Chapter 7

Feasibility and Implications of Restoring Upper Great Lakes Water Levels

Draft Text
November 10th, 2011

Lake Superior Regulation:
Addressing Uncertainty in Upper Great Lakes Water Levels

Final Report to the International Joint Commission

by the
International Upper Great Lakes Study

Chapter 7 analyzes the feasibility and implications of raising water levels of Lake Michigan-Huron to compensate for past natural and human-induced changes by means of restoration structures in the St. Clair River.

7.1 Introduction[1]

7.1.1 Scope of the Restoration Analysis

In the context of the International Upper Great Lakes Study (the Study), the term *restoration* refers to providing a permanent increase in Lake Michigan-Huron water levels, relative to what they would otherwise be, by constructing structures in the St. Clair River so as to reduce the river's conveyance capacity (*i.e.,* ability to discharge water). Restoration structures would compensate for past lowering resulting from natural and human-induced changes in the St. Clair River that increased the channel's conveyance capacity.

Restoration structures are non-adjustable, and have a permanent impact on water levels upstream. They also would have a temporary effect on water levels downstream, immediately after the structures are built. Regulation structures, by contrast, are adjustable, and can be raised or lowered to adjust water levels and flows both upstream and downstream (within certain limits) as desired.

The Study's restoration analysis focused primarily on the feasibility and impacts of non-adjustable restoration structures that would permanently raise Lake Michigan-Huron water levels. This included an analysis of structures proposed in previous studies, such as submerged weirs and dikes used to partially obstruct the channel. The analysis also considered two adjustable structures, inflatable flap gates and inflatable rubber weirs, that were reviewed for their potential to achieve some level of restoration, though they would also provide a limited ability to regulate water levels of Lake Michigan-Huron. Finally, an emerging technology, hydrokinetic turbines, was considered for its potential to raise water levels, while also providing the benefit of renewable energy. The impacts of hydrokinetic turbines on water levels would be partially adjustable, given that turbine operation could be stopped and water level impacts thereby reduced.

The restoration analysis examined the effects of all these structures on water levels and flows throughout the upper Great Lakes and the associated impacts of the different scenarios on the key interests served by the waters of the lakes and connecting channels. These effects included both the shorter term construction-related impacts, as well as the longer term system-wide impacts.

7.1.2 IJC Direction on Restoration Analysis

The Study's focus on restoration grew out of the findings of its first report to the International Joint Commission (IJC) on the physical processes and possible ongoing changes in the St. Clair River and their impacts on water levels of Lake Michigan-Huron (International Upper Great Lakes Study [IUGLS], 2009). In that report, the Study concluded that erosion of the St. Clair River had occurred subsequent to the last navigation dredging project, resulting in an increase in the conveyance capacity of the St. Clair River and a lowering of Lake Michigan-Huron water levels by approximately 7 to 14 cm (2.8 to 5.5 in). In addition, the Study found that conveyance changes in the river do not appear to be ongoing.

[1] This chapter is based on peer-reviewed research on restoration structures that was commissioned by the Study (International Upper Great Lakes Study, 2011).

In accordance with the Study's mandate, the Study Board recommended that:

- "*… remedial measures* [in the St. Clair River] *not be undertaken at this time";* and,
- "*…the need for mitigative measures in the St. Clair River be examined as part of the comprehensive assessment of the future effects of climate change on water supplies in the Upper Great Lakes basin in Report 2 of the Study, on Lake Superior regulation"* (IUGLS, 2009).

In August 2010, the IJC provided further guidance to the Study Board by asking it to investigate methods and impacts of restoring Lake Michigan-Huron water levels as potential compensation for past lowering caused by natural and anthropogenic changes in the St. Clair River. The restoration analysis would include a description of possible structures that would be capable of restoring Lake Michigan-Huron water levels by various amounts, as well as the implications on interests throughout the Great Lakes-St. Lawrence River system.

The IJC did not request that the Study Board make any recommendation as to implementing a particular restoration option. Rather, it directed that the restoration analysis:

> *"… provide Governments and the public with extremely valuable information and insight to help form the basis for rational and scientifically-based decision making".*

The IJC directed the Study Board to investigate several restoration scenarios for Lake Michigan-Huron to approximate the desired levels of compensation. Table 7-1summarizes these restoration scenarios.

Table 7-1
Lake Michigan-Huron Water Level Restoration Scenarios

Restoration Scenario	Description
Zero	Represents status quo (*i.e*., taking no restorative action)
10 cm (3.9 in)	Compensation for increases in conveyance since 1963, with the magnitude as established in the St. Clair River Report (IUGLS, 2009)
25 cm (9.8 in)	Combining the 10 cm scenario with the estimated impact of the 1960-1962 8.2 m (27-ft) navigation channel dredging project on conveyance of the St. Clair River
40 cm (15.7 in)	Scenario would approximately equal the physical effects of regime change in the St. Clair River from 1906 through today, including the 1933 to 1937 excavation of the 7.6 m (25-ft) navigation channel, the 1960 to 1962 excavation of the 8.2 m (27-ft) navigation channel, and the changes since 1963
50 cm (19.7 in)	Extends the previous analysis to cover the period of 1855 to 1906, which reflects the impacts on the St. Clair and Detroit Rivers from the deepening associated with the 6.1 m (20-ft) navigation channel

7.2 The Study's Approach to Restoration Analysis

7.2.1 Restoration Analysis Strategy

The Study Board developed a strategy to guide its restoration analysis. The strategy focused on using currently available information and models to conduct the exploratory assessment. The main components of the strategy were to:

- undertake system modelling by adjusting St. Clair River hydraulics to simulate the physical effects of water level restoration options on Lake Michigan-Huron and effects downstream through Lake Erie;
- identify candidate physical structures from past studies and evaluate these in the context of the restoration analysis, including estimating their costs;
- carry out upstream and downstream water level/flow impact analysis on the key interests served by the waters of the upper Great Lakes (see **Chapter 3**), to the extent possible using the Shared Vision Model (SVM) (see **Chapters 5** and **6** for more information on the SVM);
- conduct an exploratory environmental reconnaissance of proposed restoration options, focusing on the St. Clair River; and,
- prepare an analysis of the institutional considerations related to constructing and operating restoration structures in the Great Lakes.

The findings of the restoration analysis should be viewed within the context of the limitations and caveats that are associated with the various analyses upon which it is based. In addition, broader issues such as glacial isostatic adjustment (GIA) and climate change were addressed only in a limited way in this assessment.

7.2.2 Modelling of Impacts on Water Levels and Flows

The first step of the restoration analysis was to evaluate the impacts on water levels and flows throughout the Great Lakes system resulting from restoration of Lake Michigan-Huron water levels. One way to restore water levels on Lake Michigan-Huron is to reduce the conveyance capacity of the St. Clair River. Based on the directives provided by the IJC, this was the focus of the Study Board's analysis. Additional measures to raise levels of Lake Michigan-Huron – such as reducing or eliminating the Lake Michigan diversion at Chicago or adding or increasing the amount of water diverted into the lake from external watersheds – would be limited in their effectiveness and could have unintended consequences, and therefore were not considered in this analysis.

It was assumed for the system modelling analysis that structures of some undefined form in the St. Clair River could be used to raise levels of Lake Michigan-Huron by any of the 10, 25, 40 and 50 cm (3.9, 9.8, 15.7 and 19.7 in, respectively) scenarios outlined by the IJC. The system modelling was used to predict the physical impacts of these hypothetical structures on water levels of Lake Michigan-Huron over time, as well as the hydrological impacts on the system downstream of Lake Michigan-Huron, through lakes St. Clair, Erie and Ontario, all the way to Montreal Harbour on the St. Lawrence River, including both the short term transient impacts that occur immediately after construction, as well as longer term impacts. All results were compared to the base case, which represents the current conditions, or the "zero" restoration scenario.

The Great Lakes-St. Lawrence River system was simulated, using recorded data for the historical period (1900-2008), through a combination of regulation plan logic (using current plans 1977A and 1958DD for lakes Superior and Ontario, respectively), hydrological routing, and various empirical equations that were updated as part of the Study. A key assumption in the analysis was that under any restoration scenario, the most probable scenario for future Lake Superior releases would involve controlling outflows from Lake Superior such that any Lake Michigan-Huron restoration option would have no discernible impact on Lake Superior levels or outflows. As such, when simulating the system hydrology, lake levels and interconnecting channel flows, the flows in the St. Marys River were in most cases fixed to the flows that would be simulated by Plan 1977A without any restoration. The system was simulated using inputs of time series of net basin supplies (NBS), diversions, ice and weed retardation factors, as well as initial outflows and lake levels. The Coordinated Great Lakes Regulation and Routing Model (CGLRRM) was used to simulate the dynamic hydrology and lake levels of the mid-lakes (Michigan-Huron, St. Clair and Erie). A separate program simulated Lake Ontario levels and outflows, and empirical equations were used to estimate hydrological impacts of restoration at Montreal.

1. Simulation Assumptions

For the purposes of the analysis, the level of restoration was defined as the rise in the long-term average surface elevation of Lake Michigan-Huron caused by a permanent structural change to the St. Clair River, as compared to the base case *(i.e.*, current conditions, or the "zero" restoration scenario). All restoration scenarios were simulated using water supplies for each lake as actually recorded in the historical period from 1900 to 2008. The different restoration scenarios were simulated by adjusting the parameters in the stage-fall-discharge equations used in the CGLRRM to describe the existing conveyance regime of the St. Clair River. The base case values of the parameters represent the conveyance regime determined by a statistical regression equation from the revised coordinated St. Clair River monthly outflows for the period 1987-2006. These parameters were adjusted until the desired restoration level was achieved.

Two different simulation timing conditions were used for each of the different restoration scenarios:

- that construction could be completed instantaneously, and that water levels and flows would begin to react at the very start of the simulation period; and,
- that restoration would take place in five stages, with one-fifth of the full restoration provided instantaneously every five years.

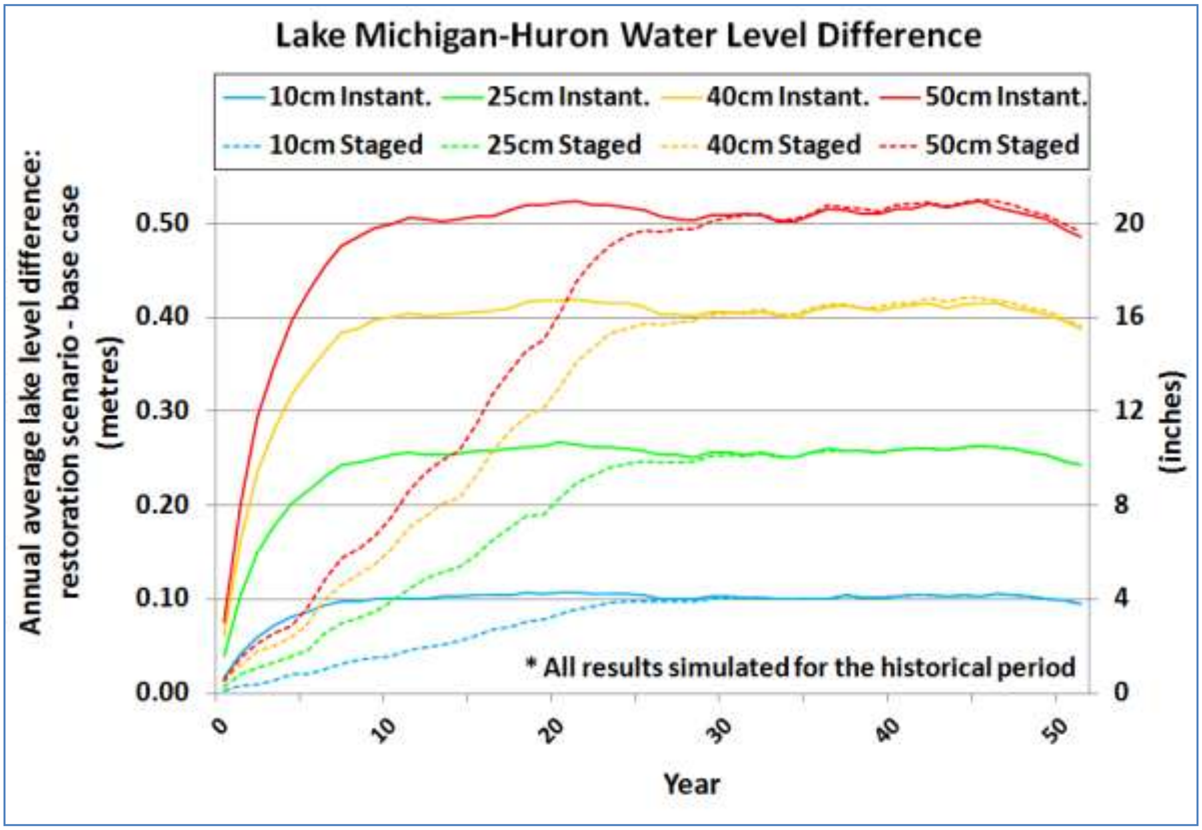
The first (and extremely unrealistic) "instantaneous" assumption illustrates the shortest period that water levels upstream would take to adjust. However, the impacts to downstream water levels and flows would also be greater under this assumption. The second "staged" assumption would see construction undertaken over a total of 25 years and therefore would require a longer period to achieve the full effect of restoration upstream, though with greatly reduced magnitude of undesirable downstream impacts, particularly in the St. Clair River- Lake St. Clair corridor. In reality, construction of restoration structures would take a number of years to complete regardless of the scenario chosen, but the instantaneous and staged simulations that were reviewed provided estimates of the range of hydrological impacts that could be anticipated.

2. Lake Michigan-Huron Water Levels

Figure 7-1 illustrates the first 50 years of simulated restoration impacts on the annual average surface elevation of Lake Michigan-Huron compared to the base case for instantaneous and staged restoration scenarios. The results showed that water levels on Lake Michigan-Huron would start to rise as soon as the St. Clair River conveyance was reduced, with the full level of restoration achieved about 10 years later for the instantaneous assumption, or about 30 years later in the case of staged construction.

Restoration would reduce the occurrences of extreme low water levels on Lake Michigan-Huron, but also increase the number of occurrences of extreme high lake levels. For example, under the 10 cm (3.9 in) instantaneous restoration scenario, the maximum monthly surface levels simulated in the base case were found to be exceeded 1 to 3 percent of the time, depending on the month; similarly, for the 50 cm (19.7 in) instantaneous restoration scenario, maximum monthly surface levels simulated in the base case were found to be exceeded about 15 percent of the time.

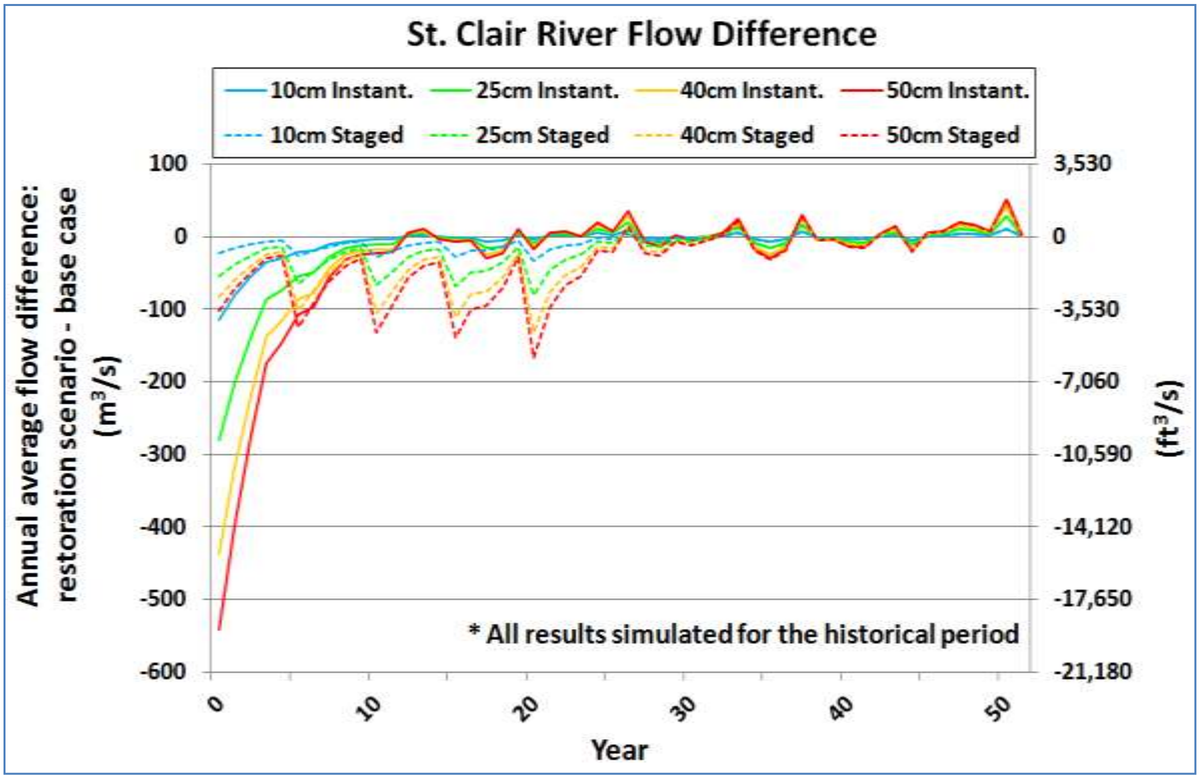
Figure 7-1
Simulated Restoration Impacts on Lake Michigan-Huron Water Levels



3. Downstream Impacts on Water Levels and Flows

Restoring water levels would also have short-term downstream impacts, as flows in the St. Clair system are temporarily decreased while water is gradually stored on Lake Michigan-Huron. Figure 7-2 illustrates the simulated restoration impacts on the annual average flow on the St. Clair River compared to the base case for instantaneous and staged restoration scenarios. The reduction in conveyance capacity would initially lower the flow through the St. Clair River. However, as levels on Lake Michigan-Huron rise, flows through the St. Clair River would again gradually increase (because of increasing head differential) until they were essentially the same as they would have been prior to restoration construction.

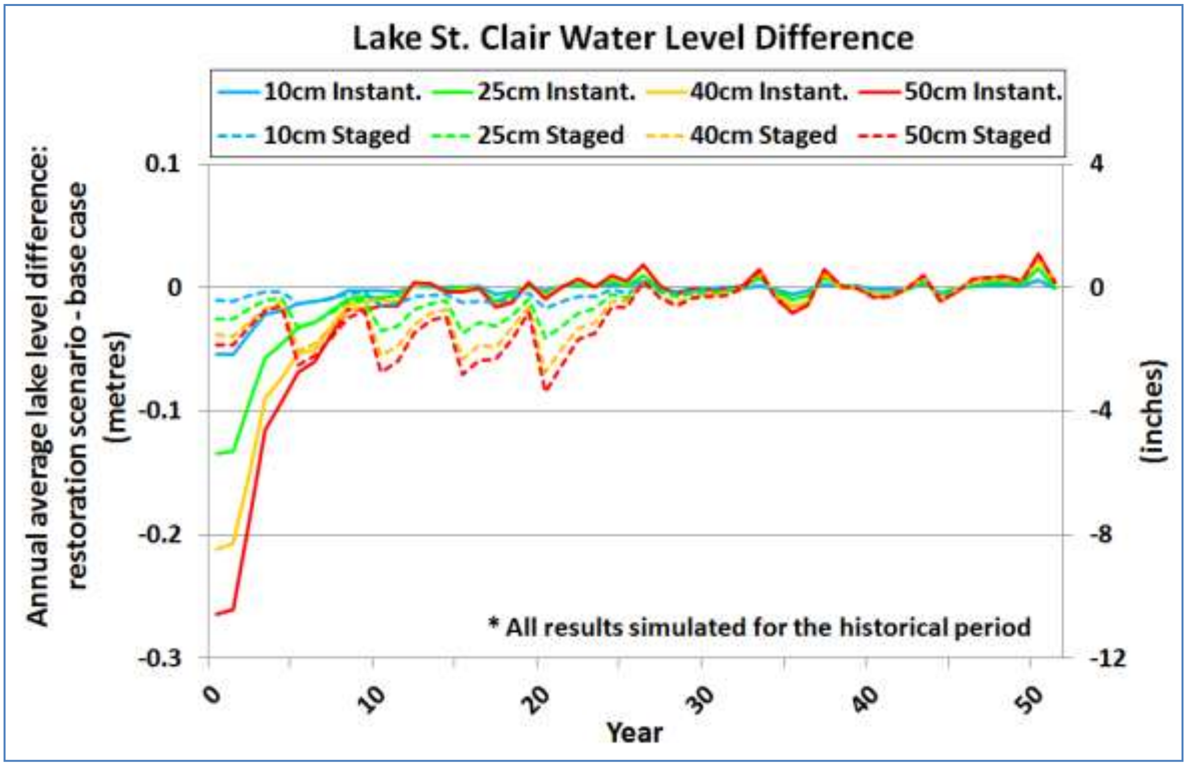
Figure 7-2
Simulated Restoration Impacts on St. Clair River Flows



The initial reduction in flow would also temporarily lower the levels of the downstream lakes. For example, Figure 7-3 shows the impacts of different restoration scenarios on Lake St. Clair water levels. Note that as the restoration level increases, its downstream impacts also increase. One way to mitigate downstream impacts is by employing a staged construction scenario, where construction of restoration structures would be scheduled over several years or even decades. For example, if it were decided to restore Lake Michigan-Huron levels by 25 cm (9.8 in), with the full restoration structure constructed all at once, then the maximum impact on the annual average water level of Lake St. Clair was estimated to be approximately 13 cm (5 in). If instead the restoration structure construction were staged in five equal increments, each spaced five years apart, then the maximum downstream impact on Lake St. Clair would be reduced to less than about a 4 cm (about 1.6 in) reduction in lake levels, though this would occur each time an additional stage of the new series of structures was installed.

The timing of restoration also plays a critical role in the magnitude of possible impacts. For example, if restoration were to occur during a low water period, it would exacerbate downstream impacts on lakes St. Clair, Erie and Ontario. Results showed that a "worst-case", poorly-timed 10 cm (3.9 in) instantaneous restoration would drop "record" low Lake Erie water levels by an additional 7 cm (2.8 in). Similarly, a "worst-case" poorly-timed 25 cm (9.8 in) instantaneous restoration would drop "record" low Lake Erie water levels by an additional 12 cm (4.7 in).

Figure 7-3
Simulated Restoration Impacts on Lake St. Clair Water Levels



7.3 Overview of Restoration Structures Options

The first component of restoration analysis, as outlined in section 7.2.2, involved the determination of the hydrological feasibility and impacts of a series of hypothetical structures. The second component of the restoration analysis involved the description and technical assessment of specific structural options that could be constructed in the St. Clair River to restore Lake Michigan-Huron water levels. Given the exploratory nature of the analysis, the work was limited to an examination of four structures previously reviewed in the literature (Bruxer, 2011), as well as two relatively new technologies.

The structures reviewed from past studies were limited to restoring water levels by up to 25 cm (9.8 in). Structures to provide greater levels of restoration likely are possible, but have not been examined to date, and would therefore require further study. The structures reviewed here do not comprise a comprehensive list of possible restoration options, but rather illustrate a range of technically feasible options that could be used to raise levels of Lake Michigan-Huron. Similarly, the construction costs presented in this section are intended to provide a general indication of the order of magnitude of the likely costs for various restoration structures, and are not intended to represent a formal estimate of future cost streams discounted to present values.

Table 7-2 summarizes the restoration structures reviewed, including the restoration level on Lake Michigan-Huron that could be achieved by means of that particular technology (based on the designs presented in past studies) and an estimate of the corresponding minimum construction costs.

Table 7-2
Summary of Restoration Structures

Restoration Structure	**Restoration Level[1]**	**Impact Duration[2]**		**Estimated Minimum Construction Cost[3]**
		Lake Huron	Downstream Lakes and Channels	
1. Submerged Sills	10 cm (3.9 in) to 25 cm (9.8 cm)	Permanent	Transient	10 cm (3.9 in): $30 million 25 cm (9.8 cm): $65 million
2. Fixed Dikes/Weirs (extending into Lake Huron at its outlet)	16 cm (6.3 in)	Permanent	Transient	$150 million
3. Fixed Dikes (across east channels at Stag and/or Fawn Islands; with training walls)	Stag Island only: 16 cm (6.3 in) Fawn Island only: 5 cm (2 in)	Permanent	Transient	Stag Island: $120 million Fawn Island: $80 million
4. Hydrokinetic Turbines	3 to 19 cm (3.5 to 7.5 in) (depending on size, number and location of turbines)	Partially adjustable[4]	Transient, but recurring	No estimate
5. Inflatable Flap Gates (across east channels at Stag and/or Fawn Islands; with training walls)	10 to 16 cm (3.9 to 6.3 in)	Adjustable	Transient, but recurring	$130-170 million
6. Inflatable Rubber Weirs	No estimate	Adjustable	Transient, but recurring	No estimate

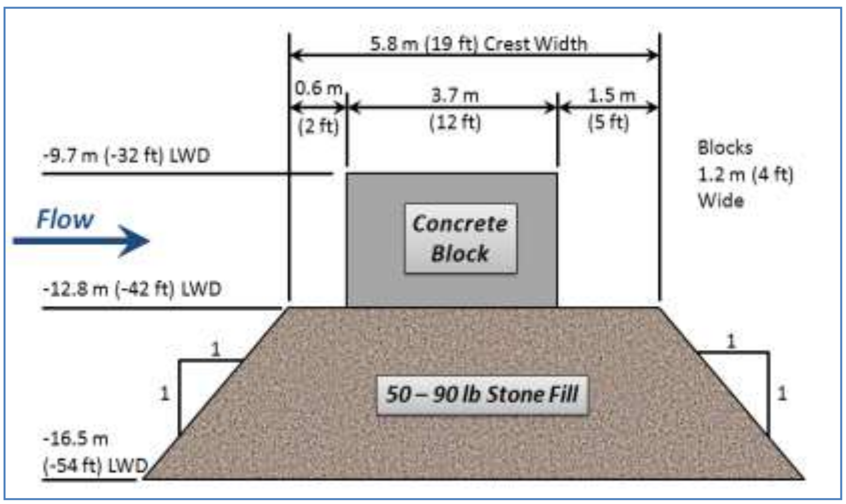
1. Depth of water restored on Lake Michigan-Huron based on designs from previous studies and studies conducted specifically for this analysis
2. Fixed restoration structures cause permanent impacts on upstream water levels and transient impacts downstream; adjustable structures can be regulated to raise upstream water levels only when desired, but this also results in recurring transient impacts
3. Costs in 2010 $US
4. Water level impacts of turbines could be reduced, but not eliminated, if turbine operation was ceased

7.3.1 Series of Submerged Sills in the Upper St. Clair River

Submerged sills act as "speed bumps" at the bottom of the river, restricting channel conveyance and raising upstream water levels by reducing the channel cross-sectional area and increasing the river bed roughness (Figure 7-4). Submerged sills have been the most studied option to date, likely as a result of their effectiveness, relatively low capital costs, and negligible impact on navigation. Previous studies (*e.g*., Moore, 1933; Franco and Glover, 1972) have suggested installing these structures in the upper reaches of the St. Clair River (Figure 7-5), given the close proximity to the outlet of Lake Huron, the narrowest and deepest area of the channel and the section with the highest velocity. Different combinations of sills could be used to provide different levels of restoration. In general, more and larger sills result in greater levels of restoration, though sill placement also affects their impacts.

Of all the different restoration structure options investigated in the restoration analysis, submerged sills were found to be the most economical alternative for nearly all levels of restoration (Frost and Merte, 2011). For example, restoration of 10 cm (3.9 in) would cost an estimated $30 million[2] using submerged sills.

Figure 7-4
Cross-section of a Submerged Sill



(Source: Adapted from Baird, 2009)

[2] Note: all dollars are in US$ unless otherwise noted.

Figure 7-5
Potential Submerged Sill Locations in the Upper St. Clair River

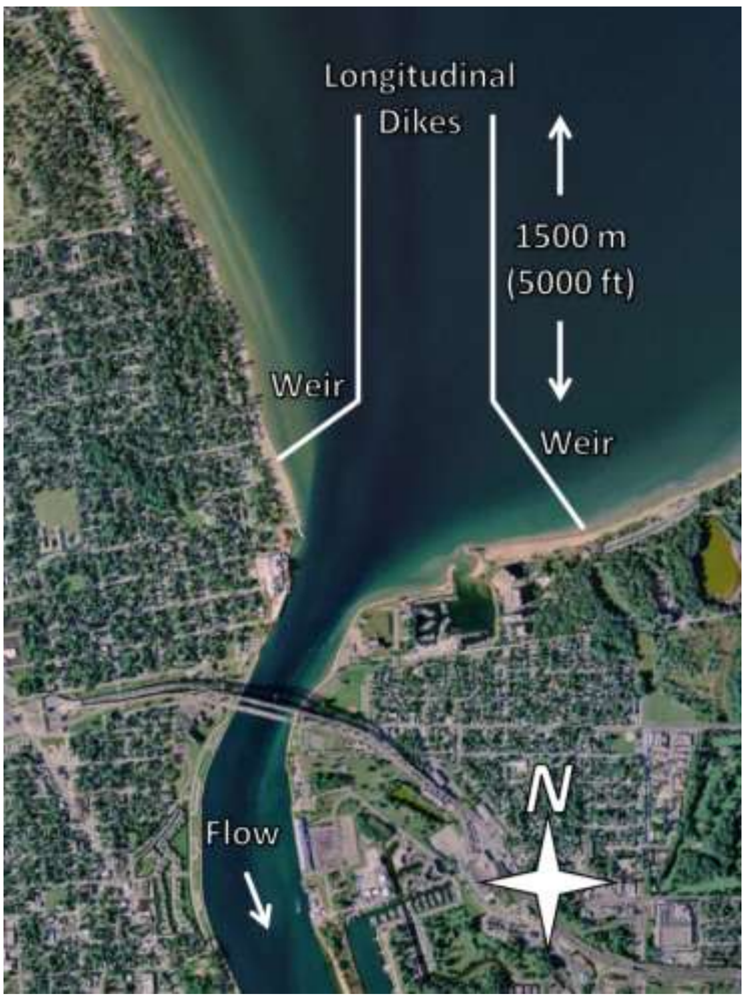
(Source: Adapted from Franco and Glover, 1972)

7.3.2 Parallel Dikes and Fixed Weirs

A second previously proposed restoration structure option involved the use of parallel dikes and weirs extending into Lake Huron. These dikes and weirs would raise the water level of the lake by decreasing the cross-sectional area of the lake outlet (*i.e.*, the St. Clair River) and extending the narrowed cross-section into the lake (Figure 7-6). Such a structure, as designed in previous studies, could be used to raise the water level of Lake Michigan-Huron by approximately 16 cm (6.3 in). The total project cost, including both construction and indirect costs, was estimated to be about $150 million.

With such a structure, some of the negative environmental impacts on the St. Clair River discussed in section 7.5 might be avoided. For example, it would not restrict fish migration between the St. Clair River and Lake Huron. However, this structure might also interfere with sediment transport, as it could trap sediment that normally enters the St. Clair River from Lake Huron. This extensive structure would also be large and visually obtrusive.

Figure 7-6
Plan View of Parallel Dikes Extending into Lake Huron



(Source: Adapted from Moore, 1933)

7.3.3 Rock-fill Dike Obstructions at Stag and Fawn Islands

Fixed rock-fill dikes acting as embankment dams across the east channel at Stag Island and Fawn Island could be used to raise water levels by restricting the total cross-sectional area of the St. Clair River and forcing all flow to pass through the west channel at each island (Figure 7-7). Training walls would be extended upstream and downstream from each island to increase the effectiveness of the structures and make the head drop more gradual so as not to interfere with navigation or cause other unintended negative consequences.

This option could be detrimental to both commercial navigation (due to increased velocities in the main navigation channel) and non-commercial boating (due to closure of the secondary eastern channels). However, effects on navigation during construction would likely be smaller than for construction of submerged weirs because vessels would be able to proceed through the unobstructed western channel.

Based on previous studies and hydrodynamic modelling, the Study found that without the training walls, the effect of the Stag Island obstruction is about a 9 cm (3.5 in) increase in water levels on Lake Michigan-Huron. With the addition of the training walls, the resulting backwater effect would be about 16 cm (6.3 in). For the Fawn Island obstruction, the effect of the weir alone was estimated to be only a 1 cm (about 0.4 in) increase in Lake Michigan-Huron water levels. With the addition of training walls, the lake level restoration effect of the Fawn Island obstruction is increased to 5 cm (2 in).

The combined effect of dike obstructions with training walls at both Stag Island and Fawn Island was estimated to be an increase in water levels of 21 cm (8.3 in). The total cost of the Stag Island obstruction was estimated to be about $120 million, while the total cost of the Fawn Island obstruction was estimated to be about $80 million.

Figure 7-7
Plan View of Rock-fill Dike Obstruction at Stag Island

(Source: Adapted from Moore, 1933)

7.3.4 Hydrokinetic Turbines

A fourth form of restoration structure considered in the analysis was hydrokinetic turbines. Similar to wind turbines, which harness the power of wind to produce energy, hydrokinetic turbines can be used to convert the kinetic energy of moving water into hydroelectricity (Figure 7-8). The St. Clair River may be a good candidate for such turbines, as are the other Great Lakes connecting channels, given their relatively swift currents in some areas, the relatively low variability of their flows and their large cross-sections. In fact, experimentation with this technology has taken place in recent years in the Great Lakes, with a pilot demonstration of turbines conducted in the St. Lawrence River near Cornwall, ON[3], and an alternative technology being tested with prototypes installed in the St. Clair River itself[4].

The installation of hydrokinetic turbines in a flowing stream would have several impacts on the hydrodynamics of the river. The physical presence of the turbines would modify flow patterns, and generation of power from the turbines will remove energy from the flowing water. Both of these impacts would result in an increase in water levels upstream. It follows that water level impacts of turbines could be reduced, but not eliminated, if turbine operation was ceased. Therefore, hydrokinetic turbines can be considered a partially adjustable option for restoring water levels of Lake Michigan-Huron. The turbines could be operated when levels were low to maximize water level impacts, and turned off when levels were high to minimize water level impacts. However, this might be undesirable from a hydropower production perspective, and operations would need to be managed with a regulation plan.

Figure 7-8
Example of a Hydrokinetic Turbine

(Source: verdantpower.com)

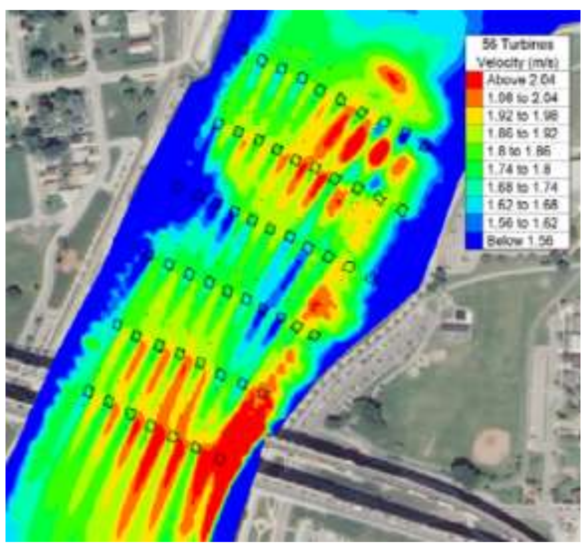
[3] See: verdantpower.com
[4] See: vortexhydroenergy.com

The impact of hydrokinetic turbines on water levels would be small and would depend on a number of factors. Results of a hydrodynamic modelling study of hydrokinetic turbines in the St. Clair River commissioned by the Study showed that the rise in Lake Michigan-Huron water levels varied depending on the number of turbines deployed, where they were located, and the flow in the river (National Research Council Canada, 2011). The most effective location for power production would be the upper St. Clair River near the Bluewater Bridge, where current velocities are highest and the channel is deepest, thereby allowing for the installation of the turbines without interfering with navigation.

Hydrodynamic modelling showed that if deployed in this area, 56 large turbines (Figure 7-9), each 6.5 m (about 21 ft) in diameter, would have an incidental impact on raising lake levels by 9 cm (about 3.5 in) under average flow conditions, while producing approximately 1.3 MW of power. Similarly, 151 turbines of the same size would raise levels by about 19 cm (about 7.5 in), while producing 2.5 MW of power.

However, as discussed in section 7.5, the upper St. Clair River is also a primary spawning area for an at-risk species, the Lake Sturgeon. If a similar number of turbines were instead installed further downstream, where currents are slower, the resulting rise in Lake Michigan-Huron water levels would be reduced substantially, with the impact of 150 turbines being between 3 and 7 cm (about 1 to 2.8 in), and with power production ranging from 0.3 to 1.1 MW, depending on turbine configuration. In addition, since depths are shallower in the downstream reaches of the river, turbines in these areas would encroach on and increase velocities in the navigation channel and interfere with commercial navigation traffic.

Figure 7-9
Wake Simulated by 56 turbines in the Upper St. Clair River

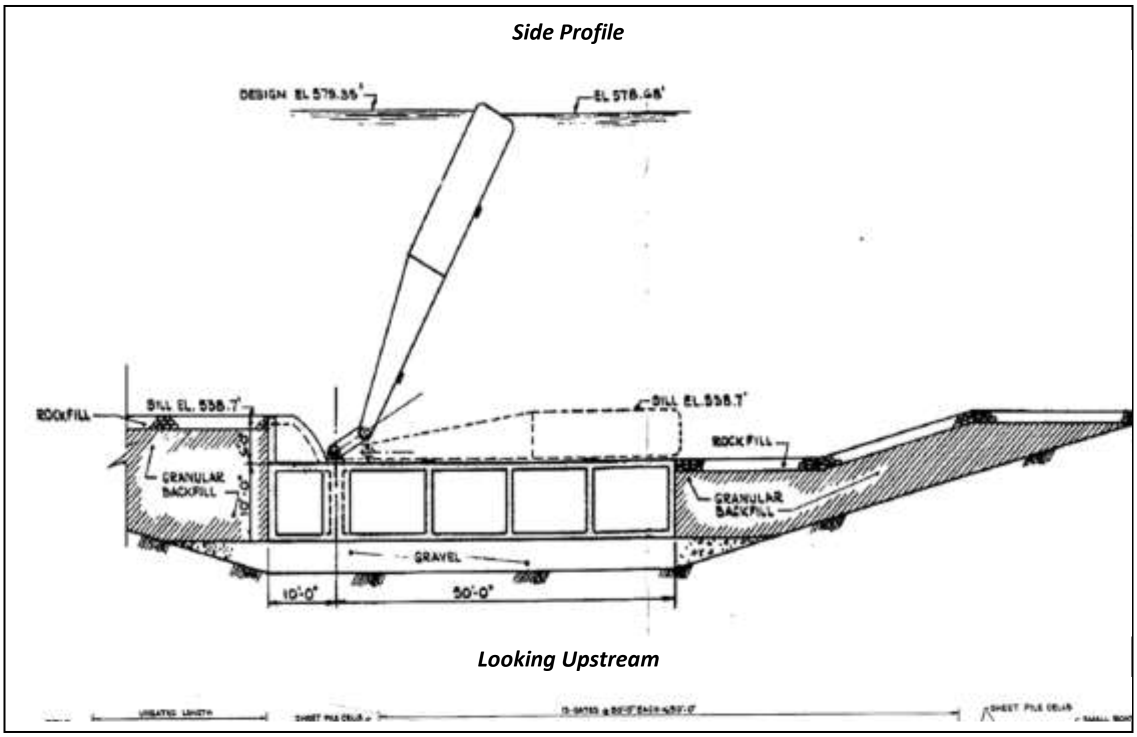


(Source: National Research Council Canada, 2011)

7.3.5 Inflatable Flap Gates

Another structural option reviewed from previous studies was an adjustable structure, using inflatable flap gates at Stag Island and/or Fawn Island (International Great Lakes Levels Board [IGLLB], 1973; Levels Reference Study Board, 1993) (Figure 7-10). Strictly speaking, this structure would not be considered a restoration structure, given that it is adjustable and would provide a limited ability to regulate water levels of Lake Michigan-Huron.

Figure 7-10
Preliminary Design of an Inflatable Flap Gate at Stag Island



(Source: Adapted from IGLLB, 1973; original imperial units, not converted to metric.)

Under this option, compressed air would be pumped into the metal flap gates to raise them and obstruct flow. The gates could be deflated to lower them out of operation. Based on the rock-fill dike results above, it is assumed that such a structure, if located at Stag Island and combined with training walls, would provide the ability to raise water levels by approximately 10 to 16 cm (3.9 to 6.3 in) when the structure is in a raised, operating position. However, in contrast to the fixed structures described above, the inflatable gates could also be lowered when levels are high, so as not to raise water levels further.

It is important to note that after raising the gates, a time-lag of several years would be required for the full effect to be realized. Similarly, upon lowering the gates, several years would be required for their impacts to be dissipated. In addition, if the flap-gate structure were raised, velocities in the western channel would increase such that, similar to the fixed obstruction option, mitigative measures may be required to slow the current and prevent erosion in this reach of the river.

The total cost of constructing the inflatable flap gate option at Stag Island (with training walls) was estimated to be in the range of $130 to $170 million. The analysis estimated that the cost of providing

150 low-submerged sills as mitigative measures would be about $50 million (in addition to the costs of the flap-gate structures themselves). Finally, any adjustable regulation structure would require a regulation plan and associated ongoing operation and maintenance costs.

7.3.6 Inflatable Rubber Weirs

Inflatable rubber weirs, one of the two relatively new technologies (along with the hydrokinetic turbines) explored in the restoration analysis, have been proposed in the past as an adjustable option for raising the water levels of Lake Michigan-Huron (Baird, 2009). Similar to the inflatable metal flap gates, inflatable rubber weirs would be considered a regulation option, as opposed to a fixed restoration option, given that they are adjustable.

These weirs are an alternative to more conventional gate options used in regulation structures. They have been primarily used in much smaller applications, such as raising the crest of an existing dam or spillway (American Society of Civil Engineers, 1994; International Commission on Large Dams [ICOLD], 1998). Currently, the largest inflatable rubber weir system in the world is the Ramspol Storm Surge Barrier in the Netherlands (Jongeling and Rövekamp, 1999) (Figure 7-11). It consists of three weirs, each 75 m long, 13 m wide and 8.35 m high (about 246 ft by 43 ft by 27 ft), which are used to prevent flooding caused by storms during periods of high water. The St. Clair River, in comparison, is much wider, between 400 and 800 m (about 1,312 to 2,624 ft) in the main channel, and much deeper, about 10 to 25 m (about 33 to 82 ft). The east channels at Stag and Fawn Islands are also relatively wide (400 and 250 m [1,312 and 820 ft], respectively) and deep (about 10 m [33 ft]). There is no known precedent for an inflatable rubber weir of this size.

Inflatable rubber weirs could also be used as submerged sills, but no examples of this application were found, and the literature reviewed indicated that these may deflate when the depth of water above the inflatable bladder is 30 to 40 percent of its height (ICOLD, 1998). Given these limitations, it appears unlikely that inflatable rubber weirs would be a viable option for the St. Clair River at this time.

Figure 7-11
Inflatable Rubber Weirs at the Ramspol Storm Surge Barrier

(Source: Delta Marine Consultants; see www.dmc.nl)

7.4 Analysis of Impacts of Restoration on the Key Interests

The third component of the restoration analysis involved evaluating the impacts of various restoration scenarios on the key interests served by the upper Great Lakes system (see **Chapter 3** for more information on these key interests) using the SVM.

7.4.1 Restoration Scenarios

The Study examined 11 restoration scenarios. These included the eight original 10, 25, 40 and 50 cm (3.9, 9.8, 15.7 and 19.7 in, respectively) restoration scenarios using both the instantaneous and staged construction assumptions described in section 0. These were labelled by the depth of water, in cm, restored on Lake Michigan-Huron and whether the restoration was effected instantaneously (**10 RI, 25 RI, 40 RI and 50 RI**) or in stages (**10 RS, 25 RS, 40 RS and 50 RS**).

Two additional scenarios, denoted as **77R1** and **77R2**, representing different Lake Superior regulation options for restoring lake levels, were also evaluated. Each of these would result in an instantaneous 10 cm (3.9 inch) restoration on Lake Michigan-Huron, but having different Lake Superior release assumptions:

- 77R1 employed the current Plan 1977A release rules for Lake Superior as opposed to the static Lake Superior assumption used for the eight RI and RS plans introduced above; and,
- 77R2 had rules to reduce the Lake Superior outflow to Lake Michigan-Huron when the latter lake is high, allowing water to be stored in Lake Superior.

The final scenario evaluated, denoted as **StagIs LR**, provided for the special case of limited regulation using a simple inflatable flap gate structure to obstruct flow through the east channel at Stag Island on the St. Clair River. Such a structure would require a set of operating rules, and for this initial investigation it was assumed that the gates would be raised and flow restricted whenever the level of Lake Michigan-Huron at the beginning of the month was below 176 m (577.4 ft), the chart datum elevation on this lake.

7.4.2 Summary of Restoration Impacts on the Key Interests

The seven Study Board criteria used to rank Lake Superior regulation plan options (see **Chapter 6**) were applied to evaluate the acceptability of the 11 different restoration scenarios. Figure 7-12 provides an overview of the impacts on the key interests.

Overall, the evaluations of the restoration scenarios revealed a mix of benefits and costs, and both positive and negative environmental impacts on the different interests. Note that the economic values assigned to benefits and impacts in this section are intended to provide an order of magnitude value by which to compare relative impacts of different restoration scenarios to the baseline (zero restoration) case. The values do not represent the results of a formal cost-benefit study in which a net stream of future benefits or costs is discounted to present values.

Figure 7-12
Summary of Restoration Impacts on the Key Interests

Domestic, Municipal and Industrial Water Uses

Restoration would have no adverse impact on municipal and industrial water users, based on historical water supplies. However, if future climate conditions are significantly drier, restoration would be expected to help offset the adverse impacts of extreme low water.

Commercial Navigation

Restoration would permanently raise Lake Michigan-Huron levels, allowing ships to carry heavier loads and reduce costs. There would be some negative impacts on Lakes St. Clair and Erie during the initial period as water levels adjust to the new regime, but these negative impacts would be minimal when compared to the long-term benefits gained on the upstream lakes.

Hydroelectric Generation

At the St. Marys River, restoration of Lake Michigan-Huron levels would cause a decrease in the head difference between the upper and lower St. Marys River, resulting in a permanent decrease in power production. Downstream, restoration would cause a temporary decrease in hydropower production at Niagara River plants, as water held back to raise levels of Lake Michigan-Huron would be unavailable downstream.

Ecosystem

Restoration would provide some benefits to ecosystems, including improved fish spawning habitat in the St. Marys River and maintenance of fish access to eastern Georgian Bay wetlands. However, ecosystems in the St. Clair River system, including habitat that supports several species at risk, would be adversely affected.

Coastal Zone

Restoration would increase extreme high lake levels, leading to more flooding and erosion. Changes in water level management scenarios could alter the magnitude, frequency and duration of water levels outside the normal range, adversely affecting the functional lifespan of existing shore protection infrastructure and leading to increased failures. Restoration would generally cause the greatest damages around the more heavily-populated southern shores of Lake Michigan and the south-eastern shores of Lake Huron.

Recreational Boating and Tourism

Restoration of Lake Michigan-Huron water levels would be beneficial for recreational boaters, as there would be less chance that marina slips would have insufficient depth to be used during low water periods, and boat launches would not have to deal with low water conditions. Downstream, restoration would not benefit recreational boaters, but the negative impacts would be only minor, temporary increases in unusable marina slips during the period immediately after the restoration project is constructed.

Indigenous Peoples

Indigenous peoples make extensive use of the fish and biological resources of the St. Clair River system. They would be adversely affected by restoration structures that impact fish habitat and ecosystems in the St. Clair River and Lake St. Clair.

For example, commercial navigation interests would benefit from greater depths resulting from restoration, with the SVM estimating net benefits of about $4 million annually for the 10 cm (3.9 in) restoration scenarios, and up to $15 million annually for the 50 cm (19.7 in) scenarios. Recreational boating interests would also benefit from greater depths. By contrast, coastal zone interests would be adversely affected, with annual shore protection costs estimated to increase by $500,000 for the 10 cm (3.9 in) staged restoration scenario (**10 RS**) and up to approximately $3 million dollars for the 50 cm (19.7 in) instantaneous restoration scenario (**50 RI**). Hydroelectric generation interests would also experience negative impacts, with losses estimated at up to an average of $3 million annually for the 50 cm (19.7 in) restoration scenarios. Similarly, there is a tradeoff between the positive ecological effects, which would be concentrated in the wetlands of the Georgian Bay region, and the uniformly negative ecological effects in the St. Clair River system (*i.e*., the St. Clair River, Lake St. Clair and the Detroit River) that would result from any of the proposed restoration structures (see section 7.2.5). Under the base case scenario, Georgian Bay wetlands experience up to six years where severe, long-lasting or permanent adverse impacts occur, but these were found to be entirely eliminated by restoration of 25 cm (9.8 in) or greater.

Also of note is that while the **StagIs LR** scenario would help prevent adverse shore protection impacts (because this adjustable structure would be lowered during periods of high water), the benefits to navigation and the ecosystem interests would be reduced (*e.g.*, net benefits of only $1 million annually on average for commercial navigation; Georgian Bay wetlands would experience only three fewer years of the most adverse water level conditions). This is a result of the small increase in water levels this structure would establish (about 10 cm or 3.9 in) coupled with the long period of time it would take to achieve this (about 10 years) whenever the structure were put into operation.

Finally, there has been considerable development around the Great Lakes over the past 50 years. Much of this development has adapted to the historical range of levels through various land use regulations. Adding an increment of restored water levels to the Lake Michigan-Huron system would require a broad-scale regulatory adjustment, across numerous agencies and jurisdictions, to minimize future flood damages.

Restoration, GIA and Climate Change

In considering the impacts of restoration on the key interests, the effects of both GIA and climate change must be taken into account. For example, note that in the Georgian Bay area, GIA is causing the land in this area to rise, relative to the lake outlet, at a rate of approximately 17 to 27 cm (about 6.7 to 10.6 in) per century (Mainville and Craymer, 2005), depending on the location (see **Chapter 1**). As a result of GIA, Georgian Bay will continue to experience relatively lower water levels over time compared to other areas of Lake Michigan-Huron. Restoration would temporarily help to counteract the effects of GIA and lowered water levels in Georgian Bay. However, much of the densely populated southern portion of each of the Great Lakes, which includes large urban centers such as Chicago and Milwaukee, is experiencing an increase in water levels over time as a result of GIA. The land in this region is subsiding relative to each lake's outlet, with rates varying from about 8 to 25 cm (3.1 to 9.8 in) per century. Therefore, even a 10 cm (3.9 inch) restoration of Lake Michigan-Huron levels would compound the effects of GIA, with increased flood damage and erosion.

In addition, the impacts of restoration that were analyzed by the Study were based on simulated results using recorded historical NBS. Future climate scenarios were not directly considered. However, as outlined in **Chapter 4**, the Study Board concluded that there is significant uncertainty regarding how climate change will affect Great Lakes water levels. The possibility cannot be ruled out that water levels both higher and lower than those observed in the past could be experienced in the future. As a result, the impacts of restoring Lake Michigan-Huron water levels – both positive and negative – would be magnified by the impacts of climate-driven changes in water supplies. For example, if water levels become generally lower in the future, the commercial navigation sector and Georgian Bay wetlands will be negatively impacted, and restoration could help mitigate these adverse effects. Conversely, if water levels become generally higher in the future, flood damages would increase, and restoration would exacerbate these negative impacts.

7.5 Environmental Considerations in the St. Clair River System

The Study concluded that restoration structures would have both positive and negative environmental effects. Higher Lake Michigan-Huron levels as a result of restoration would provide benefits in:

- the St. Marys River, with improved fish spawning habitat; and,
- Georgian Bay, where wetlands, which have suffered significantly during low water levels in the past, support important fish habitat.

However, the Study determined that restoration structures would have significant adverse environmental impacts on the St. Clair River system, home to five listed species-at-risk (endangered or threatened), including the Lake Sturgeon. Environmental laws of both Canada and the U.S. require that this unique habitat be protected.

For example, a series of submerged sills or a network of hydrokinetic turbines in the upper St. Clair River would have serious adverse impacts on the Lake Sturgeon population, as this area of the river, with its fast currents and clean cobble substrate, represents the most significant Lake Sturgeon spawning habitat in the Great Lakes (Figure 7-13). Lake Sturgeon also migrate through this area as they travel between the lower reaches of the river and Lake Huron during their life cycle. Potential Lake Sturgeon spawning habitat sites have also been identified near Stag and Fawn Islands. Moreover, Lake Sturgeon have been extirpated from every tributary in Lake Erie as well as the Michigan side of Lake Huron. The St. Clair-Detroit River corridor population now functions as the source population for this region, and is vital to recovery efforts taking place in this part of the Great Lakes in both the United States and Canada. Additional stresses on this population caused by structures of any form would unquestionably impede these efforts. The potential for significant adverse environmental effects on Lake Sturgeon and other fish species as a result of the establishment of restoration structures on the St. Clair River was confirmed to the Study by independent experts in both Canada and the United States.[5]

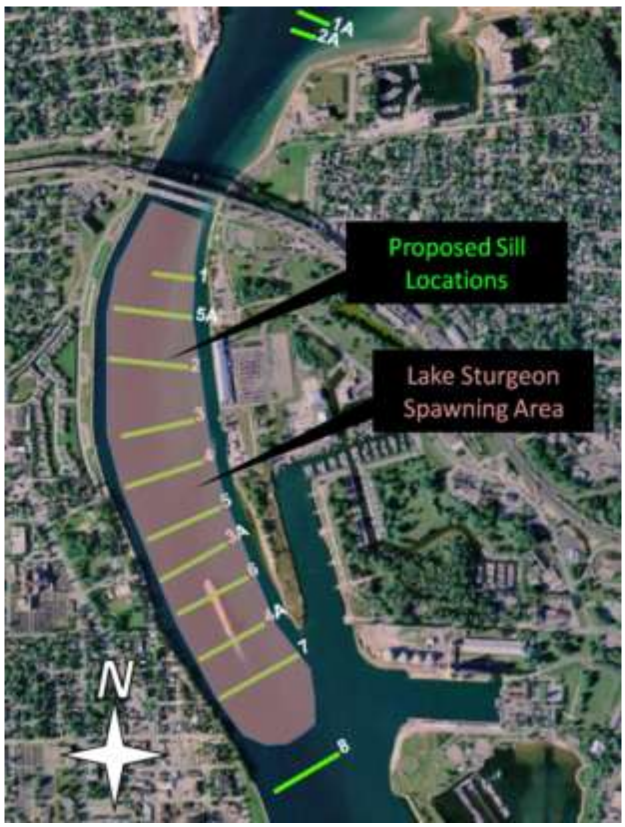
Significant reductions in water levels, such as those which might occur during the time it takes for water levels to adjust to the restoration structures, also could have a significant adverse, though transient, impact on the Lake St. Clair fishery. The lake supports an extremely valuable recreational fishery for Walleye, Yellow Perch, Smallmouth Bass and Muskellunge, and provides habitat for several other recreationally and commercially important species. As indicated in Figure 7-3, these transient impacts could last about 10 years after construction was completed.

[5] Personal communications to the Study, October 17, 2011 from: L. Mohr, Ontario Ministry of Natural Resources; and J. Boase, United States Fish and Wildlife Service.

Restoration also could cause an increased risk for disturbance and re-suspension of the contaminated sediments that are located throughout the St. Clair River, particularly along the Canadian shoreline. The placement of structures at or near Stag Island may be of particular concern, given that this location is associated with high priority contaminated sites. Additionally, restoration structures can disrupt sediment transport. For example, the longitudinal dikes and weirs extending into Lake Huron could trap sediment that normally enters the St. Clair River from the lake, while structures constructed in the river can trap sediment that normally moves down the channel itself. This loss of sediment supply from Lake Michigan-Huron could affect bottom substrates further down the river, impacting critical fish habitat.

Finally, residents of the First Nations Reserve Walpole Island, located at the St. Clair River delta, make extensive use of fish and biological resources in this area. Any negative impacts to these resources would affect this interest directly and require formal consultations.

Figure 7-13
Overlapping Zone of Proposed Sill Locations and Lake Sturgeon Spawning Habitat in the Upper St. Clair River



(Source: adapted from Haas and Thomas, 2011)

7.6 Institutional Considerations

The Study investigated the key institutional issues concerning restoration of Lake Michigan-Huron water levels, focusing on procedures and requirements for building new structures (Brown, 2011). These considerations included: an assessment of the need for a bi-national study and the scope and nature of that study; required authorizing legislation; the requirement for new IJC Orders of Approval; other required regulatory and environmental approvals; the specific role of the IJC versus 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.

The construction of any new restoration structure would require the ongoing commitment and financing of the governments of Canada and the United States, a process that could take 20 years or more for the full range of planning, environmental reviews, regulatory approvals and design steps. If the IJC were to recommend structural measures in the St. Clair River and the governments of Canada and the United States agreed to pursue this recommendation, then it is likely that a new bi-national entity, comparable to the one established for the St. Lawrence Seaway project, would need to be considered. Furthermore, the IJC and its International Lake Superior Board of Control would have to adjust the Lake Superior regulation plan to accommodate the higher water level regime that would be established on Lake Michigan-Huron.

7.7 Key Points

With respect to the analysis of the feasibility and implications of raising water levels of Lake Michigan-Huron to compensate for past natural and human-induced changes by means of restoration structures in the St. Clair River, the following points can be made:

- Non-adjustable restoration structures have a permanent impact on water levels upstream, as well as a temporary effect on water levels downstream. Adjustable restoration structures affect water levels upstream and downstream with each deployment.

- The IJC directed the Study to conduct an exploratory analysis of methods and impacts of restoring Lake Michigan-Huron water levels. The IJC stated that it did not request the Study Board to make any recommendation as to implementing a particular restoration option. Rather, it directed that the restoration analysis *"... provide Governments and the public with extremely valuable information and insight to help form the basis for rational and scientifically-based decision making"*.

- The Study conducted modelling of the Great Lakes-St. Lawrence River system by adjusting St. Clair River hydraulics to simulate the physical effects of water level restoration options on Lake Michigan-Huron and effects downstream through Lake Erie. The results showed that:

  - water levels on Lake Michigan-Huron would start to rise as soon as the St. Clair River conveyance was reduced, with the full level of restoration achieved about 30 years later in the case of staged construction;
  - restoration would reduce the occurrences of extreme low water levels on Lake Michigan-Huron, but also increase the number of occurrences of extreme high lake levels;
  - the reduction in conveyance capacity would initially lower the flow through the St. Clair River; however, as levels on Lake Michigan-Huron rise, flows through the St. Clair River would again

gradually increase until they were essentially the same as they would have been prior to restoration construction; and,
- the initial reduction in flow of the St. Clair River would temporarily lower the levels of the downstream lakes; the greater the restoration level, the greater the downstream impacts.

- The Study reviewed the feasibility of permanently raising Lake Michigan-Huron water levels by means of four previously studied and two new engineering technologies that could be installed in the St. Clair River system. The analysis concluded that several of the technologies were technically feasible. The four technologies reviewed from past studies were limited to providing up to 25 cm (9.8 in) of restoration. Updated construction cost estimates ranged from about $30 million to about $170 million, depending on the technology and level of restoration provided.

- The Study Board examined the impacts of 11 restoration scenarios. The results showed a mix of benefits and costs for the key interests served by the upper Great Lakes system. Commercial navigation and recreational boating and tourism interests would benefit, while coastal zone, hydroelectric generation and Indigenous peoples interests would be adversely affected.

- The Study Board concluded that restoration structures would have both positive and negative environmental effects. Positive effects would be concentrated in the wetlands of the Georgian Bay region, which have suffered significantly during low water levels in the past, but would benefit from higher Lake Michigan-Huron levels. Significant adverse environmental effects would be experienced in the St. Clair River system, a system that has also been stressed in the past, as restoration structures would impact important habitat of endangered species, including the Lake Sturgeon, and would have adverse effects on the Lake St. Clair fishery. Restoration also could lead to an increased risk for disturbance and re-suspension of the contaminated sediments that are located throughout the St. Clair River, particularly along the Canadian shoreline.

- Any future restoration effort in the upper Great Lakes basin must take into account GIA, which is causing different regions of the basin to rise or fall relative to each lake’s outlet. Without restoration, as a result of GIA, Georgian Bay will continue to experience relatively lower water levels over time compared to other areas of Lake Michigan-Huron. Restoration would temporarily help to counteract the effects of GIA and lowered water levels in Georgian Bay. However, restoration of Lake Michigan-Huron levels would compound the effects of GIA in much of the densely populated southern portion of the upper Great Lakes, which is subsiding relative to the lake’s outlet.

- The impacts of restoring Lake Michigan-Huron water levels – both positive and negative – also would be magnified by the impacts of climate change. For example, if water levels become generally lower in the future, the commercial navigation sector and Georgian Bay wetlands will be negatively impacted, and restoration could help mitigate these adverse effects. Conversely, if water levels become generally higher in the future, flood damages would increase, and restoration would exacerbate these negative impacts.

- Finally, in reviewing the institutional considerations of restoring Lake Michigan-Huron water levels, the analysis found that restoration structures would require the ongoing commitment and financing of the governments of Canada and the United States, a process that could take 20 years or more for the full range of planning, environmental reviews, regulatory approvals and design steps.