or no environmental risk.[93]

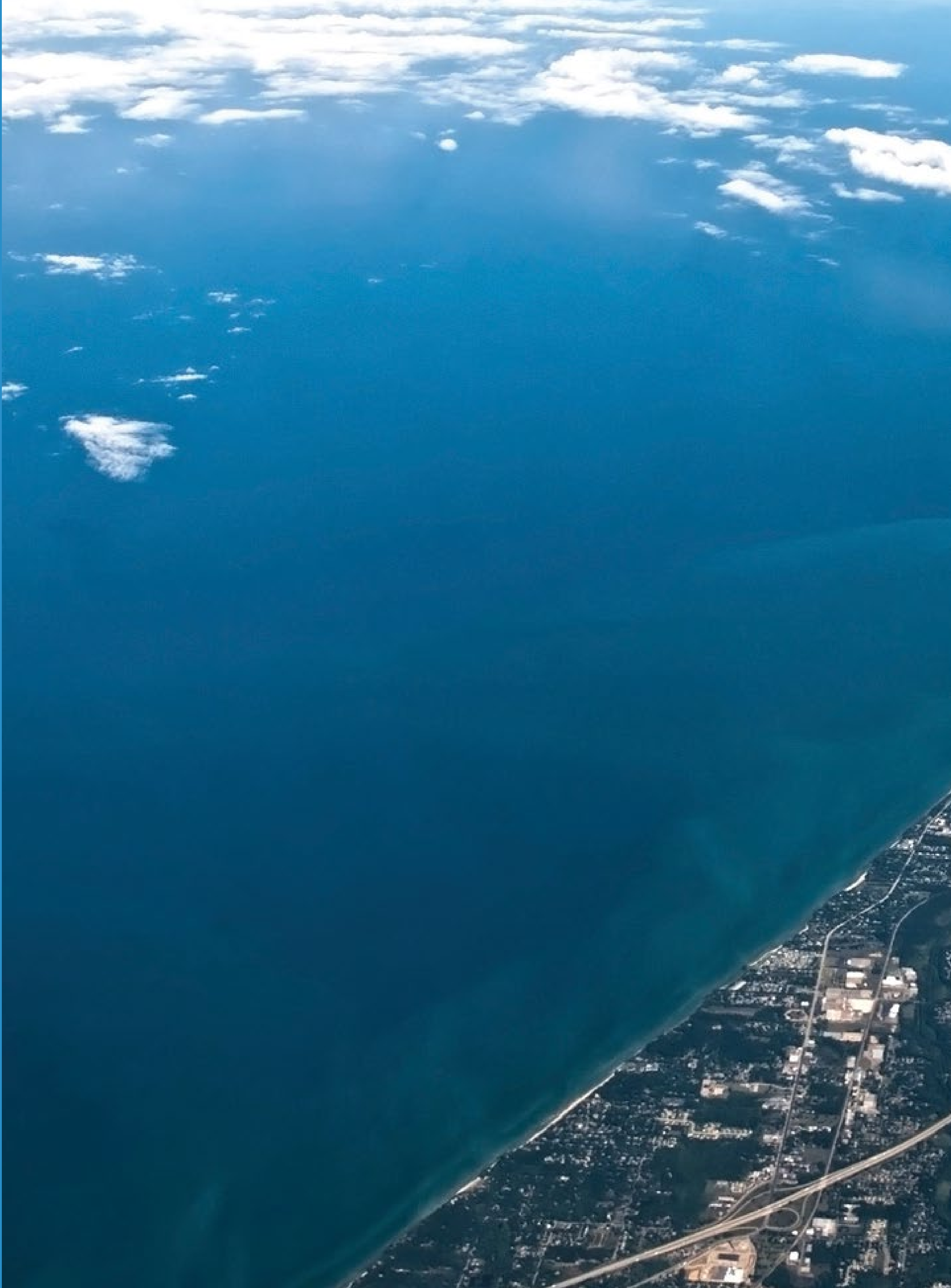
This is major source of frustration among residents of Georgian Bay, where wetlands and property values have suffered as a result of dredging-induced water losses. The US Army Corps of

92 For a more detailed discussion of ecological threats, see IUGLS, 2012: 126-127.

93 This is why the Sierra Club proposes building sills on stilts, which, it argues, would allow sturgeon to safely travel underneath. See, for example, Bialkowski, 2012. But this and other proposals to mitigate ecological risks have not been widely studied or discussed. Other groups, such as Georgian Bay Forever, note that lake Sturgeon are not considered endangered in Ontario (they are considered species of special concern) and that there is no “ecological justification for sacrificing the habitat of numerous [endangered or threatened species in Georgian Bay] in order to protect a species of special concern” (Georgian Bay Forever, 2012: 22).

Engineers designed structures to offset dredging in the 1960s, but high water supplies caused lake levels to surge shortly after and the structures were never built. This raises the question of whether the pre-dredged conditions of the St. Clair — rather than today's water levels — ought to be the baseline for policy decisions. Both governments approved dredging, after all, albeit without IJC involvement.

It is a difficult moral question, but it appears, for practical purposes, to be moot. The decision to install compensating structures preceded environmental review and today's status quo — not pre-dredged conditions — clearly anchors current policymaking.



Part 5: Multi-Lake Regulation

Restoration has a number of drawbacks, the most notable of which may be higher risk of flooding on Lake Michigan. Hybrid options mitigate these risks, but not fully. They still increase the risk of flooding and are incapable of lowering water levels in the event of extreme highs. The inadequacies of restoration are only likely to grow. Water levels are dominated by climate factors and these factors are becoming increasingly variable and difficult to forecast. Water levels are apt, therefore, to mirror these volatile and unpredictable trends.

This reality has strengthened calls for regulatory structures capable of raising and lowering water levels, within certain limits, as conditions dictate.[94] Two Great Lakes — Superior and Ontario — are already regulated by dams and regulation plans subject to IJC Orders of Approval. The question is whether to extend this approach to the GLSLS as a whole. This would require new regulation plans and, in all likelihood, new regulatory structures and further channel excavation.

Our discussion of multi-lake regulation is qualitative and draws heavily on the findings of other reports, including the IUGLS and Tolson and colleagues.[95] A quantitative analysis was not possible given data constraints and our deterministic hydraulic scenario. The goal of regulation is not to achieve a permanent increase in water levels, but to limit the frequency with which extreme highs and lows occur. Not only is this process error-prone (there is always some probability of regulation plans missing their mark), but it is not designed to maintain a fixed water level (regulation plans would permit a degree of fluctuation). Thus, we cannot assume a fixed increase in water levels in the event of intervention, as we do with our restoration scenarios. We would need to simulate large numbers of future monthly water levels; use these simulations to construct monthly probability distributions; calculate the economic impacts across these distributions; and use this information to generate expected economic impacts in the presence and absence of intervention. This analysis is beyond the scope of our study and may not even be possible given data constraints. A major reason why we focus on low water levels is the lack of economic impact data for high-water conditions. There is always some probability — even under dry climate scenarios — of realizing the latter. A stochastic model would, therefore, force us to estimate costs for outcomes for which data do not exist.

5.1 Background and findings of the International Upper Great Lakes Study (IUGLS)

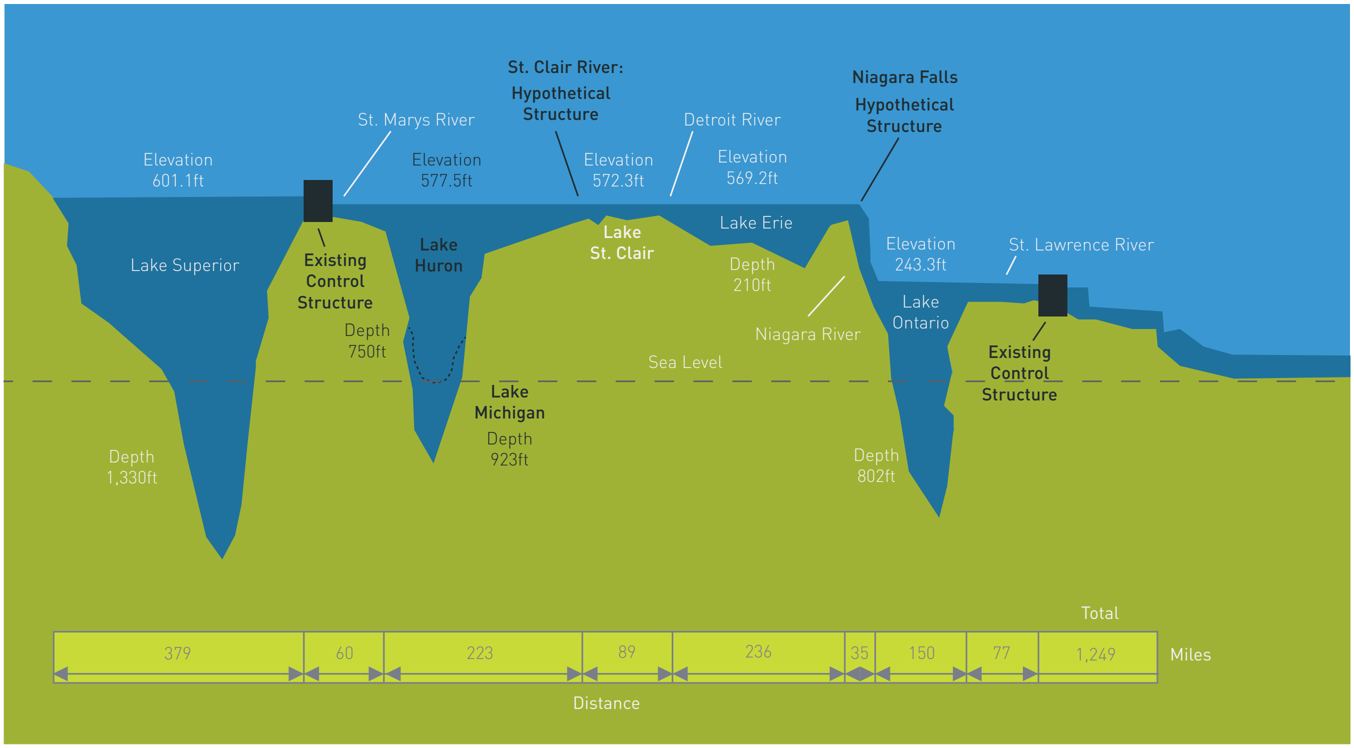
Multi-lake regulation would regulate water levels throughout the GLSLS by opening and closing dam-like structures on the system's connecting channels. Decisions to release water at regulation points would not be ad hoc. They would be governed by the mathematical rules defining regulation plans.[96]

The IUGLS explored the costs and benefits of multi-lake regulation, but without conducting a formal CBA.[97] The study had two components. In the first, researchers simulated water levels under a series of multi-lake regulation plans, including current plans for regulating lakes Superior and Ontario, which they used as their base case. The study assessed the efficiency or ability of the plans to limit the occurrence of extreme water levels, relative to the base case, under eight climate scenarios.

94 Specifically, according to the IUGLS, it would involve "operating regulation structures to benefit the Great Lakes-St. Lawrence River system as a whole to keep the entire system within observed historical extremes on all lakes under more extreme climate conditions in the future" (IUGLS, 2012: 212).
95 Tolson, Razavi and Asadzadeh, 2011.

96 These mathematical rules are known as rule curves (IUGLS 2012, 134).
97 The following summary comes from chapter 8 of the IUGLS report. See IUGLS, 2012.

FIGURE 5.1 Cross-Section of the Great Lakes-St. Lawrence River System indicating existing and hypothetical regulatory structures



Note: Diagram adapted from Michigan Sea Grant.

In the second component, the IUGLS compared the tradeoffs of plan performance and cost. The IUGLS did not quantify the economic impacts of water levels. It did, however, assume that extreme water levels were costly and ought, therefore, to be avoided. It also compared the expected construction and excavation costs of various regulation plans. Four types of plans were considered:

» Two-point regulation using existing structures on the St. Marys and St. Lawrence rivers.

» Three-point regulation combining existing structures with a hypothetical dam on the St. Clair River (which would target Lake Michigan-Huron).

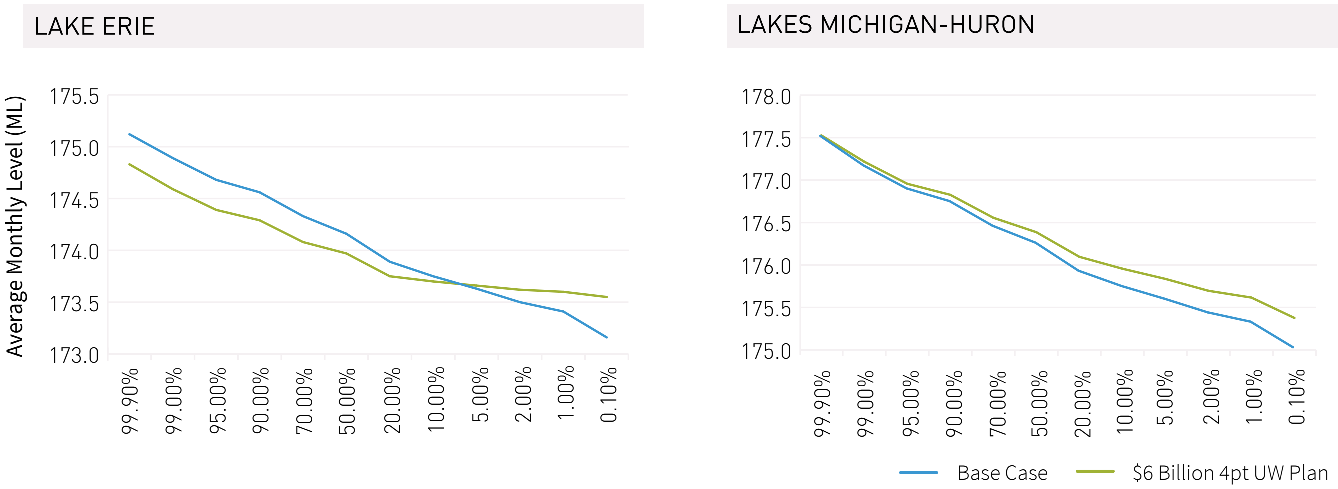
» Three-point regulation combining existing structures with a hypothetical dam on the Niagara River (which would target Lake Erie, but also affect Lake Michigan-Huron).

» Four-point regulation combining all four structures (existing and hypothetical).

Figure 5.1 visualizes how these systems would work. It is a cross-section of the Great Lakes system with arrows pointing to existing and hypothetical regulation points. All points are located along the system's connecting channels and would raise and lower water levels by managing outflows from target lakes. At each point, if upstream levels were higher than the corresponding long-term average, gates would open, outflows would increase and downstream water levels would rise. If water downstream levels were higher than the corresponding long-term average, gates would close, outflows would decrease and downstream water levels would fall.

The IUGLS identified several plans capable of limiting extreme highs and lows, at various points, throughout the system. The four-point plans were most effective, but three-point plans combining existing structures with a new structure on the

FIGURE 5.2 Impact of multi-lake regulation on Lake Erie and Lake Michigan-Huron (IUGLS simulations)



Where multi-lake regulation is potentially beneficial is in easing redistributive tensions between upstream and downstream property owners. Effective regulation plans would limit lows in Georgian Bay and other low-water areas, without inflicting undue risk on flood-prone locations.

Niagara River also performed well.[98] Figure 5.2 illustrates water levels for lakes Michigan-Huron and Erie at various percentile ranks under the IUGLS base case and the $6 billion, four-point plan. As we would expect, the four-point plan lowers water levels at the highest percentiles and increases water levels at the lowest percentiles for Lake Erie, providing suggestive evidence of the plan's capacity to limit the occurrence of extreme highs and lows. A slightly different pattern emerges for Lake Michigan-Huron. The four-point plan increases water levels at the lowest percentiles, but has little effect at higher percentiles.

But efficiency comes at a cost. The most efficient four-point plan was expected to cost $29 billion USD ($1 billion[99] for control structures on the St. Clair and Niagara rivers and over $28 billion for excavation on the same rivers). Another four-point plan involving the same structures and lower excavation costs was expected to cost roughly $6 billion, but would perform significantly worse. A three-point plan requiring regulation and excavation along the St. Clair River would cost $23 billion, but would perform poorly, while a three-point system with excavation and a new structure along the Niagara River would perform better and cost significantly less (just $2 billion).

The IUGLS did not quantify the economic impacts of water levels on shipping, tourism and other economic sectors. It was not possible, therefore, to estimate which, if any, of these plans would be optimal. The study also excluded the costs of lost

98 Three-point regulation with a new structure on the St. Clair River, by contrast, was estimated to provide little, if any, benefit. Two-point regulation was even more inefficient.

99 All figures in this paragraph are from the IJC's Levels Reference Study (LRSB, 1993) and were converted in the International Upper Great Lakes Study (IUGLS, 2012) into 2010 US dollars. These numbers are likely dated. As the IUGLS notes, real "costs of construction, materials and any additional requirements (e.g., the need for an environmental assessment) may differ today from what they were during the Levels Reference Study in the early 1990s" (2012: 136). A number of other costs — including the costs of excavation — may differ as well.

efficiency on the lower St. Lawrence River, where the simulations revealed that multi-lake regulation would increase the occurrence of extreme water levels. Any multi-lake regulation plan would need to mitigate these effects.[100] This would not be cheap, as it would require additional structures and excavation costs.[101]

5.2 Political feasibility

Multi-lake regulation and restoration face similar political obstacles. All four-point and certain three-point plans call for dams on the St. Clair River. The optimal location for these structures is the upper reaches of the river, where dams would take advantage of the narrow channel and — if hydroelectric generation were a priority — the steep slope of the water surface. But dams in this location would disturb contaminated sediment, interfere with sturgeon spawning grounds and possibly have other negative environmental impacts.

Where multi-lake regulation is potentially beneficial is in easing redistributive tensions between upstream and downstream property owners. Effective regulation plans would limit lows in Georgian Bay and other low-water areas, without inflicting undue risk on flood-prone locations. The question is whether the benefits outweigh the costs. The answer is unknown. Economic outcomes depend on water levels and climate in turn, but these outcomes are fraught with uncertainty.

And any attempt to extend regulation would also have to take downstream impacts — including costs on the St. Lawrence River — into account. The IUGLS did not systematically study these costs, but it did say that the lower St. Lawrence levels would require billions of dollars of mitigating measures, including excavation and control structures.[102] Indeed, the study recommended no further analysis of multi-lake regulation unless these costs are assessed.[103]

Inevitably, these uncertainties — along with the magnitude and geographic coverage of the projects — would delay construction. The IUGLS estimates that it would take 20 years or more to complete “the necessary planning, environmental reviews, regulatory approvals and design steps.”[104]

Ultimately, the IUGLS advised against further analysis of multi-lake regulation at this time. It argued that multi-lake regulation had the potential to limit extreme water levels, but that this potential was more than offset by high costs, environmental concerns, institutional requirements and uncertainty over “climate and its impact on Great Lakes hydrology.”[105]

It would seem, therefore, that the first step in adopting any engineering solution — whether restorative or regulative — is establishing better monitoring, modelling and assessment of water levels and their economic impacts.[106] It is to these issues that we now turn.

100 According to the IJC, any approvals to change regulation upstream would require “suitable and adequate provision” to protect interests on the lower St. Lawrence River (IUGLS 2012, 133).

101 In addition to examining the costs and benefits of multi-lake regulation, a number of studies have also looked at the potential for improving the existing regulation of lakes Ontario and Superior. The IJC, for example, recently proposed an alternative plan for Lake Ontario, which would continue to compress water levels but within in a wider range (see box on page 22). Asadzadeh and his colleagues (2014) designed a new regulation policy for Lake Superior in the form of a parametric rule-curve and optimized the parameters using a multi-scenario simulation-optimization framework. Their plan outperformed the previous Lake Superior plan (Plan 1977A) under the historical water level scenario (see Table A4.1) by increasing operational benefits and limiting extremely high and low water levels across the Upper Great Lakes. The optimized plan also demonstrated significant benefits under the other future climate scenarios described in Table A4.1. The most significant benefit was the plan’s ability to limit extremely low water levels under an extremely dry future climate scenario (a scenario that caused Plan 1977A to stop releasing water from Lake Superior). Costs and benefits were estimated using IJC-approved software. The estimates focused on commercial navigation, hydroelectric generation and shoreline protection.

102 IUGLS, 2012: 187.

103 IUGLS, 2012: 151.

104 IUGLS, 2012: 147.

105 IUGLS, 2012: 187.

106 IUGLS, 2012: 148.

Part 6: Adaptive Management

Restoration and regulation would respond to shifting water levels by altering water flows. This section considers a third strategy, adaptive management (AM). AM does not involve managing or raising water levels (though it can be combined with these approaches). Rather it is a structured, iterative process of improving responses to changing water levels through long-term monitoring, modelling and assessment of hydrological trends and impacts.[107] We are not in a position to quantify the costs and benefits of this approach, but we assess its merits qualitatively.

6.1 Adaptive management – key characteristics and the IJC's AM strategy

Over the past half century, the IJC has conducted a number of detailed studies of Great Lakes water levels.[108] These studies shed considerable light on Great Lakes hydrology, but they occur sporadically — usually in response to sustained periods of extreme water levels — with limited research in between. This has led to gaps in data and knowledge and an inability to track and verify hydrological trends and their impacts.[109]

The IUGLS has recognized this problem and called for more sustained collaboration, data collection and analysis among stakeholders and public officials. In May 2012, the IJC called on the International Great Lakes-St. Lawrence River Adaptive Management (GLAM) Task Team to develop an AM plan for the Great Lakes and St. Lawrence River System. The proposed plan has two parts. The first is an ongoing review and evaluation of the effectiveness of the regulation of Lake Superior and the Niagara and St. Lawrence rivers. The second, which is more relevant to our analysis, is the collaborative development and evaluation of solutions to problems associated with extreme water levels that cannot be solved through regulation alone.

107 IUGLS, 2012

108 These studies include: Regulation of Great Lakes Water Levels Reference Study (under 1964 reference) (International Great Lakes Levels Board, 1973); Great Lakes Diversions and Consumptive Uses Reference Study (under 1977 reference) (IGLDCUSB, 1981); Limited Regulation of Lake Erie Study (under 1977 reference) (ILERSB, 1981); Water Levels Reference Study (under 1986 reference) (LRSB, 1993); Report on the Protection of the Waters of the Great Lakes (under 1999 reference) (IJC, 2000); Lake Ontario-St Lawrence River Study (under 2000 IJC directive) (ILOSLRSB, 2006); International Upper Great Lakes Study (under 2007 IJC directive) (IUGLS, 2012).

109 The International Great Lakes-St. Lawrence River Adaptive Management Task Team, 2013: 5.

The IJC has yet to establish a clear leadership role in this area. It has, however, proposed the establishment of the Great Lakes and St. Lawrence River Levels Advisory Board (LAB), which would initiate a series of AM pilots and "engage agencies, organizations and institutions from across the [GLSLS]" to develop five system-wide networks responsible for:

» **Hydroclimate Monitoring and Modelling** to improve knowledge on water balance and water supply, the forecasting of net basin supply, lake levels and climate modelling.

» **Performance Indicators and Risk Assessment** to assess risks of extreme water levels to shoreline property, commercial navigation, municipal and industrial water uses, recreational boating, ecosystems, hydropower and other interests.

» **Evaluation and Decision Tools** to maintain, update and improve the tools needed for the evaluation of regulation plans over time and to develop new tools to support decision-making on potential responses to extreme water levels.

» **Information Management and Distribution** to facilitate the sharing of water level-related data and information among the Great Lakes and St. Lawrence River System community.

» **Outreach and Engagement** to educate and establish two-way communication on water level-related issues through the Great Lakes and St. Lawrence River System community.

— From *The International Great Lakes-St. Lawrence River Adaptive Management Task Team, 2013: iii.*

While each of these activities is vital, the second — assessing the risks of extreme water levels to economic and ecological interests — is particularly relevant to our report. Better data and modelling of outcomes would go a long way in broadening and deepening the analysis of engineering options.

6.2 Benefits and political feasibility

AM is more viable, currently, than regulation or restoration for three reasons. First, it provides clear benefits for all sectors. Property owners, hydroelectric producers, municipal users and others groups all stand to benefit from more and better information about the direction and risks associated with water levels. Second, AM is not as controversial as restoration or multi-lake regulation. It does not put lake sturgeon at risk nor does it risk flooding flood-prone areas. It is unlikely, therefore, to face significant political resistance. Finally, AM is not merely useful in its own right. It is also a necessary, albeit insufficient, condition for structural interventions. Neither restoration nor multi-lake regulation has any chance of approval unless uncertainty over their impacts is reduced. AM would not eliminate this uncertainty, but it would mitigate it, perhaps opening the door to a reliable analysis of engineering options.

But we also acknowledge the technical limits of this approach. Experimenting with new technologies is a key part of AM, but it excludes, by definition, raising or lowering water levels. This confines the analysis of engineering structures to lab settings, where ecological risks, such as threats to lake sturgeon, are difficult to assess.

A potential workaround, suggested by members of our steering committee, would be to combine AM with smaller scale interventions or pilot projects, such as a limited number of sills in the upper St. Clair River. Theoretically, this would allow researchers to assess the costs and benefits of structures while limiting their risks. But no mitigating structure, regardless of its scale, faces an easy path. They all involve the same redistributive struggles and institutional hurdles, including authorizing legislation, IJC orders or approval, environmental and regulatory approvals, and public consultation.[110]

110 Presumably, for example, pilot sills would be located in the upper St. Clair River. This is where they would have the biggest impact, but it is also where sturgeon spawn.

Part 7: Summary, lessons and recommendations

We encourage the Canadian and US governments to approve the IJC's proposals to strengthen AM on a bi-national basis. Specifically, we support the creation of a Levels Advisory Board (LAB) capable of facilitating monitoring and modelling of hydrological trends and their impacts.

This study has assessed the economic impacts of raising water levels on Lake Michigan-Huron. It has also examined, in a largely qualitative fashion, the economic implications of multi-lake regulation and adaptive management and the political feasibility of each approach.

Our quantitative analysis reveals several options capable of generating positive net benefits. However, we refrain from recommending specific options for three reasons: (1) our estimated impacts are modest; (2) they are subject to considerable uncertainty; (3) and they face significant political obstacles.

This is not to suggest that restoration is impossible or ill advised or that we cannot recommend options until uncertainty is eliminated; merely that the political obstacles are daunting and that our knowledge is insufficient to recommend options at present.

With these thoughts in mind, we draw three conclusions.

First, the economic viability of restoration structures requires further research.

This research ought to include ecological impacts;[111] more economic impacts;[112] better data on the economic impacts we do include;[113] a wider range of hydraulic scenarios;[114] more sophisticated modelling of economic outcomes; updated cost estimates of existing proposals;[115] and, if existing proposals are incapable of redressing redistributive conflicts, promising proposals for new structures. In the absence of significant capacity and resources, this research ought to start small, focusing on specific lakes, sectors or even impacts within them. This would allow researchers to collect more fine-grained data and develop better models of individual impacts. Eventually, it would provide the foundations of a deeper and broader CBA.

Second, future research needs to grapple with the politics of restoration.

As this paper has argued, decisions over GLSLS water levels are taken by unofficial consensus, where virtually any group can veto measures expected to cause significant harm. The problem,

111 Not all ecological outcomes are possible or appropriate to quantify. But dollar estimates of some outcomes could, in theory, be collected through contingent valuation surveys (i.e., surveys that ask citizens how much they would be willing to pay to protect particular ecological services under particular circumstances).
112 Although our analysis is strictly economic, there are a number of impacts our study does not quantify. Some of these omissions are sectoral (for example, the impacts on the recreational boating and tourism industries). Others concern specific rivers and lakes (for example, the impact of temporarily lower water levels on the St. Lawrence River).
113 Measures of several impacts are less than ideal, forcing us to push our data in some cases. An example is hydroelectric revenues. We estimated the impact of lower water levels on the revenues of plants in the Niagara region. But we only had data for one plant and extrapolated these estimates to other facilities in the region. Ideally, we would rely on plant-specific estimates.
114 Ideally, we would have estimated the costs of restoration under a high-water level scenario. Unfortunately, we lacked the economic impact data to do so.
115 Our study only analyzes proposals with adequate cost data. Unfortunately, a number of these options were engineered prior to 1977. Recent technological advances could improve the cost effectiveness of these structures.

of course, is that any structure is likely to benefit some groups at the expense of others. Researchers ought to admit this constraint and identify ways of redressing it. Ultimately, this means identifying policies and structures capable of eliminating or limiting redistributive conflicts and environmental risks. This is no easy task.

The study's shortcomings limit the policy recommendations we can make. However, we do make one recommendation, which, we believe, will improve the capacity of actors to adapt to water levels and pave the way for future research.

We encourage the Canadian and US governments to approve the IJC's proposals to strengthen AM on a bi-national basis. Specifically, we support the creation of a Levels Advisory Board (LAB) capable of facilitating monitoring and modelling of hydrological trends and their impacts.

AM is the most politically practical means of addressing fluctuating water levels: it is not as controversial as restoration or multi-lake regulation, and would help all actors, regardless of their preferences over water levels, by providing them with more and better information on hydrological conditions. But AM is not merely useful in its own right. It is also a necessary, albeit insufficient, condition for structural interventions. Neither restoration nor multi-lake regulation has any chance of approval unless uncertainty over hydrological trends and their impacts is reduced. AM would not eliminate this uncertainty, but it would mitigate it, opening the door to a more reliable analysis of engineering options.

Appendix 1:
Canadian dollar conversions

The tables below represent CAD values for tables 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 and 4.10.

TABLE A1.1 Estimated costs and restoration levels for sills (figures expressed in millions of 2012 CAD)

Cost/Benefits	Option A	Option B	Option C	Option D
Restoration level	6 cm	21 cm	8 cm	23 cm
Construction	11.31	60.64	36.12	192.49
Non-construction	1.65	7.82	4.15	21.09
Construction time	18 months (our assumption)	18 months	18 months (our assumption)	31 months

Note: Options A and B use type 4 sills, whereas, options C and D use type 11 sills. See Bruxer (2011) for descriptions of these types.

TABLE A1.2 Estimated net present value for sills (figures expressed in millions of 2012 CAD)

Adaptation option	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
6cm	3.85	78.72	-5.79	35.38
21cm	212.15	259.46	56.47	135.37
8cm	-18.21	89.49	-35.40	42.63
23cm	94.45	192.79	-68.57	107.27

Note: 4 per cent discount rate.

TABLE A1.3 Estimated costs and restoration levels for weirs (figures expressed in millions of 2012 CAD)

Cost/Benefits	Option A: Stag Island	Option B: Fawn Island
Restoration level	16cm	5cm
Construction	110.78	75.58
Non-construction	14.04	9.68
Construction time	34 months	23 months
Operation and maintenance	0.84	0.84
Sill costs	55.30	55.30
Sill construction time	16 months	16 months

Source: Bruxer, 2011.

TABLE A1.4 Estimated net present value for fixed rock-filled dikes (figures expressed in millions of 2012 CAD)

Adaptation option	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
16cm	111.10	249.46	44.79	121.27
5cm	-125.99	-15.10	-63.05	-6.97

Note: 4 per cent discount rate.

TABLE A1.5 Estimated costs and restoration levels for dikes and weirs (figures expressed in millions of 2012 CAD)

Cost/Benefits	
Restoration level	16cm
Construction	146.23
Non-construction	18.44
Operation and maintenance	NA
Construction time	30 months

Sources: Bruxer, 2011; Frost and Merte, 2011.

TABLE A1.6 Estimated net present values for parallel dikes and weirs (figures expressed in millions of 2012 CAD)

Adaptation option	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
16cm	36.05	196.99	10.83	97.26

Note: 4 per cent discount rate.

TABLE A1.7 Estimated costs and restoration levels for inflatable flap gates (figures expressed in millions of 2012 CAD)

Cost/Benefits	Low estimate	High estimate
Restoration level	16cm	16cm
Construction	125.59	160.05
Non-construction	15.88	20.15
Operation and maintenance	0.84	1.05
Construction time	Unknown	Unknown
Sill costs	Not necessary	55.30
Sill construction time	Not necessary	16 months

Source: Bruxer, 2011.

TABLE A1.8 Estimated net present values for inflatable flap gates (figures expressed in millions of 2012 CAD)

Adaptation option	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
16cm high cost	58.69	210.82	10.95	97.38
5cm	-33.67	149.25	5.17	83.50

Note: 4 per cent discount rate.

TABLE A1.9 Estimated net present values for hydrokinetic turbines (figures expressed in millions of 2012 CAD)

Adaptation option	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
19cm	-60.33	139.07	-30.65	76.18
9cm	-138.65	10.81	-64.90	13.81

Note: Construction values were estimated from Kumar and Saini and are based on projects comparable to the Verdant RITE project, which uses turbines similar to those proposed in the IUGLS.

Sources: IUGLS, 2012; Kumar and Saini, 2014; authors' calculations.

Appendix 2:
Data and methodology on economic impacts

This appendix describes our methodologies for calculating the economic impacts of low water levels. More detailed descriptions of calculations are available from appendices two through six of our Low Water Blues report.[116] Note that we apply two time horizons: 2015 to 2064 and 2015 to 2084. For the latter, we assume that water levels remain constant from 2064 to 2084. That means that, in the absence of discounting, losses would be constant across that period.

A2.1 Commercial shipping and harbours

Carrying capacity: In general, lower water levels harm shipping interests. Most vessels in the region are designed to carry as much cargo as possible at existing depths. A sharp decline in water levels would increase the risk of vessels running aground. Shippers would have to take measures – including reducing speeds and cargo loads – to keep under-keel clearances (or the distance between the lowest part of the hull and the bottom of the river or lake) above legal minimums.[117]

We estimate the costs of replacing lost carrying capacity — measured in ton miles — in the event of low water levels. Replacement could, in theory, involve increased trucking and rail transit. However, these methods are significantly more expensive than marine navigation. Thus, we assume replacement will occur through reduction of cargo loads and the expansion of existing fleets. We calculate these costs in four steps.

First, we estimate the lost carrying capacity for bulk cargo for the median-length ship in both the Canadian and the US shipping fleets. Data on median-length ships comes from Greenwood's.[118] Quinn[119] provides figures for the estimated tonnage loss per inch decline in water levels for vessels of various sizes. We use Quinn's data to identify the lost load per inch of the median Canadian and US ships.

Second, we multiply tons lost per foot by the projected water level loss in the year 2064, using 2014 as our base water-level year.

Third, we calculate the reduction in ton capacity by dividing tonnage losses for 2064 by the tonnage capacity of the median ship for both fleets. We multiply this figure by 100 to give us the percentage reduction in ton capacity. We assume that the reduction for the median ship is the same for all vessels in the national fleet.

This allows us to take our fourth step, which is to multiply the reduction in ton capacity of the median vessel by the total ton miles travelled in the Canadian and US fleets in 2013.[120] This gives us the reduction in ton miles for each fleet for 2064.

116 Shlozberg et al., 2014.
117 IUGLS, 2012: 27.
118 Greenwood's, 2013.
119 Quinn, 2002.
120 Canadian data comes from English and Hackston, 2013. US data come from the United States Department of Maritime Administration (2013).

Next, we estimate ton miles lost for the remaining years by linearly interpolating annual values between 2014 and 2064.

Finally, we calculate dollar value losses per year by multiplying ton miles lost by the cost of replacement. Anonymous industry sources estimate replacement costs at 10 cents per ton mile, which is the levelized cost of purchasing, maintaining and operating new vessels for the fleet over an extended period of time.

Harbour infrastructure: Lower water levels increase the costs of maintaining harbour infrastructure. We focus on the costs of maintaining harbour docks. Low water levels increase these costs by exposing docks to dry rot. We could also analyze the costs of slip and harbour dredging. However, we assume shippers will adapt to lower water levels by reducing cargo loads (see above), thereby negating or at least reducing the need for dredging. We estimate the costs of harbour maintenance in four steps.

First, we identify the costs of replacing and repairing individual docks. Bergeron and Clark[121] estimate the cost of replacement at $5,000 per dock foot and the cost of repair at $3,000 per dock foot.

Second, we identify the dock footage and dock-face depths of each dock on each lake. Dock footage tells us how much infrastructure needs maintenance. Dock-face depth tells us whether maintenance requires repair or replacement. This information, which we have for 544 docks, comes from Greenwood's.[122]

Third, we assume that after 20 years of persistently low water levels, docks are going to require maintenance.

Fourth, we determine whether maintenance would involve repair or replacement. Bergeron and Clark[123] assume it is optimal to replace docks when dock-face water level depths exceed 30 feet. Otherwise it is optimal to repair.

Finally, we sum the costs of repairing and replacing docks and spread the costs equally over the 2014 to 2064 period. When we extend our time horizon to 2084, we assume water levels and costs are constant from 2064 onward.

A2.2 Tourism and recreational water activities (marinas)

Low water levels create a number of costs for marinas. We estimate two: the costs of lost rental income from stranded slips and the costs of additional dredging to ensure water is deep enough to allow boats to enter and leave. Our cost estimates come from a survey of marina owners on lakes Erie and Michigan-Huron. The true populations of marinas for each lake is unknown, making it difficult to reliably extrapolate the results to the population at large. Nonetheless, they provide the most representative cost estimates available.[124]

121 Bergeron and Clark, 2011.
122 Greenwood's, 2013.
123 Bergeron and Clark, 2011.
124 Ontario Centre for Climate Impacts and Adaptation Resources, 2010.

The study reports average estimates of minimum and maximum costs for owners on lakes Erie and Michigan-Huron. We use the average minimum values to ensure conservative estimates and extrapolate these to all marinas on each lake. Estimates of the number of marinas come from Boating Ontario[125] and the US Army Corps of Engineers.[126]

The study provides cost estimates for one-, two- and three-foot drops. Unfortunately, we do not have estimates for drops between one and two and two and three feet. Thus, we linearly interpolate losses over a three-foot range, assuming zero losses at 2014 water levels.[127] The projected water level losses for 2064 are 3.2 feet for Lake Michigan-Huron and 2.6 feet for Lake Erie.

A2.3 Hydroelectric generation

Research on the economic impacts of water levels on hydroelectric revenues in the GLSLS is scarce. Our study draws heavily on work by Buttle and his colleagues,[128] which quantifies the dollar losses of replacing hydroelectric production with natural gas powered plants, the next cheapest source of electricity.

Buttle et al. provide estimates of dollar losses of low water levels for three sets of facilities: the Adam Beck facilities on the Niagara River; the Saunders facility on the St. Lawrence River; and the Clergue facility on the St. Marys River. All three are located in Ontario and all three are operated by Ontario Power Generation. We want to analyze the costs of low water levels in the Niagara region, but only have data for the facilities studied by Buttle et al. Rather than collecting data for additional facilities, we assume the relationship between revenues and water levels is the same for all facilities in the region and use this assumption to extrapolate losses at the Adam Beck facilities[129] to Robert Moses and Lewiston, both of which are located in the US.

Our calculations consist of four steps. First, we estimate the lost hydroelectric revenues per foot. Buttle et al. estimate the losses per year under the CCCma2050 climate model for the Adam Beck facilities. We divide this estimate by the difference between the projected average annual water levels for Lake Erie under CCCma2050 and Lake Erie's historic annual average. This gives us the estimated revenue loss per foot loss of water levels, which is needed to calculate the yearly losses estimated for each year (and subsequently each water level) over our time horizon.

Second, we take the average yearly revenue losses per foot of water levels for the Adam Beck facilities from Buttle and his colleagues and estimate the potential losses to other facilities on the Niagara River. We do this by adjusting the revenue losses to different plant capacities,[130] assuming the same load factor used in Buttle et al. To accommodate the study of additional facilities, we also assume that all production loss will have to be made up by additional sources, in this case combined cycle gas turbine plants. We update the generation costs used in Buttle to $67 MW/h[131] and apply this value to Buttle et al.'s calculations to find the total cost of the replacement power for each facility.

Third, we sum the losses for each facility for 2064.

125 Boating Ontario, n.d.
126 USACE, 2008.
127 This refines our Low Water Blues methodology, where we used one- and two- foot drops as proxies for our two water level drops scenarios. This change enables us to estimate the potential benefits of different restoration options, impossible under the Low Water Blues methodology. This change also results in more conservative impact estimates.
128 Buttle et al., 2004.
129 Buttle and his colleagues generate a single estimate for Adam Beck 1 and 2 and the Adam Beck Pump Generation Station.
130 Data on plant capacities comes from utility and company websites and Wikipedia-compiled lists. For details, see Shlozberg et al., 2014: 102.
131 The values come from the United States Energy Information Administration, 2014. We use combined cycle gas turbines, which are commonly used for energy replacement in the north east of North America.

Fourth, we linearly interpolate costs from 2014 to 2064.

Note an important difference between our approach and Buttle et al.'s. Buttle et al. assume a positive and convex relationship between revenue losses and water level declines. Unfortunately, we do not have access to their cost function. In its place, we linearly approximate their function (1) by matching our 2064 water level projection to their projected revenue loss for that water level and (2) assuming zero revenue losses for 2014. This latter approach is slightly problematic, as Buttle et al. use Lake Erie's average historic level as their base case, whereas we use the 2014 level. Fortunately, the difference between these figures is only four centimeters or 0.13 standard deviations of the annual historic average. If Buttle et al.'s convex function is correct, our linear approximation overestimates the potential costs of lower water levels in all but the final year of our forecast.

A2.4 Waterfront properties

In *Low Water Blues*, we estimated the impact of changes in water levels on percentage changes in property values. Our data, which came from Ontario's Municipal Property Assessment Corporation (MPAC), were not disaggregated to the level of individual properties. We did, however, have access to average property values for 105 Ontario municipalities located next to lakes Huron, Superior, Erie and Ontario. Data were available for three years: 2003, 2008 and 2012, which allowed us to look at changes in property values over two periods: 2003 to 2008 and 2008 to 2012.

We estimated impacts by regressing the percentage change in average municipal property values on the change in water levels in adjacent lakes. We restricted our sample to municipalities identified by MPAC as containing at least one seasonal recreational property.[132] This reduced our sample to 84 municipalities.

According to our estimates, average municipal property values decline, on average, by 14 per cent for every one foot decline in water levels. We were concerned, however, that this estimate was too large: while our model controlled for changes in average non-waterfront properties, it omitted a number of possible causes of lower values. Accordingly, we took a conservative approach, adjusting our estimate downwards by subtracting two standard errors. This yielded an impact of six per cent, which we used in our impact analysis.[133]

132 We do not expect water levels to affect the property values of non-seasonal recreational properties, such as properties in downtown Toronto.
133 In other words, we used the lower bound of our 95 per cent confidence interval.

Appendix 3:
Detailed CBA tables and results

This appendix provides a detailed breakdown of the costs and benefits of each of our restoration options. The tables identify (1) construction, non-construction and operation and maintenance costs; (2) the upstream benefits of higher water levels on Lake Michigan-Huron; and (3) the downstream costs of temporarily lower water levels on Lake Erie. Additional power production is also included in upstream benefits for hydrokinetic turbines.

TABLE A3.1 Estimated net present values for sills (figures expressed in millions of 2012 USD)

Adaptation option	Impact	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
6cm	Cost	-11.29	-7.48	-11.95	-10.21
	Benefit	215.37	171.57	98.29	78.30
	Downstream	-200.62	-93.24	-91.56	-36.25
	Net	3.46	70.85	-5.21	31.84
21cm	Cost	-61.32	-40.63	-64.30	-25.34
	Benefit	753.81	600.48	344.03	274.05
	Downstream	-501.56	-326.34	-228.90	-126.88
	Net	190.94	233.51	50.82	121.83
8cm	Cost	-191.28	-126.75	-187.81	-64.64
	Benefit	825.60	657.67	376.79	300.15
	Downstream	-549.32	-357.41	-250.70	-138.97
	Net	85.00	173.51	-61.71	96.54
23cm	Cost	-191.28	-126.75	-187.81	-64.64
	Benefit	825.60	657.67	376.79	300.15
	Downstream	-549.32	-357.41	-250.70	-138.97
	Net	85.00	173.51	-61.71	96.54

Note: 4 per cent discount rate.

TABLE A3.2 Estimated net present values for rock-filled dikes (figures expressed in millions of 2012 USD)

Adaptation option	Impact	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
16cm	Cost	-92.21	-55.39	-47.41	-30.60
	Benefit	574.33	457.51	262.12	208.80
	Downstream	-382.14	-177.60	-174.40	-69.05
	Net	99.99	224.52	40.31	109.14
5cm	Cost	-125.68	-78.86	-62.36	-41.32
	Benefit	179.48	142.97	81.91	65.25
	Downstream	-167.19	-77.70	-76.30	-30.21
	Net	-113.39	-13.59	-56.75	-6.28

Note: 4 per cent discount rate.

TABLE A3.3 Estimated net present values for parallel dikes and weirs (figures expressed in millions of 2012 USD)

Adaptation option	Impact	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
16cm	Cost	-159.75	-102.62	-77.96	-52.21
	Benefit	574.33	457.51	262.12	208.80
	Downstream	-382.14	-177.60	-174.40	-69.05
	Net	32.44	177.29	9.75	87.53

Note: 4 per cent discount rate.

TABLE A3.4 Estimated net present values for flap gates (figures expressed in millions of 2012 USD)

Adaptation option	Impact	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
16cm high costs	Cost	-139.38	-90.17	-77.86	-52.11
	Benefit	574.33	457.51	262.12	208.80
	Downstream	-382.14	-177.60	-174.40	-69.05
	Net	52.82	189.74	9.85	87.64
16cm	Cost	-222.50	-145.58	-83.06	-64.60
	Benefit	574.33	457.51	262.12	208.80
	Downstream	-382.14	-177.60	-174.40	-69.05
	Net	-30.30	134.33	4.65	75.15

Note: 4 per cent discount rate.

TABLE A3.5 Estimated net present values for hydrokinetic turbines (figures expressed in millions of 2012 USD)

Adaptation option	Impact	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
19cm	Cost	-307.53	-215.84	-140.35	-98.50
	Benefit	707.02	551.89	319.87	249.07
	Downstream	-453.79	-210.90	-207.10	-82.00
	Net	-54.30	125.16	-27.59	68.57
9cm	Cost	-159.92	-112.23	-72.98	-51.22
	Benefit	336.06	261.82	151.92	118.03
	Downstream	-300.93	-139.86	-137.34	-54.38
	Net	-124.79	9.73	-58.41	12.43

Note: 4 per cent discount rate.

Appendix 4:
Our hydraulic scenario in context

This section provides a rough sense of the comparability of our hydraulic scenario with the climate sequences simulated in the IUGLS and the Lake Ontario-St. Lawrence Study Board (LOSLSB) report. To reiterate from section 2.1.4, we use projected average water levels from 2041 to 2060 from the CCCma 2050 scenario. We then assume these levels for 2064 (the last year of our immediate construction time horizon) and linearly interpolate values for missing years using 2014 as our start point.

We want to get a sense of the likelihood of observing our 2064 or low water level point under the climate sequences simulated in the IUGLS and LOSLSB studies. Table A4.1 provides descriptions of selected scenarios used to generate the sequences in these reports. Table A4.2 reports the percentile rank of our low water level point relative to the monthly observations simulated under these 109-year sequences.

The assumptions of our dry, low water level scenario most closely approximate the assumptions of the reports' T1 scenario. According to Table A4.2, 20 per cent of the simulated monthly levels for Lake Michigan-Huron in T1 fall below our 2064 level (these simulations assume the current regulation plan for Lake Superior remains in place), whereas none of the simulated monthly levels for Lake Erie in T1 fall below our 2064 level. 10 per cent of simulated monthly levels for Erie do, however, fall below our 2064 level in the studies' TR or trend scenario.

Figures A4.1 through A4.4 plot the maximum, average and minimum water levels under the HI and T2 scenarios for each of the Great Lakes. The dashed lines refer to monthly values for the HI scenario. The solid lines refer to monthly values for the T2 scenario. Scenarios for lakes Superior, Michigan-Huron and Erie apply the 2014 Lake Superior regulation plan. The scenarios for Lake Ontario apply Plan 2014 and regulation Plan 58DD for Lake Ontario.

As figures A4.1 through A4.4 indicate, our 2064 estimate is roughly comparable to the projected average for Lake Superior under T2. It is slightly below average for lakes Michigan-Huron and Erie.

TABLE A4.1 Description of IUGLS sequences

Classification Name	Ranking from least severe scenarios to most severe scenarios for low water levels	Climate scenario	Scenario description
HI	6	Historical Average	Recorded NBS for 1900 to 2008
AT	5	Uncertain change	One of the sequences produced by the Canadian regional climate models (RCM) that produces higher highs and lower lows.
AV	4	Change to drier	A Canadian RCM sequence that produces lower levels.
T1	3	Change to drier	One of hundreds of climate change sequences in which the climate change effect becomes more pronounced over time.
T2	2	Change to drier	Another sequence in which climate change effect becomes more pronounced over time, but more severe than T1.
TR	1	Change to drier	This sequence did not use climate models, but just extended historical NBS trends assuming the means would continue to change as they have in the last four decades.

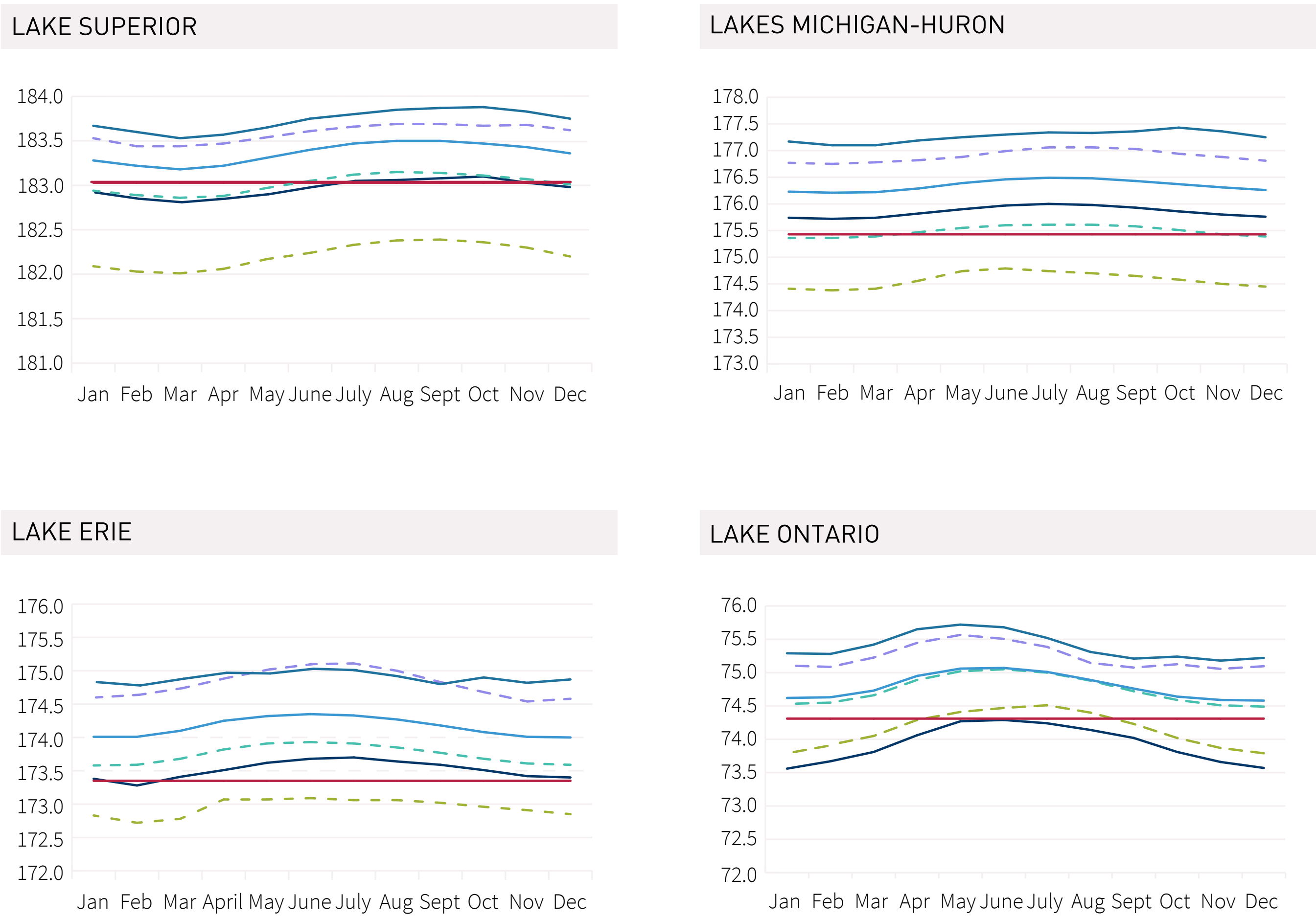
TABLE A4.2 Percentiles comparable by year

Classification Name	Regulation plan NatOpt3 (Current regulation plan for Lake Superior)		
	Superior	Michigan-Huron	Erie
HI	0.02	0.00	0.00
AT	0.05	0.00	0.00
AB	0.05	0.01	0.00
T1	0.20	0.20	0.00
T2	0.50	0.10	0.00
TR	0.50	0.20	0.10

TABLE A4.3 Water levels past, present, and future

Lake	2014 water levels (in meters)	Historical average water levels (1918-2014 in meters)	CCCma2050 projection (in meters)
Superior	183.51	183.40	183.03
Michigan-Huron	176.30	176.42	175.43
Erie	174.20	174.14	173.35
Ontario	74.77	74.75	74.31

FIGURE A4.1 Monthly and yearly averages of different climate scenarios for the Great Lakes



See page 69 for a description of these figures.

Appendix 5:
Sensitivity analysis results

Our analysis applies a four per cent discount rate. However, we also conduct sensitivity analyses using two per cent and six per cent rates. Tables A5.1 and A5.2 report the net present values of the impacts of our four sill options on lakes Michigan-Huron and Erie using these discount factors.

TABLE A5.1 Estimated net present values for sills (figures expressed in millions of USD, 2 per cent discount rate)

Option	Impact	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
6cm	Cost	-11.62	-9.35	-16.00	-14.47
	Benefit	343.10	286.43	230.90	192.76
	Downstream	-224.66	-114.35	-151.19	-67.48
	Net	106.82	162.73	63.71	110.81
21cm	Cost	-63.12	-50.78	-68.94	-42.35
	Benefit	1,200.84	1,002.51	808.13	674.66
	Downstream	-561.64	-400.22	-377.97	-236.18
	Net	576.08	551.51	361.23	396.13
8cm	Cost	-196.90	-158.40	-198.72	-114.77
	Benefit	1,315.21	1,097.98	885.10	738.91
	Downstream	-615.13	-438.34	-413.96	-258.67
	Net	503.18	501.25	272.41	365.46
23cm	Cost	-196.90	-158.40	-198.72	-114.77
	Benefit	1,315.21	1,097.98	885.10	738.91
	Downstream	-615.13	-438.34	-413.96	-258.67
	Net	503.18	501.25	272.41	365.46

TABLE A5.2 Estimated net present values for sills (figures expressed in millions of USD, 6 per cent discount rate)

Option	Impact	No policy delay, non-staged construction	No policy delay, staged construction	20-year policy delay, non-staged construction	20-year policy delay, staged construction
6cm	Cost	-10.97	-6.12	-9.16	-7.64
	Benefit	143.78	109.56	44.83	34.16
	Downstream	-179.92	-77.69	-56.10	-20.00
	Net	-47.11	25.75	-20.42	6.52
21cm	Cost	-59.60	-33.25	-60.65	-16.10
	Benefit	503.23	383.46	156.91	119.57
	Downstream	-449.80	-271.92	-140.25	-70.00
	Net	-6.17	78.30	-43.99	33.46
8cm	Cost	-185.93	-103.71	-179.03	-38.07
	Benefit	551.16	419.98	171.85	130.95
	Downstream	-492.63	-297.81	-153.61	-76.67
	Net	-127.41	18.46	-160.78	16.21
23cm	Cost	-185.93	-103.71	-179.03	-38.07
	Benefit	551.16	419.98	171.85	130.95
	Downstream	-492.63	-297.81	-153.61	-76.67
	Net	-127.41	18.46	-160.78	16.21

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C G L R

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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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