Prepared for:
Georgian Bay Forever

Prepared by:
AECOM Technical Services, Inc.
April 29, 2016

Providing Structural Solutions for Adaptive Management in the Great Lakes

Creating Climate Resilience

Photo Courtesy of Upper Great Lakes Study Board

Table of Contents

Appendices

Tables

Figures

Executive Summary

Georgian Bay Forever (GBF) has had a long-standing concern over pronounced water level fluctuations, and the adverse impacts that extreme highs and lows have on Lake Michigan-Huron and the Great Lakes-St. Lawrence River System as a whole. An economic impact assessment commissioned by GBF and released in 2014, for example, found that declining water levels in the system will result in $18.82B in economic loss over the next 25 years if structural interventions do not take place. Building upon that work, GBF commissioned AECOM Technical Services, Inc. (AECOM) to prepare a study to "provide viable structural options for the long term climate resilient protection of water levels in the upper Great Lakes." In so doing, AECOM responded to an unmet need in the 2012 International Upper Great Lakes Study (IUGLS), where the International Joint Commission (IJC) indicated that an examination of additional lake level control structures had merit, although it was beyond the scope of that study.

The AECOM study entailed the examination of over a dozen structural alternatives organized into categories of Compensatory Structures (i.e., submerged sills, weirs, jetties, river training walls, wing dikes); Power Generating Structures (i.e., conventional hydroelectric dams, In-stream turbines); Adaptive Management Structures (i.e., inflatable flap gates, inflatable dams, control/sector gates); and "Other" Structures (i.e., ice booms, landfill and control gate structures). These alternatives range from well-established, extensively researched structures, to emerging technologies with limited applications, to new ideas developed specifically to address lake level controls within the Great Lakes-St. Lawrence River System.

The various alternatives were examined by AECOM in light of existing data and information, and subsequently evaluated on the basis of seven criteria that include performance, implementation, cost, regulatory requirements, climate resiliency, environmental impacts, and social/cultural considerations. That review culminated in a decision to select three of the initiatives for additional analysis and "concept level" development:

- **In-stream turbines** to be installed on the river bed at two locations (i.e., Upper St. Clair River by the Blue Water Bridge, upstream of the St. Marys River Compensation Works). By reducing river flow when in operating mode, they will impact river hydrodynamics and increase water levels upstream, with power generation as an ancillary benefit.

- **Inflatable dams**, to be installed in the St. Clair River at Stag and/or Fawn Islands. As with the previous alternative, when the inflated dam is operational, river flow is reduced with a resultant increase in upstream water levels.

- **Park fill/control gates system**, to be constructed at the mouth of St. Clair River. The structure is composed of two new islands (involving stone revetment, sand fill, topsoil and landscaping) and two flood control gates that will be adjusted, as needed, to reduce river flow and increase upstream water levels.

The analysis of these three alternatives was complemented by a series of conversations with various interested parties to gain perspectives on the notion of additional structural controls for Lake Michigan-Huron.

Based on evaluation outcomes and the "concept level" analyses, it was found that these three structural alternatives have potential merit as additional lake level control mechanisms, either singly or in combination, to achieve a GBF goal for the "long term climate resilient protection of the water levels of the upper Great Lakes." All three of these structural alternatives, as noted by AECOM, are characterized by strengths and weaknesses and, while they are potentially promising, all have data gaps that need to be filled to provide additional detail on items such as lake level control capabilities, installation and operational costs, regulatory considerations, and perspectives of affected parties. For these reasons, it is *recommended that the IJC and the two federal governments support detailed design work on the three alternatives to better understand their potential to augment existing lake level control plans, procedures and structures.*

Preface

This report was commissioned by Georgian Bay Forever (GBF) and prepared by AECOM Technical Services, Inc. (AECOM).

GBF is a charity dedicated to scientific research and public education on Georgian Bay's aquatic ecosystem. Its mission is to "protect, enhance, and restore" the ecosystem "by funding accredited research on water levels, water quality, wetlands and invasive species; by educating the public and governments on issues regarding the environmental protection, conservation, the safety and preservation of the water and the natural features of the Georgian Bay area of Ontario; and by enhancing the public's appreciation for their environment."

GBF recognizes that pronounced fluctuations in the water levels of Lake Michigan-Huron have a substantial impact on an array of water-based activities. These fluctuations are exacerbated by impacts of climate change that are expected to result in a continued downward trend in levels in future years. A GBF-commissioned economic impact assessment released in 2014, for example, demonstrated that declining water levels in the Great Lakes-St. Lawrence River System will result in $18.82B in economic loss over the next 25 years if structural intervention does not take place.

In its 2012 International Upper Great Lakes Study (IUGLS), the International Joint Commission (IJC) indicated that an examination of structural measures to reduce pronounced lake level fluctuations has merit, while acknowledging that such a review was beyond the scope of that study.

This AECOM study addresses that unmet need by investigating "viable structural options for the long term climate resilient protection of water levels in the upper Great Lakes." Through the identification and evaluation of various long-term measures (i.e., physical infrastructure), the intent is to explore means to better regulate the level of Lake Michigan-Huron to mitigate the impacts of climate change and protect the $5.1 Trillion Great Lakes regional economy. Study outcomes will contribute to, and advance ongoing regional dialogue on structural alternatives that "take the edges off" pronounced fluctuations in water levels and, in so doing, enhance and safeguard the ecological and economic health of the resource.

This report is subject to additional review, prior to broad distribution, to address any minor, non-substantive items that may be found. Any such review will not affect study data, findings or recommendations.

I. Study Goals and Objectives

The goal of this study is to "provide viable structural options for the long term climate resilient protection of water levels in the upper Great Lakes." In this context, "climate resilience" pertains to the capacity of the system to adapt to a range of climate-induced stressors to maintain and sustain ecological function and economic value over the long term.

Various structural alternatives (previously and newly identified) were subjected to methodical review and evaluation based upon a series of criteria including performance, implementation, cost, regulatory requirements, climate resiliency, environmental impacts, and social/ cultural considerations. Ultimately, this produced several "preferred" structural alternatives that were then developed to "concept level" design and analysis.

Numerous objectives associated with the above-noted goal include the following:

- Undertake a thorough and methodical review of the literature to document and draw from, as appropriate, past studies of lake level fluctuation impacts and associated control mechanisms;
- Consider the preferences and suggestions of various affected parties regarding proposed alternatives, and endeavor to maximize ecological and economic benefits while minimizing or eliminating social, cultural and other concerns;
- Elevate attention to observed and anticipated climate change implications for water levels, and prospective mitigative actions;
- Build upon findings of the US/Canada International Upper Great Lakes Study (IUGLS) that recognized the merit of investigating various additional structural alternatives for lake level controls; and
- Identify and develop (to concept-level design), structural alternatives that warrant additional detailed analysis by the two federal governments as discussions of binational lake level regulation plans continue.

In addressing this goal and its multiple objectives, this report provides a basis for taking IUGLS outcomes a step further. Identified within are several structural alternatives that, based upon concept level design and analysis, may be viable means of achieving the "long term climate resilient protection of water levels in the upper Great Lakes."

II. Study Background and Methodology

A. Evolution of the Water Levels Issue

System-wide, Great Lakes water levels are highly dynamic and vary on different temporal scales, based on precipitation and evaporation levels (long-term), along with locally-induced storm events (short term). The issue of water level fluctuations (particularly those in Lake Michigan-Huron) has been a long-standing one; studies and discussions have taken place for decades.

Concerns have been exacerbated by the pronounced increase in lake levels in the 1980s, a precipitous drop in the level of Lake Michigan-Huron in the late 1990s, and an extended period of lower trending levels since that time. This trend is expected to continue, while recognizing that short-term surges will be observed given the dynamic nature of the system. The genesis of this trend can be found, in part, in structural changes to the St. Clair River due to factors such as navigational dredging and extraction of aggregates over an extended, multi-decadal period.

Water levels tend to reach a maximum in the summer months (i.e., reduced evaporation) and minimum in the winter months, with a long-term seasonal variation of approximately one to two feet. Recorded water level fluctuations sometimes exceed this range. For example, over the past 100 years, the annual average lake level rise or fall for Lake Michigan-Huron is between one and two feet, but the maximum range in fluctuation (maximum to minimum) is approximately seven feet. High water levels exacerbate concerns over coastal erosion and increased shoreline maintenance requirements, while low levels prompt concerns over adverse impacts on commercial and recreational navigation as well as beach quality (among others).

Periods of high or low water levels tend to persist for several years. For Lake Michigan-Huron, an extended period of high levels occurred between 1971 and 1989, while low water levels were observed between 1999 and 2012 (with a rebound in 2013). At present, the average lake level is approximately 2.0 ft Low Water Datum (LWD), which is 0.6 ft. above the long-term recoded average of 1.4 ft LWD. It is unclear whether current higher water levels represent an end to a period of low water levels, based on research by the National Oceanic and Atmospheric Administration (NOAA). It is possible that water levels may return to a low condition, based on the latest studies correlating water mass balance, precipitation and ice cover trends for the Great Lakes.

Connecting channels play a vital role in water level fluctuations. The Great Lakes have significant storage capacity; if the connecting channels have a restricted outfall, then large variations to the lakes supply will be compensated by the regulated outfalls, resulting in controlling lakes levels.

Dredging and deepening of the St. Clair River dates back to the1850s, and the subsequent increase in available flow area and river conveyance has resulted in a permanent change in the water level relationship between Lake Michigan-Huron and Lake Erie. This change, as well as lake level fluctuations at the system-wide level, has prompted a number of studies and legislative initiatives over the years. Among many others, this has included lake level references by the IJC, a GBF-funded study of the St. Clair River (2005), and a (long-standing yet dormant) U.S.

Congressional authorization for compensating works in the St. Clair and Detroit Rivers. Most recently, the IJC's Upper Great Lakes Study (UGLS) documented the historical significance of climate-induced lake level impacts on Lake Michigan-Huron and suggested that mitigative measures might include new structures in the St. Clair and/or Niagara Rivers.

GBF has a long-standing interest in the water levels of Lake Michigan-Huron and, more generally, the Great Lakes-St. Lawrence River System. The organization has expressed concern over the negative impacts of extreme fluctuations, as well as uncertainties associated with climate change impacts on future water levels. In response, GBF retained AECOM to prepare this study to advance regional dialogue on acceptable means to "take the edges off" extreme lake level fluctuations.

B. Key Assumptions in Study Conduct

In proceeding with this study, a series of key assumptions were adopted to guide the development and execution of study methodology. They are as follows:

1. Climate change has, and will continue to affect the levels and flows of the Great Lakes-St. Lawrence River System, potentially increasing the volatility (and extremes) of lake level fluctuations;

2. Identifying viable structural alternatives to enhance lake level control requires a multi-disciplinary approach that draws from engineering (i.e., coastal, water resources, civil), planning, economics, environmental sciences, social/cultural sciences, permitting/ regulatory affairs, and stakeholder engagement;

3. An objective, science and engineering-based approach to alternatives identification and analysis will be embraced. There is no presumption at study onset that any single alternative (or combination of alternatives) will be found to merit additional analysis;

4. Given the interrelatedness of the various components of the Great Lakes-St. Lawrence River System, the study focus is not limited to the St. Clair River alone. Control structures in the Niagara River, among others, will be considered;

5. The analysis will not be based on any specific lake level projection (or set of projections) over the long term. Rather, the focus will be on structural alternatives to enhance lake level control, irrespective of whether levels are above or below long-term averages at any given point in time. Therefore, an emphasis will be placed on resilient controls able to adapt to dynamic conditions;

6. The existing, substantial body of literature (e.g., reports, peer-reviewed articles, reference studies, regulation plans, legislative actions) will provide a basis for the study, complemented by new thoughts and ideas generated by the Project Team and via consultations with interested parties.

7. Any structural alternatives found to have potential merit will be developed to a conceptual level, relying on existing data, information and analysis. Such alternatives will be recommended for detailed design and any associated modeling, engineering, cost estimating, permitting and consultations with interested parties.

C. Primary Steps and Sequence

The AECOM study methodology, featuring 12 primary steps, is summarized below:

1. *Kick-off Meeting:* providing an opportunity for AECOM, in consultation with GBF, to finalize project schedule and scope of services; discuss individual tasks and deliverables; and review previously identified lake level control alternatives in the interest of generating a comprehensive list of those to be evaluated;

2. *Quality Assurance/Quality Control (QA/QC) Protocol:* ensuring that study execution is responsive to GBF requirements and its content is complete, accurate and well-documented;

3. *Detailed Project Schedule:* providing for timely completion of tasks and submittal of deliverables, consistent with GBF expectations;

4. *Literature Review and Analysis:* accessing and reviewing relevant reports, studies and documents in the interest of achieving an in-depth understanding of 1) the natural Great Lakes water balance and associated water levels; 2) the basis of historical water supplies and flows; and 3) climate change impacts on the Great Lakes water balance;

5. *Consultations with the GBF Board, Committee(s) and Interested Parties:* soliciting data, information, opinions and ideas to collectively assist in the identification and assessment of various structural alternatives for lake level control;

6. *Detailed Report Outline:* facilitating GBF review, discussion, and approval of report content and approach;

7. *Criteria for Assessing Structural Alternatives:* providing an analytical framework for AECOM to select, in consultation with GBF, a subset of all identified structural alternatives for additional analysis and conceptual level development;

8. *Inventory of Existing and New Structural Alternatives:* generating a descriptive listing of previously identified alternatives- and new ideas resulting from this study- in areas that include (among others) compensatory works, power generating structures, and adaptive management structures;

9. *Alternatives for Concept Level Development:* resulting from the application of evaluation criteria to the existing and new structural alternatives;

10. *Feasibility Assessment of Selected Alternatives:* including concept level design; preliminary estimates of capital and operating costs; preliminary layout plans; and a discussion of implications relative to regulatory compliance, environmental impacts, climate resiliency, and prospective social/cultural acceptability.

11. *Draft Report for GBF Review:* responding to the study goal and objectives, consistent with the approved report outline; and

12. *Final Report for Submittal to GBF:* following review/finalization of the draft study.

III. Literature Review and Analysis

A. Introduction

Study methodology entailed a thorough review of relevant reports, with an emphasis on IJC reference studies and related efforts. Toward that end, all reports referenced in the GBF Request for Proposal were reviewed in detail by AECOM to glean data, information and ideas of potential relevance. Summaries are provided in subsections B and C (below), complemented by a Section IV focus on a range of available technologies for water level controls.

B. Descriptive Inventory of Past Studies

The Council of the Great Lakes Region (June 2014). Low Water Blues: The Economic Impact of Declining Water Levels in the Great Lakes St. Lawrence River Region

This study forecasts the negative impacts of persistent low Great Lakes water levels on the regional economy, focusing on five categories and two timeframes, as noted below:

- Recreational boating and fishing ($6.65B through 2030 and $12.86B through 2050);
- Commercial shipping and harbors ($1.18B through 2030 and $1.92B through 2050);
- Hydroelectric generation ($951M through 2030 and $2.93B through 2050);
- Residential waterfront- Ontario ($794M through 2030 and $976M through 2050); and
- Rural groundwater users ($28M through 2030 and $35M through 2050).

The report also encourages dialogue for future steps (i.e., use of science, accounting and planning for future uncertainty with water levels, community and stakeholder engagement).

U.S. Army Corps of Engineers (May 2013). Decision Document Review Plan: St. Clair River

This document defines the scope and details for a prospective U.S. federal peer review of St. Clair River Compensating Works. It provides an historical overview of St. Clair River dredging activity, as well as a framework for the future study of compensating works and associated alternatives.

Dredging of the St. Clair River for navigation purposes began in 1852, with major events that included dredging operations to construct a 22' channel (1910-1923), a 25' channel (1933-1936), and a 27' channel (1958-1962). This dredging activity resulted in a 10" to 16" permanent reduction of water levels in Lake Michigan-Huron. Various studies examining prospective compensating works for water levels controls on Lake Michigan-Huron were conducted between 1925 and 2011.

The scope of this prospective General Reevaluation Report (GRR) includes a review of previous reports and design alternatives, as well as identification and analysis of additional alternatives not previously studied. It calls for an economic analysis of each alternative (including Benefit Cost Analysis) as well as preparation of an Environmental Impact Statement (EIS).

The GRR is proposed to examine both fixed and adjustable structures. Should one or more recommended alternatives be selected, authorizing and appropriations actions will be required of the U.S. Congress. It is also noted that this effort must be pursued in full cooperation with the IJC and the Canadian Government.

International Joint Commission (March 2012). Lake Superior Regulation: Addressing Uncertainty in Upper Great Lakes Water Levels

The IJC initiated a series of studies in 2007 that addressed the issue of St. Clair River water levels. This was followed by a 2012 report focusing on the formulation and evaluation of Lake Superior outflows, as well as an examination of multi-lake regulation alternatives.

Lake Superior outflow has been regulated on the St. Marys River (via a hydropower facility) since 1921. Seven regulation plans have been developed, with the most current (1977A) having been in-place since 1990.

The IJC review of Plan 1977A was prompted by several factors:

- Uncertainty in future water supplies and corresponding Great Lakes water levels;
- Availability of new research and data since the plan was implemented in 1990; and
- The need to address the wide spectrum of interests of those served by the Upper Great Lakes system.

Over 100 alternative plans were formulated and evaluated to improve Plan 1977A. The selected plan, titled "Lake Superior Regulation Plan 2012" provides the following benefits in comparison to Plan 1977A:

- Superior performance for maintaining water levels under drier climate scenarios;
- Reduced impact on fish spawning habitat in the St. Marys River;
- Reduced monthly variations in St. Marys River water level fluctuations; and
- Modest benefits for commercial navigation, hydroelectric generation and coastal zones.

In assessing the feasibility and implications of Lake Huron-Michigan compensation structures in the St. Clair River, the IUGLS Board found that:

- Several alternatives appear to be feasible, with an estimated construction cost between $30M and $170M;
- Commercial navigation, recreational boating and tourism would benefit, while coastal zones, hydroelectric generation and indigenous stakeholders would be adversely impacted;
- Georgian Bay wetlands would benefit from higher water levels; and
- Restoration structures would adversely impact St. Clair River fisheries.

The Study Board also considered the feasibility of multi-lake regulation by operating both existing and new structures on a system-wide basis (i.e., structures in the St. Marys, St. Lawrence, St. Clair and Niagara Rivers). The Study Board concluded that multi-lake regulation alternatives and prospects for construction are impacted by future climatic conditions and water supplies, and are characterized by high costs and environmental concerns. It was further noted that, even with additional regulation capabilities, extreme water levels may not be unavoidable.

The study recommends that the IJC undertake the following:

- Approve Lake Superior Regulation Plan 2012;
- Issue Orders of Approval to facilitate Plan implementation;
- Improve the climate change numerical analysis and enhance hydroclimate data collection in the Upper Great Lakes Basin;
- Develop and implement an Adaptive Management strategy to improve available tools for decision makers by integrating water quality and quantity considerations;
- Establish a Great Lakes St. Lawrence River Levels Advisory Board;
- Pursue funding opportunities and coordinate Adaptive Management activities; and
- Withhold approval of any Multi-lake Regulation Plan at this time.

The study notes that the Great Lakes Basin represents a hydrodynamic system that is only partially understood. Uncertainty remains relative to predicting lake levels, although it is understood that levels are likely to fluctuate, but remain within their relatively narrow historical range. It is further noted that lake evaporation is likely increasing and, while this is partially offset (in Lake Michigan-Huron) by an increase in precipitation, Lake Superior precipitation levels have not increased over the past 60 years. Given inherent uncertainties associated with our understanding of the future Great Lakes water balance, robustness is key to any future regulation plan.

The study addresses the prospective installation/operation of compensating works in the St. Clair River to restore Lake Michigan-Huron water levels. It is noted that St. Clair River dredging activity has permanently lowered water levels in Lake Michigan-Huron. The study effort included the conduct of computer modeling to simulate a range of water level increases, as follows:

- 10 cm (3.9 in)- compensation for increases in conveyance since 1963;
- 25 cm (9.8 in)- combining the 10 cm with the 1960-1962 dredging activity impact;
- 40 cm (15.7 in)- cumulative impact of 1906 to date; and
- 50 cm (19.7 in) - cumulative impact of 1855 to date.

Numerical analysis found that water levels in Lake Michigan-Huron will increase as soon as the St. Clair River conveyance decreases, and a full level of restoration will be achieved within 10 years of construction, or 50 years if the construction is staged. This will reduce occurrences of low water levels, but increase the frequency of extremely high water levels. Under the 10 cm scenario, for example, monthly high water levels will be exceeded up to three percent of the time while, for the 50 cm scenario, monthly high water levels will be exceeded 15% of the time.

The study report provides an overview of previously proposed structures, with a focus on both non-adjustable and adjustable structures, for a scenario up to 25 cm (9.8 in). This includes submerged sills (restoration target 10 to 25 cm); fixed weirs/dikes (restoration target 16 cm);

hydrokinetic turbines (restoration target 3 to 19 cm); inflatable flap gates at Stag Island and/or Fawn Island (restoration target 10 to 16 cm); and inflatable rubber weirs. The latter does not include a restoration target or proposed location.

In examining the proposed structures, it is noted that non-adjustable structures have a permanent impact on water levels upstream, and a partial effect on levels downstream. Adjustable structures also affect water levels both upstream and downstream. Preliminary construction costs range between $30M to $170M. These restoration structures will have both positive impacts (e.g., Georgian Bay region wetlands, commercial navigation) and negative impacts (e.g., hydroelectric generation, St. Clair River fish habitat and spawning).

With regard to alternative approaches to the development of a multi-lake regulation plan, the study addressed the following:

- Two-point plans: new rules for the existing structures at the outlets of Lake Superior and Lake Ontario;
- Four-point plans: new rules for the existing structures and new proposed (Lake Michigan-Huron and Lake Erie);
- St. Clair three-point plan: new rules for the existing structures and new proposed (outlet of Michigan-Huron on St. Clair River);
- Niagara three-point plan: new rules for the existing structures, and new proposed (Lake Erie outlet on the Niagara River);
- Four-point plans: existing structures and outlet control points on St. Clair and Niagara Rivers could be designed to reduce the frequency of extreme water levels; and
- Three-point plans (existing structures and a new control point on the Niagara River).

U.S. Army Corps of Engineers (February 2010). Supplemental Reconnaissance Report: Great Lakes Navigation System Review

This report summarizes a reconnaissance study undertaken by the U.S. Army Corps of Engineers (USACE) that focused on the Great Lakes Navigation System (GLNS) comprised of the upper four Great Lakes and their navigable connecting channels – the St. Marys River, the Straits of Mackinac, and the St. Clair/Detroit River System. A description is provided for each area of the GLNS, followed by a summary of alternatives developed to improve navigation, as well as identification of targets for future federal studies.

The report recommends that the following elements be included in future studies:

- Deepening the Great Lakes connecting channels to improve vessel traffic, along with potential channel and port modifications;

- Improving the St. Lawrence Seaway by replacing the existing locks with larger and deeper chambers and providing channels compatible with the larger lock dimensions; and

- Deepening individual ports and harbors within the GLNS, including modifications to existing infrastructure and channels to accommodate deeper draft vessel traffic.

The future “without-project” condition for the GLNS assumes completion of authorized improvements at the Soo Locks, while maintaining the status quo elsewhere in the U.S. portion of the GLNS.

Five alternatives (presented below) were formulated and a preliminary economic analysis was performed:

- Alternative 1 - Includes the many combinations of improvement alternatives for the Great Lakes connecting channels and harbors, combined with eventual replacement of the Seaway locks at current dimensions;
- Alternative 2 - Same improvements as Option 1 above, coupled with construction of a deeper (35’ draft) and larger (110’x1200’ lock chambers) Welland Canal;
- Alternative 3 - Replacing the Montreal-Lake Ontario (MLO) section of the Seaway with a deeper and larger system of locks and channels, and extending the 35’ draft system to Detroit;
- Alternative 4 - Similar to Alternative 3, except that the 35’ draft extends into Lake Michigan-Huron by deepening the entire St. Clair/Detroit River system; and
- Alternative 5 – Extending the 35’ draft throughout the system as a result of deepening the St. Marys River and lowering the sill depth of the Soo Locks.

This Supplemental Reconnaissance Report also describes the aging infrastructure and conditions of major Great Lakes ports and harbors, and recommends that a detailed Feasibility Study be conducted for the alternatives listed above, with estimated construction costs and economic analysis.

International Joint Commission (December 2009). Impacts on Upper Great Lakes Water Levels: St. Clair River

This is the first of two major reports presenting the findings and recommendations of the bi-national International Upper Great Lakes Study (IUGLS), a five-year investigation undertaken by the IJC in 2007. The Study Board concluded that the difference in water levels between Lake Michigan-Huron and Lake Erie has declined by approximately 23 centimeters (nine inches) between 1963 (following the last major navigational channel dredging in the St. Clair River) and 2006, based on three key factors:

- A change in the conveyance (i.e., water-carrying capacity) of the St. Clair River contributing an estimated seven to 14 cm (2.8 to 5.5 inches) of the decline;
- Glacial isostatic adjustment (i.e., the uneven shifts of the earth’s crust since the last period of continental glaciations ended) contributing an estimated four to five cm (1.6 to 2.0 inches) of the decline; and

- Changes in climatic patterns contributing an estimated 9 to 17 cm (3.5 to 6.7 inches) to the decline. (This factor has become increasingly important in recent years, accounting for an estimated 58 to 76 percent of the decline between 1996 and 2005.)

The Study Board notes that these estimates are highly dependent on the choice of the specific time period being analyzed within the 1963-2006 timeframe. Additionally, it is noted that there has been no significant erosion of the channel bed along the length of the St. Clair River since at least 2000.

Study Board recommendations include the following:

- St. Clair River remedial measures (to address past damages or adverse effects) should not be pursued at this time; and
- The need for mitigative measures in the St. Clair River should be examined as part of a comprehensive assessment of the future effects of climate change on water supplies in the (See the IJC's 2012 Lake Superior Regulation Study.)

W.F. Baird and Associates (February 2009). Preliminary Study of Structural Compensation Options for the St. Clair River

This report summarizes a preliminary reconnaissance level study of structural alternatives and available technologies to mitigate the impacts of the St. Clair River dredging. The study features:

- A literature review of reports/ studies addressing water level regulation alternatives; and
- An examination of structures and available technologies not previously considered, as grouped in the categories of 1) Compensation Works (with a goal to restore headwater to a target elevation for Lake Michigan-Huron); and 2) Adaptive Management/ Regulatory Works (with a goal to provide a flexible approach to flow regulation).

Compensation works considered include submerged sills, fixed weirs and river training structures. Adaptive Management structures include control gates, inflatable weirs, ice boom deployment, conventional hydroelectric plant, and in-stream power generation.

A general assessment of structures and available technologies is presented, along with estimates of construction costs as follows: submerged sills ($10 - $17M); ice boom ($3.7M); Lake Huron channel structures ($63M); and compensating and control structures ($350M).

C. Outcomes and Relevance to Current Study

Documents reviewed over the course of this study, including those noted above, provide a foundation for additional analysis. Recurrent key points and themes include the following:

- The Great Lakes-St. Lawrence River System is a highly complex and dynamic one that is not yet fully understood. Continued research, ranging from the science of fluctuating water levels to the Cost Benefit Analysis of additional control alternatives, is needed.

- Human-induced changes to lake levels and flows date back to the onset of dredging activity in the St. Clair River in the 1850s for navigation purposes. Collectively, this activity has resulted in a significant permanent reduction in Lake Michigan-Huron water levels. This has prompted various investigations, studies and reports over the past century.

- The negative implications of a prolonged period of low water levels have been quantified for multiple water-dependent sectors such as recreational boating and fishing, commercial shipping and harbors, hydroelectric generation, residential waterfront, and rural groundwater users. These impacts are substantial, ranging between $35M and $2.93B) through 2050, depending on the sector.

- An array of structural alternatives to address concerns over lake level fluctuations (and prolonged periods of high or low water) has been developed in varying levels of detail over a number of decades. These have ranged from large scale, system-wide plans (i.e., three and five lake regulation) to smaller, site-specific plans (e.g., measures focusing on Lake Huron and Georgian Bay).

- The chronology of events centers largely on reference studies conducted by the IJC, the implementation of regulation plans jointly approved by the U.S. and Canadian governments though the IJC, and legislative authorizations directing USACE to undertake studies and civil works projects.

- Of particular relevance to Lake Michigan-Huron is the current Lake Superior regulation plan (1977A). In effect since 1990, it is intended to prevent the monthly mean level from rising above, or falling below, a range of water levels. It also provides for a minimum monthly flow supply to operate the navigational locks, maintain the aquatic habitat at the St. Marys River rapids, and meet the needs of industrial and municipal users. Temporary deviations to the plan, upon the recommendation of the International Lake Superior Board of Control, may take place for hydropower plant works or to alleviate flooding risks.

- While there are many unknowns regarding future trends in water levels, it is generally agreed that regulating the upper Great Lakes at a single location has significant limitations. Thus, there is a need to look at multiple locations (and various combinations of structures) when examining mechanisms for additional control. .

- While the most ambitious regulation plans (i.e., three or five lake) are capable of greatly reducing the likelihood of extreme water level fluctuations (and prolonged periods of highs and lows), future uncertainties associated with climate conditions and water supply suggest that the likelihood of such fluctuations cannot be entirely eliminated. For this reason, structural and non-structural Adaptive Management measures (under a range of lake level regulation scenarios) are of increasing interest.

Structural alternatives for lake level control, as identified in past studies and ongoing analyses, can generally be placed in the categories of compensating works, in-stream turbines, adaptive management mechanisms, and "other" mechanisms. These categories form the basis of the analysis presented in Section IV.

IV. Structural Alternatives for Lake Level Controls

A. Introduction

Lake levels controls in the Great Lakes-St. Lawrence River System are presently found at the St. Marys River Compensating Works (Lake Superior regulation) and at the Moses-Saunders Dam in the St. Lawrence River (Lake Ontario regulation).

Lake Superior's outflow is regulated at Sault Ste. Marie, where the St. Marys River discharges to Lake Huron. The outflow from Lake Michigan-Huron largely occurs via the St. Clair River; an additional small outflow from Lake Michigan flows to the Mississippi River Basin through the Chicago Diversion. Lake St. Clair receives Lake Huron discharge via the St. Clair River, and then carries it to Lake Erie via the Detroit River. Lake Erie discharges to Lake Ontario through Niagara River and the Welland Canal, and the St. Lawrence River subsequently carries Lake Ontario outflow to the Gulf of St. Lawrence and Atlantic Ocean.

As depicted in Figure 1, a complex flow pathway in the St. Marys River at Sault Ste. Marie connects Lake Superior and Lake Michigan-Huron.

Figure 1. Sault Ste. Marie Flow Paths (image courtesy University of Michigan)

Outflows from Lake Superior and the St. Marys River have been regulated since 1921. This is primarily accomplished through the compensating works-hydropower plants and 16 gated dams, as depicted in Figure 2. In order to meet the demand for electricity (which fluctuates daily and weekly), the plants vary their flows; the plants will increase releases during the day on weekdays ("peaking"), and reduce the releases at night and on weekends ("ponding"). These flow variations impact water levels downstream of the plants and in the Lower St. Marys River.

Figure 2. Compensating Works, St. Marys River (image courtesy IJC)

The St. Lawrence River is the system's natural outlet to the Atlantic Ocean. Lake Erie supplies approximately 80% of the Lake Ontario and St. Lawrence River water supply (IJC, 2014), with precipitation and runoff accounting for the remaining 20%. Lake Ontario water levels vary with the water balance (i.e., water supply minus the outflow). The supply to Lake Ontario is unregulated and uncontrolled, while the outflow is regulated and controlled. As depicted in Figure 3, the principal structure controlling Lake Ontario outflows is the Moses-Saunders Power Dam (constructed in the 1950s), located between Cornwall, ON and Massena, NY.

Figure 3. Moses-Saunders and Long Sault Dam (image courtesy Google Maps)

The Long Sault Dam acts as a spillway when Lake Ontario outflows exceed the capacity of the Power Dam. Based on USGS 04264331 gauge recorded data, the river maximum daily discharge is 378,000 cubic feet per second (10,704 cubic meters per second), with a long-term average of approximately 250,000 cubic feet per second (7,079 cubic meters per second).

There are limitations to the amount of water that can be released by the Moses-Saunders Dam, as large releases reduce Lake Ontario water levels, but increase downstream river flood potential.

Alternatively, small releases will increase Lake Ontario water levels, but reduce the St. Lawrence River navigable water depths.

B. Descriptive Inventory: Existing and New Alternatives

A review of previous studies, complemented by new ideas generated though this study, elicited fourteen structural alternatives that were subsequently categorized as follows:

- *Compensatory:* submerged sills, weirs/jetties, river training structures (existing and new ideas);
- *Power Generating:* conventional hydroelectric dam, instream turbines (existing and new ideas);
- *Adaptive Management*: Inflatable flap gates, inflatable dams (existing and new ideas), control/sector gates; and
- "*Other":* Ice booms, landfill and control gate system.

A brief review of each follows, providing a summary description and location, background information, a review of strength and weaknesses, and a summary statement. The "strengths and weaknesses" discussion is guided by a series of seven evaluation parameters (i.e., performance; implementation; cost; regulatory considerations; climate resiliency; environmental considerations; social/cultural considerations).

1. Compensatory Structures (Compensation Works)

These structures are placed in a Great Lakes connecting channel to modify water levels upstream (and downstream) of their location. As permanent, non-adjustable structures, they do not adapt to variations in levels and flows. Installation of such structures (e.g., weirs, sills, training walls) will decrease channel conveyance capacity, thereby increasing upstream water levels. Conversely, removal of any existing structures and/or additional dredging activity, will increase channel conveyance and, as a result, decrease upstream water levels.

1.1 Submerged Sills

a. <u>Summary Description and Location</u>: This alternative entails the placement of submerged stone sills in the Upper St. Clair River to restrict flow area and conveyance, thus increasing water levels upstream of the structures.

b. <u>Background:</u> This alternative has been the focus of numerous studies (including mathematical equations, desktop and physical models) dating back to 1926 (Joint Board of Engineers). The number of proposed structures has varied from one study to the next, with different geometry and locations. For example, 31 structures were proposed in a 1931 study, and subsequently revised to 13 in a 1971 study (see Figure 4).

Figure 4. Proposed Submerged Sills (IJC, 2012 adapted from Franco and Glover, 1972)

Two restoration levels were defined by IJC in 2010: a 10 cm level to compensate for conveyance increases since 1963, and a 25 cm level to compensate for cumulative increases in conveyance for the 1960-62 channel dredging deepening. The estimated implementation cost of the former is $33M, with the latter estimated at $72M (in 2011 dollars).

c. Strengths and Weaknesses: Submerged sills offer an effective means to raise upstream water levels by reducing flow area and conveyance. Their impact is optimized when placed in close proximity to the Lake Huron outlet in an area with considerable depth and flow velocity. Further, submerged sills have a comparatively low capital cost, no operational costs and, if placed in deep water and/or outside of shipping channels, have negligible impacts on commercial navigation.

Disadvantages of this alternative are found in several areas. As a permanent, fixed structure, this alternative is not adaptable to changing climate conditions; it can exacerbate downstream problems in periods of extreme low levels and upstream problems in periods of extreme high levels. Submerged sills (and their associated effects on levels, flows and river bottom characteristics) have been found to have negative impacts on the aquatic ecosystem, particularly with regard to lake sturgeon spawning (IUGLS, 2011). Further, the placement of a permanent, fixed structure in or near connecting channels will result in complex environmental permitting and coordination requirements in both the U.S. and Canada. Finally, while there are no direct operational costs for this alternative, periodic dredging may be required given that sills filled with sediment have been found to be less effective.

d. Summary Statement: Despite the various strengths of this alternative, it was not selected by AECOM for further analysis, given its inability to adapt to changing climate conditions, negative environmental impacts (as noted in previous studies), and anticipated regulatory constraints.

1.2 Parallel Dikes and Fixed Weirs

a. Summary Description and Location: This alternative features the placement of rubblemound (i.e., stone) structures such that they extend into Lake Huron at the mouth of the St. Clair River (as depicted in Figure 5). The structures would decrease the available cross-section of the lake outlet (flow area), thus increasing upstream water levels.

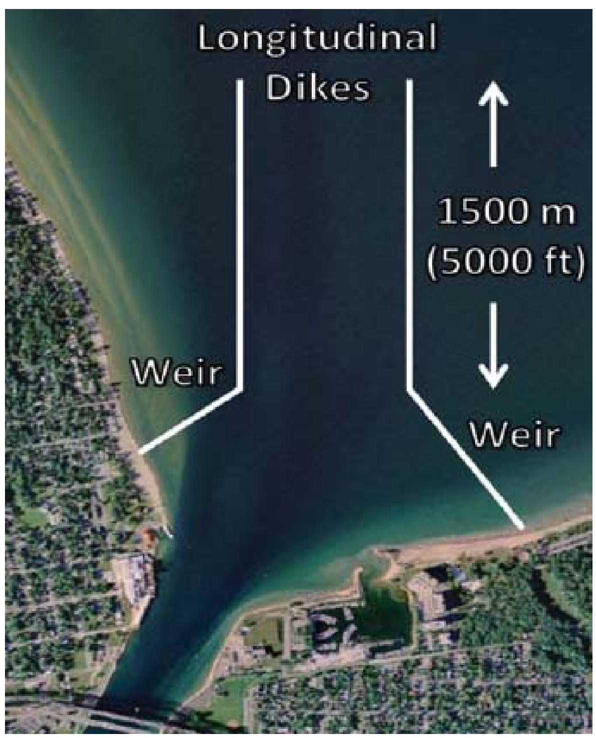

Figure 5. Parallel Dikes-Lake Huron (IJC, 2012 adapted from Moore, 1933)

b. Background: This alternative was first formulated by Moore (1931) and most recently included in a 2012 IJC report. Two variations of this alternative include a single breakwater with multiple sills, and two breakwaters, each approximately 1,500 m (4,900 feet) in length. Total estimated installation and operational costs for the latter configuration are $150M (IJC, 2012 dollars).

c. Strengths and Weaknesses: As with submerged sills, parallel dikes and fixed weirs offer an effective means to raise upstream water levels by reducing flow area and conveyance. Increasing channel lengths via two breakwaters can be expected to raise water levels upstream by approximately 16 cm (6.3 inches). As permanent structures, post-construction operational costs are negligible. Further, their proposed location outside of the commercial navigation channel avoids major concerns with maritime commerce.

   As permanent structures, however, parallel dikes and fixed weirs are not adaptable to changing climate conditions and, thus, do not satisfy the "climate resiliency" criterion against which various alternatives were evaluated. Negative environmental impacts are also associated with this alternative (e.g., sediment buildup, alteration of bottomlands) although they are expected to be less significant than those of the submerged sills alternative in terms of fish migration and spawning, particularly with regard to the lake sturgeon. Environmental permitting and coordination requirements typically associated permanent structures can be expected to be complex in both the U.S. and Canada. The construction cost of this alternative is considerably higher than that of the submerged sills alternative (depending on the configurations involved). In addition, significant adverse social/cultural impacts are anticipated given the length of the structures and associated aesthetic/visual impacts to shoreline residents/users. These impacts are also likely to include some interference with recreational boating and, potentially, water quality concerns in areas of reduced flow and open water exchange.

d. Summary Statement: This alternative was not selected by AECOM for further analysis. While past studies demonstrate its potential effectiveness in raising upstream water levels, it does not fare favorably when evaluated against multiple criteria and, in particular, those relating to cost, climate resiliency, environmental impact, regulatory requirements, and social/cultural considerations.

1.3 River Training Walls/Wing Dikes

a. Summary Description and Location: Wing dikes are typically rubblemound (i.e., stone) structures placed in a perpendicular arrangement to the shoreline or river flow. Training walls are also typically rubblemound structures, and are placed in a parallel arrangement to river flow. Figure 6 depicts wing dike structures on the Mississippi River, while Figure 7 presents a combined wing dike/training wall arrangement at Stag Island in the St. Clair River. As envisioned, this alternative would be located at either Stag Island or Fawn Island on the St. Clair River.

Figure 6. Mississippi River Stone Dikes (image courtesy USACE)

Figure 7. Dikes and Training Structures at Stag Island
(IJC, 2012 adapted from Moore, 1933)

Given their perpendicular placement to the shoreline or river flow, wing dikes decrease channel conveyance and, consequently, increase water levels upstream. Training walls enhance the effectiveness of the wing dikes because they decrease the available cross section (i.e., flow area) of the east channel of the St. Clair River, forcing the flow to pass through the west side of the islands. The structures would decrease the available cross-section (flow area) of the St. Clair River east channel, forcing the flow to pass through the west side of the islands.

b. Background: Stone wing dikes and training walls are widely used on the Mississippi River and have been employed by USACE for many years. Wing dikes presently exist on the Detroit River (i.e., Stony Island, Bois Blanc Island) and Niagara River (i.e., Black Rock Lock, Grand Island) as flow control measures to compensate for St. Clair River dredging and the Black Rock channel diversion. The wing dikes at Stag Island were first proposed and studied by Moore (1931 and 1933) and are also mentioned by the IJC in its 2012 report. With regard to prospective placement in the St. Clair River, the total estimated implementation costs are $120M for Stag Island, and $80M for Fawn Island, (IJC, 2012 dollars).

c. Strengths and Weaknesses: A training wall/wing dike system provides an effective means of increasing upstream water levels, according to past studies (Moore, 1931 and 1933, IUGLSB, 2008 and 2009) examining the individual and cumulative effects of such installations in the St. Clair River. For Stag Island, it was determined that wing dikes without training walls would increase upstream levels by 9 cm (3.5 in), increasing to 16 cm (6.3 in) with the addition of training walls. For Fawn Island, wing dikes without training walls would increase upstream levels by 1 cm (0.4 in), increasing to 5 cm (2 in) with the addition of training walls. The combined effect of the dikes at both islands is estimated to be 21 cm (8.3 in).

The anticipated performance of a wing dike/training wall system at the two locations is a primary strength of this alternative with respect to increasing upstream water levels. Further, while installation is expected to result in some negative environmental consequences, they would likely be less significant than those associated with other permanent compensatory structures. For example, stone wing dikes can be constructed with gaps to allow fish passage and enhance aquatic habitat.

A primary weakness of this alternative, as with all permanent compensatory structures, is the lack of climate resiliency; it will effectively raise upstream levels in periods of lower water for Lake Michigan-Huron, but cannot be modified/adjusted when high water suggests a desire for enhanced conveyance to the lower lakes. Beyond this, adverse impacts are largely associated with the closure of the east channel. Beyond environmental considerations as referenced above, this includes impacts on recreational boating (i.e., no upstream/downstream access via the east channel, potential hazards associated with the training walls); prospective water quality degradation due to interrupted flow in the east channel; aesthetic concerns for shoreline residents/visitors; and the likely difficulties/complexities associated with permitting/regulatory processes (due in part to the potential for disturbing contaminated bottom sediments). Further, the capital costs for installing a wing dike/training wall system are high in comparison to other prospective compensatory structure.

d. Summary Statement: Given the numerous weaknesses of the wing dike/training wall system in light of evaluation criteria, AECOM did not select this alternative for further analysis.

1.4 Wing Dikes-Niagara River

a. Summary Description and Location: This alternative is similar to that described above, although it focuses on wing dikes alone and, specifically, their prospective installation in the Niagara River. Such placement will decrease the available cross-section (i.e., flow area) in the river channel, thereby increasing the water level upstream. Figure 8 depicts a schematic for two proposed Niagara River wing dikes, perpendicular to shore and just downstream of the Peace Bridge.

Figure 8. Niagara River Wing Dikes (Aerial courtesy Google Maps, https://www.google.com/maps)

b. Background: Unlike the St. Clair and Detroit River, the Niagara River has not been subjected to extensive maintenance dredging activities. Consequently, various compensation structures have been proposed as a component of various lake flow diversion proposals (e.g., Black Rock Canal). The first two compensation studies were conducted by the Joint Board of Engineers (1926) and Moore (1931 and 1933), respectively. The former focused on dikes with submerged sills, while the latter focused on dikes without submerged sills. Later studies were focused on means to mitigate for the Long Lac and Ogoki diversions; it was found that partial fill in the river (e.g., Peace

Bridge and the channel encroachments at various upper river locations) has partially compensated for these diversions. More recent studies (International Great Lakes Levels Board-IGLBBB, 1973, International Lake Erie Regulation Study Board-ILERSB, 1981 and Levels Reference Study Board, LRSB, 1993) have focused on increasing river capacity (i.e., by removing river fill or dredging) in order to lower Lake Erie water levels. These studies also included physical modifications to the Black River Canal (e.g., adding control gates or diverting flow through a new excavated channel). The estimated effect of the proposed dikes without any modifications to the Black River Canal is to raise upstream levels by approximately 13 cm (5 in).

The total estimated cost to install wing dikes in the Niagara River, without any physical modifications to the Black River Canal, is $10M. If such modifications to the canal are necessary, previous studies estimate the cost at between $40M and $400M (Environment Canada, 2010 dollars).

c. Strengths and Weaknesses: Conditions of the Niagara River differ from those of the St. Clair River. Consequently, one advantage of installing wing dikes in the former is that commercial navigation is not a significant constraint. Further, installation of the wing dikes is comparatively much less expensive than the cost of other permanent compensatory structures.

   Adverse impacts are similar, although less pronounced than those previously identified for wing dikes. As permanent structures that raise upstream water levels by restricting conveyance, they are not climate resilient. They can also expect to have some adverse impacts on recreational boating and aesthetics, as well as on the aquatic ecosystem (e.g., alteration of bottomlands that can compromise fish spawning). Also, there is uncertainty as to what, if any, operational or structural modifications may be required to the Black River Canal and lock system.

d. Summary Statement: This alternative was not selected by AECOM for further analysis, based upon the various weaknesses identified when evaluation criteria were applied.

2. Power Generating Structures

This second category of prospective structural lake level control mechanisms includes power generating structures (both hydroelectric dams and arrays of in-stream turbines) that can be strategically placed and operated for backwater head control. Among others, three primary characteristics distinguish this category of alternatives from compensation works: 1) they are adaptable to changing water level control needs; 2) they have secondary capabilities (i.e., power and revenue generation) to potentially help offset installation and operational costs; and 3) they have operational/maintenance costs not associated with permanent compensatory structures.

2.1 Hydroelectric Dams

a. Summary Description and Location: This alternative entails the installation and operation of one or more new hydroelectric dams at strategic locations within the Great Lakes-St.

Lawrence River System. While the impetus for such facilities has historically been founded in power generation and commercial navigation needs (i.e., lock systems typically associated with dams), their potential for lake level control can be substantial depending upon facility configuration and location.

b. Background: Hydroelectric power plants have been fixtures within the Great Lakes-St. Lawrence River System for well over a century. The first such facility, constructed at Niagara Falls in 1879, has been followed by many others, primarily on system tributaries. Various studies have been conducted to determine the feasibility of hydroelectric dams as mechanisms for lake level control. The Joint Board of Engineers (1926) investigated their prospective installation at the inlet to the St. Clair River while more recent studies, including LRSB (1993) and Hydrosult (1993), investigated the prospective installation of hydroelectric dams and navigation locks at Sorel and Donnacona, Quebec. Their estimated cost is over $740M (1993 dollars).

c. Strengths and Weaknesses: As noted above, hydropower facilities provide a degree of adaptability not found with fixed, permanent compensatory structures. Gates can be adjusted, as needed, to alter conveyance and, is so doing, will affect both upstream and downstream water levels. A secondary benefit to the construction of dams for lake level control is the power generating capability of such facilities which can help offset construction and operational costs.

While the cost of constructing and operating a new hydroelectric dam will vary with location and the nature of the structure, it can be expected to far exceed the cost of most, if not all, other alternatives. Other weaknesses are substantial as well, including adverse environmental consequences (e.g., interrupting natural flow regimes and sediment transport, compromising/precluding fish passage); creating obstructions for both commercial and recreational navigation; difficulties/complexities in securing requisite regulatory permits; and anticipated opposition by those who reside in the area or engage in water-dependent activities.

d. Summary Statement: Given the adverse impacts of dam construction and operation in light of the evaluation criteria and, on the basis of an extensive literature review, AECOM did not select this alternative for further analysis.

2.2 In-Stream Hydrokinetic Turbines

a. Summary Description and Location: This alternative entails the installation of turbine units on the river bed at two locations: the Upper St. Clair River by the Blue Water Bridge, and upstream of the St. Marys River Compensation Works (see Section V for additional detail). Individually and collectively, these in-stream hydrokinetic turbines serve as obstructions to the moving river flow and, by impacting river hydrodynamics, they will increase water levels upstream. The turbines are regarded as a partial adjustable technology in that they can be operated during low flow periods (to raise upstream levels) and can be shut down during high flows. In both cases, they will have some impact in raising water levels upstream, although much more so when they are operational.

b. Background: In-stream and tidal power generation (low head power generation) is an emerging technology in the river marine hydrokinetic (RMHK) power industry. Power is generated by placing turbines directly in river flow or tidal currents. The hydrokinetic power available is primarily a function of flow velocity. The minimum velocity range required to efficiently operate a hydrokinetic device is typically 1 - 2 m/s (3.4 - 6.8 ft/s), but optimal currents are found to be in the 2.5 - 3.5 m/s (8.2 - 11.8 ft/s) range.

There are a multitude of configurations for hydrokinetic turbines, but they can generally be categorized as either horizontal or vertical axis, and either bottom or surface mounted. Horizontal axis can either be in line with flow, or perpendicular to it. There is no consensus on the most effective turbine configuration for RMHK applications, due to variable site conditions. The primary recognized turbine categories are Axial Flow (i.e., two or three blades mounted on a horizontal shaft); Cross-Flow Turbines (i.e., a rotor with two or three blades parallel to a shaft); Reciprocating Devices (i.e., to use the flow of the water to produce the lift or drag of an oscillating part transverse to the flow direction); Riverbed Mounting Systems (i.e., underwater monopoles); Gravity Base on Bottom Surface; and Floating Mooring (e.g., Bluewater Bluetec in the Netherlands).

Large scale commercial application of this alternative is presently limited to a New York project application with 30 turbines. In 2012, the Federal Energy Regulatory Commission (FERC) issued a commercial license for the Roosevelt Island Tidal Energy (RITE) Project, located in the East Channel of the East River, New York. Verdant Power was authorized to install up to 30 Gen5 KHPS turbines in the East Channel, employing a phased approach with staged environmental monitoring as the turbine field expands. The estimated total cost of the project is $20M and, when complete in 2016, is expected to generate up to 2,400 MWh annually. The turbines will also collect important environmental data on fish and river sediment, and employ a team of professionals to maintain and monitor the equipment.

When the river water velocity exceeds approximately 1.0 m/s (3.3 ft/s), the turbine blades begin to rotate and the units generate electricity. As the tide shifts direction, the turbines turn to generate power from the current flowing in the opposite direction. This cycle repeats approximately every six hours. Figure 9 shows a Verdant Power turbine used for the project during installation, as well as the proposed turbine grid. The table below summarizes a few known applications of in-stream power generation turbines.

Table 1. Selected In-stream and Power Generation Projects

Source	Project / Year Built	Location	Turbine Type / Number	Power	Notes
Tidal/ River	Roosevelt Island Tidal Energy (RITE)/ 2006-present	New York Harbor, NY, USA	Horizontal axis, In-line, blade, bottom mounted/ 30	35 KW ea	World's first operation of a grid-connected tidal turbine array. Received commercial license 2012. Permitted to install 30 turbines producing 1.05 MW.
Tidal/ River	Atlantis/ 2011	Orkney, Scotland	Horizontal Axis, In-line, blade, bottom mounted/ 1	1 MW	One of the largest turbines ever built.
River	Hydro Green Energy/ 2009	Hastings, MN, USA	Horizontal Axis, In-line, enclosed, surface mounted / 1	100 kW	Located downstream of non-power generating USACE Lock & Dam No. 2. First commercial, federally-licensed hydrokinetic power project.
River	Vortex Hydro Energy/ 2010, 2012	St. Clair River/Port Huron, MI, USA	Oscillating, bottom mounted / 1	Unknown	Only known in-water tests in St Clair River. To expand installation up to six units in 2016.
River	InStream Energy/ 2013	Yakima, WA, USA	Vertical axis, surface mounted / 1	25 kW	Field study to measure turbine efficiency.

Figure 9. RITE Turbine Installation and Proposed Grid (courtesy Verdant Technologies and In-

Focus, 2011: http://www.solarfeeds.com/in-focus-tidal-energy-2/)

Hydrokinetic turbines are being considered for some of North America's major rivers, including Fort Simpson, Mackenzie River (Canada) and New Orleans Greater Area, Mississippi River (US). A monitoring study focused on Vortex Induced Vibration (VIV) technology was conducted on the St. Clair River (near Port Huron, MI) by the University of Michigan in 2012. Other open water tests (in the Netherlands and in New Jersey) have subsequently been conducted. Various feasibility studies have also been conducted (by Verdant Energy) for the Cornwall Ontario River Energy (CORE) Project on the St. Lawrence River.

The total cost of this alternative is a function of the number and type of turbines to be installed and operated. Considering a reference cost of $20M for 30 turbines (reported RITE project cost), an estimated cost for 50 to 150 turbines in the St. Clair River is in the range of $33M to $100M.

c. Strengths and Weaknesses: In-stream turbines are climate resilient in that they can be turned on or off to adapt to changing lake level conditions. They are also attractive from a power generation perspective, an ancillary benefit that could help defray the cost of installation and operation, while helping to meet U.S. and Canadian goals for renewable energy. Environmental studies performed for the aforementioned RITE project have found only minor and, in some cases, no adverse impacts to aquatic resources.

Disadvantages of this alternative relate, in part, to the fact that energy production is the primary impetus for installation. Consequently, limited research has been done to date on 1) the hydrodynamic implications of in-stream turbines (especially on the St. Marys River); and 2) the prospective performance of a turbine array in controlling lake levels. Options for locating turbines are limited (i.e., due to depth, flow velocity, maximum impact on water levels, avoidance of navigation channels), and installation/operation must contend with multiple issues (e.g., debris, sediment, frazil and surface ice; river dynamics, corrosion, fluid leaks, recreational boat traffic, recreational/commercial fishing, site access limitations). While minor in comparison to other structural alternatives, environmental impacts do exist relative to effects on aquatic resources, changes in sedimentation patterns, and electromagnetic interference from electrical conduit. There are no visual aesthetic issues post-construction and, given the minor anticipated environmental concerns and the inherent appeal of an ancillary clean energy benefit, it is anticipated that this alternative will receive a generally favorable reception from a social/cultural standpoint. However, due to the more recent nature of this alternative and limited investigations to date, the social/cultural implications cannot be fully anticipated.

d. Summary Statement: This alternative was selected by AECOM for further evaluation due to its comparatively promising characteristics in light of evaluation criteria, and the need for additional analysis to better assess its lake level control benefits. It is addressed in further detail in Section V.

3. Adaptive Management (Compensation Works)

This third category of prospective structural lake level control mechanisms includes adaptive management structures and technologies that are capable of being removed or otherwise adjusted to fully adapt to changing lake level control needs based on target upstream water levels. Three such alternatives, which can be employed individually or in combination, include inflatable flap gates, inflatable dams, and control/sector gates.

3.1 Inflatable Flap Gates

a. Summary Description and Location: This alternative entails the installation of a fully adjustable structure consisting of a hinged metal flap gate resting on the river bottom. Compressed air is pumped into the gate, allowing it to float and obstruct flow during periods of low water levels as a means to increase upstream water levels. During periods of high water, the gate is lowered to facilitate flow. Inflatable flap gates are most effectively installed in areas of high flow, with a likely location being at Stag and/or Fawn Island in the east channel of the St. Clair River.

b. Background: Inflatable flap gates were considered in previous studies (International Great Lakes Levels Board, 1973, Lake Reference Study Board, 1993), with a focus on the Stag and Fawn Island locations. When the flap gates are in a vertical position, the predicted impacts are found to be similar to the results of the stone wing dikes presented in Alternative 1.3. For Stag Island, the impact would be between 9 cm (3.5 in) and 16 cm (6.3 in); for Fawn Island, the impact would be between 1 cm (0.4 in) and 5 cm (2 in). The combined effect of the flap gates at both islands would be up to 21 cm (8.3 in).

   The estimated cost to install an inflatable flap gate at Stag Island is US \$130M to \$150M (2011 estimate). Using an average of the 2011 estimate (\$140M) for reference purposes, the estimated current cost is approximately \$170M, resulting in a unit cost of \$140,000/LFT for Stag Island (average span east channel of approximately 1,200 feet). Using the same approach, the estimated current Fawn Island cost is \$70M (for an average span of 500 feet). The 2016 estimate was developed by employing the USACE Civil Works Construction Cost Index System (USACE, September 2015) to convert to 2015 dollars, and a marine construction inflation rate of 2.5% was then applied (2016 costs).

c. Strengths and Weaknesses: Flap gates represent a fully adjustable technology characterized by good water level control and more climate resiliency than permanent, fixed compensatory works. When not operational, they avoid the adverse impacts associated with many of the permanent structures.

   When the flap gates are operational (i.e., gates are raised), sediment transport can be adversely impacted, as material is trapped on the upstream/updrift side. Fish passage is also compromised during that period as well, and the change in flow patterns can potentially result in temporary localized water quality concerns (until the flap gates are lowered). Recreational boating in the east channel will also be temporarily affected while the flap gates are operational.

d. Summary Statement: While the climate resilient aspect of this alternative is appealing, its weaknesses are found to be similar to those of Alternative 1.3 (River Training Walls-Wing Dikes) and, consequently, AECOM determined that it did not merit additional analysis.

3.2 Inflatable Dams

a. Summary Description and Location: This alternative consists of a semi-adjustable structure with four main system components: inflatable rubber fabric, concrete foundation, control room (i.e., automation and controls), and a piping system. The structure is inflated with air and/or water, and raises the water level upstream. This alternative would be located in the St. Clair River.

b. Background: Inflatable structures are increasingly popular adjustable technologies. The first inflatable dam (for flood mitigation) was constructed in the Los Angeles River, California in 1950s. Since that time, several advancements (i.e., new technology, availability of new materials, increasingly practical construction procedures) have allowed these structures to be installed in a variety of climates, including northern regions with temperatures as low as -40C (-40F). Figure 10 shows a fully inflated dam (Taoyua Rubber Dam, Yi River, China) and, a dam during deflation (Adam T. Bower Dam, Susquehanna River, Sunbury, PA).

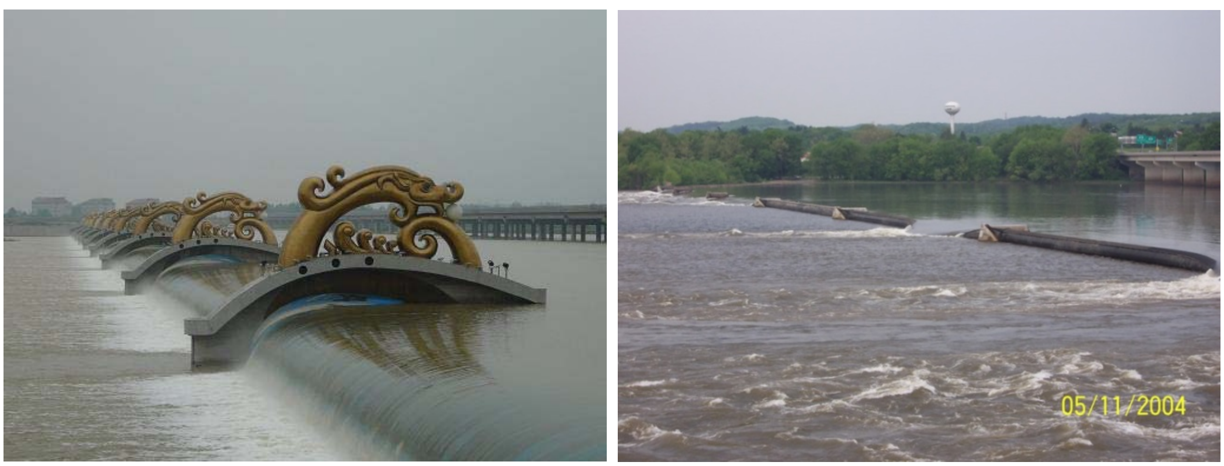

Figure 10. Taoyua Rubber Dam (image courtesy Shandong Linyi Hydraulic Engineering), and Adam T Bower (image courtesy NOAA, http://www.erh.noaa.gov/marfc/100_0284a.jpg)

The inflatable medium consists of high-strength synthetic fabrics and compound rubber. This material is anchored to a concrete foundation to form a sealed bladder using water and/or air depending on ambient conditions. The foundation is raised from the river bed due to risk of sediment build up and erosion/friction. Air is typically used more than water as an inflation medium due to several factors (i.e., small required membrane area, water debris can clog pipes, ease of design and construction, less inflation/deflation time, smaller foundation footprint.)

Some systems use both water and air as an inflation medium, depending on site conditions. The dam is typically provided with a double anchoring system attaching the dam to the concrete foundation when the dam height is at least two meters (6.6 feet). Figure 11 shows a schematic of the inflated dam and the concrete foundation with a double anchoring system.

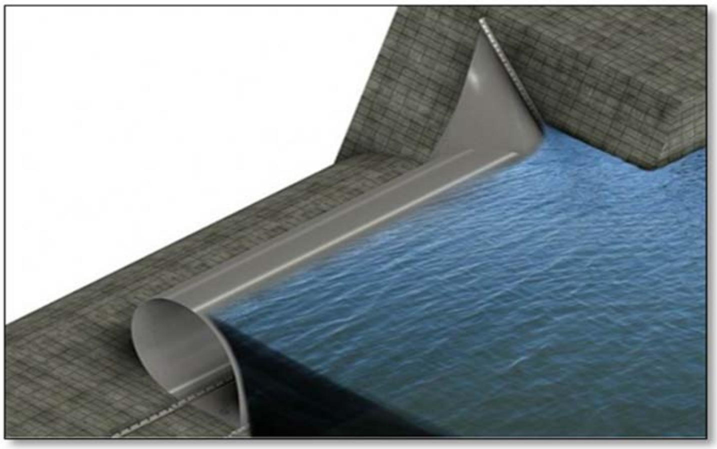

Figure 11. Schematic of Inflated Dam (image courtesy Dyrhoff: Nelaug, Norway Dam project)

An automated control system adjusts the inflation and deflation of the dam membrane according to the water level variation; this can be used in daily operations of water level management and control. Parameters can be set and adjusted remotely through monitoring software for video surveillance and daily management. The system can also be remotely controlled, including via mobile phone. The largest constraint with the inflatable dams is the vibration due to induced current and the "vee notch" that sometimes forms with water flowing at high velocity over the structure, also increasing the risk for bottom scour. A deflector (i.e., fin) is sometimes installed on the downstream side to reduce the flow-structure interaction.

Most dams are designed with a 25 to 30-year lifespan, but have a 10-year warranty. Monitoring and maintenance experience has found that some dams require membrane replacement or repairs every 10 to 12 years. Perhaps the most significant dam failure example is Tempe, Arizona in 2010. The dam had eight sections (240 feet each) and was installed in 1999; a rip in the seam caused the dam sections to fail after 11 years of service. However, it is the only reported Bridgestone manufactured dam problem in the United States out of over 200 installations.

The most significant risks for this alternative are vandalism as well as impacts from sharp objects/debris in high velocity conditions. The vandalism risk primarily applies to bullet and knife cuts. In response, manufacturers have incorporated Kevlar and ceramic chips in the outer dam membrane. A closed circuit for monitoring is also available. Maintenance removal of sedimentation in front of the dam is performed to reduce the risk of puncturing due to large stones and other objects. There are numerous dam applications in severe winter climate; they were found to perform well, passing ice and floating debris without recorded problems. Examples include the Rainbow Falls and Broadwater Dams in Montana on the Missouri River; Palmer Falls on the Hudson River, Corinth, New York; Bolton Falls on the Winooski River, Bolton, Vermont; Highgate Falls, Missisquoi River, Highgate, Vermont; and Silvian Station, Mississippi River, Brainerd, Minnesota.

The following table summarizes relevant information and parameters for several inflatable dams installed around the world:

Table 2. Selected Inflatable Dam Projects

Project/Year Built	Location	Single/Multiple Span	Dam Dimensions	Notes
Ramspol Dam	Ramsdiep Ramsgeul, Netherlands	Three spans	Three sections, each 75 m, total length 225 m (740 feet). Largest reported crest of 8.35 m (26 feet) above the foundation.	Inflation: air and water. Three equal inflatable dams were built because Ramsdiep is a shipping channel and Ramsgeul is a flow channel, and also because the failure probability of three equal dams is smaller. Bridgestone product. Cost. \$50.8 M (2002), Approx. \$74.6M (2016).
Highgate Falls Power Dam, 1992.	Swanton, Vermont	Single Span	4. 6 m (15 ft) X 67 m (220 ft)	Inflation: air. Bridgestone product, 5-ft high concrete sill/foundation. Approx. cost \$1.2M (1992), \$2.3 M (2016).
Taoyuan or "Nine Dragon" Rubber Dam, March 2005	Yihe River, Linyi, Shandong Province, China	10 spans	Total Length – 770 meters (2,525 feet); Inflated Height – 4.5 meters (14.8 feet).	Inflation: water. Designer: HTE Engineering. Cost: \$8.6 M (2004), 11.5 M (2016). Qingdao Huahai Environmental Protection Industry Co.
Adam T. Bower, 1970, 1980's. Reconstructed in 2007 (2 sections) and 1 section in 2012.	Susquehanna River, Sunbury, PA	Seven spans 6 x 91 m (300 ft), 1 x 53 m (175 ft)	Total Length – 640 meters (2,100 feet); Inflated Height – 4.0 meters (13 feet) from river bottom.	Inflation; water and air. Span replacement cost: \$2.0 M (2012). Bridgestone product. The original dam built in 1970 was replaced in the 1980s, and reconstructed in 2007 and 2012.

The largest inflatable dam in operation (until 1997) was the Adam T. Bower. The Shandong Linyi Yi River East Dam is now reported to be the longest (1,247 m, or 4,091 ft).

Most existing floating dams have individual spans limited to approximately 100 m (328 ft), due to difficulty of placement and construction, and the increase in the applied loading forces over a greater length. The limited span length offers a potential benefit in that failed sections can be more easily replaced, as needed, than spans of a greater length.

The typical maximum height for an inflatable dam was previously considered to be in the six to 10 m range (19 to 33 ft). This includes the total height (i.e., foundation and inflatable dam). The current practical manufacturing limitation for the inflatable rubber dam above the foundation is believed to be five meters in the United States and six meters for products manufactured in China.

A 2013 study makes a parallel between the existing Ramspol floating dam and the proposed Bolivar Roads (Galveston, Texas) dam barrier at the Galveston Bay inlet. This location was selected as a case study to install an inflatable dam for hurricane storm surge protection, using the Ramspol as a reference project. The design analysis found that the Bolivar Roads Dam Barrier is a potentially feasible inflatable dam project in deep water with significant wave heights and storm surges. Figure 12 shows a conceptual model of the multi-span proposed dam.

Two locations on the St. Clair River were selected for the feasibility analysis of inflatable dams: Stag and Fawn Islands. These locations have been previously considered for the

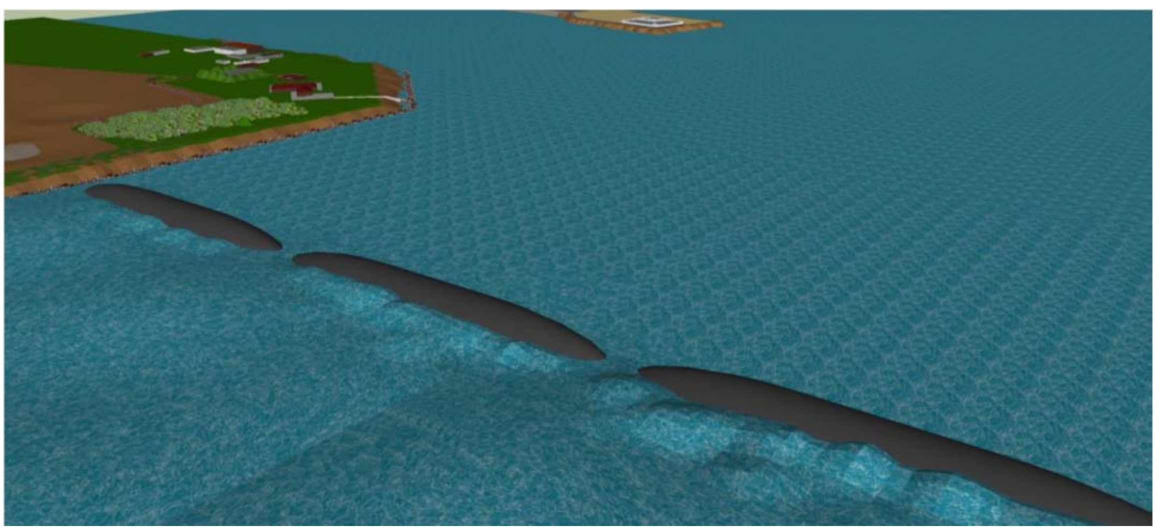

Figure 12. Bolivar Roads Dam Model (image courtesy TUDelft, http://repository.tudelft.nl/view/ir/uuid%3A3fb26157-ac79-491f-a3bb-94f7fb4d1f61/)

performance evaluation of stone dikes. It is expected that the inflatable dams (when fully inflated) will have a similar impact on the water levels, as follows: Stag Island: increase upstream levels by 9 cm (3.5 in), and 16 cm (6.3 in) with the addition of the training walls; for Fawn Island, increase upstream levels by 1 cm (0.4 in) and 5 cm (2 in) with the addition of the training walls. The combined effect of the dikes at both islands is estimated to be 21 cm (8.3 in).

The estimated cost to install and operate inflatable dams varies on the basis of site conditions and, in particular, on water depth. Estimates for two St. Clair River locations are presented in Section V.

c. Strengths and Weaknesses: Inflatable dams represent a semi-adjustable technology with good water level control. If installed in the east channel of the St. Clair River and, when fully inflated, the velocity in the main west channel would increase.

   Some of the disadvantages include mitigative measures that may be required to decrease the flow/velocity in the west channel. The dam foundation will likely impact sediment transport, trapping sediment on the upstream/updrift side and requiring periodic maintenance dredging. Also, during those periods when the dam is inflated, recreational boating may be adversely impacted.

d. Summary Statement: This alternative was selected by AECOM for further evaluation, given its climate adaptability and comparative standing when all evaluation criteria are considered.

3.3 Control/Sector Gates

a. Summary Description and Location: This alternative consists of fully adjustable structures that can be hydraulically closed during periods of low water levels, resulting in an increase in water levels upstream. These units would be installed in the east channel of the St. Clair River at Stag and/or Fawn Island (i.e., same locations as the inflatable dams).

b. Background: Sector gates have been installed in a variety of settings over the last 20 years, particularly in Europe as a response to significant storm surges and flooding. A relevant example of a surge barrier is the Maeslant system, constructed in the Netherlands in 1997. A design competition for the project resulted in five different proposed designs. The selected design (BMK sector gate) addresses a waterway width of 360 meters (1,180 feet), and consists of two sector gates, each 22 m (72 feet) high and 240 m (780 feet) long. Each gate is circular in shape and connected to a hinge point by two steel trusses. This design was found to have practical advantages over other gate types, and comparably lower operation and maintenance costs. Among others attributes, it has rapid closure (i.e., full closure in 2.5 hours and 80% in 1.5 hours); a design life of 100 years; and an ability to accommodate substantial commercial navigation traffic. The gates are floating during closing/opening operations and are stored in two land-based dry docks. They are ballasted with water and sunk to the bottom while in position to close, and rest on a sill made of concrete blocks. The approximate construction cost (1997 dollars) is $450M (approx. $750M current value). The BMK sector gate is shown in Figure 13.

   USACE maintains a Storm Damage Risk Reduction System (HSDRRS) post Hurricane Katrina, designed for the 100-Year Return Event (1% probability of exceedance in any given year). The HSDRRS includes levees, flood gates, surge barriers and pump stations along Lake Borgne, Lake Pontchartrain at the East Bank, and the Barataria Basin at the West Bank of the Mississippi River.

Figure 13. Maeslant Barrier (image courtesy Van Wijngaarden Marine Services B.V., http://www.wijngaarden.com/en/projects_18/the-netherlands/general-assistance.html)

Various studies were conducted to identify possible flood surge protection systems for the City of New Orleans. One of those proposed is a hybrid barrier system with a primary swing gate for navigation (and flow), as well as secondary lift gates. The primary gate size is 18 m (59 ft) deep and 275 m (902 ft) wide to allow for shallow and deep draft navigation.

Another example of this alternative was prompted by Hurricane Sandy. New York City solicited proposals for a system designed for a Category 3 hurricane. The selected proposal (Arcadis Team) entailed a system with a sector gate and 18 lifting gates at the Verrazano Narrows area (approximately 4,800 feet long and up to 70 ft water depth). The proposed design allows for large commercial and recreational vessel passage. The estimated cost of the proposed structure is over $6B, with an annual estimated operations and maintenance budget of over $75M. Figure 14 shows a schematic of the proposed design.

The estimated cost to install and operate sector gates varies, primarily based on the required span. The Stag Island span is similar to the state-of-the-art Maeslant Barrier (1,200 feet). Therefore, for reference purposes, it is assumed that construction costs will be similar. Using the Maesland barrier unit price (dollars per foot), the Stag Island barrier would cost up to $750M while the Fawn Island barrier would cost up to $312M.

c. Strengths and Weaknesses: Control/sector gates represent a fully adjustable technology, with good water level control. As with the inflatable dam alternative, control/sector gates are adaptable to changes in climate and corresponding fluctuation in water levels.

Figure 14. Proposed Verrazano Narrows System (image courtesy Arcadis)

This alternative represents a very significant and costly investment in both infrastructure installation and operation. It does have the potential for negative environmental impacts on river bottomlands and aquatic life, as well as on recreational boating (particularly during construction and active operation). Aesthetic considerations for shoreline residents and visitors are relevant as well. Additionally, detailed information on the potential effectiveness of this alternative in controlling lake levels is presently unavailable, as the structure has been primarily designed for use as a storm surge protection barrier.

d. Summary Statement: This alternative was not selected by AECOM for further evaluation, based largely on the estimated high cost in comparison to other alternatives.

4. Other Structures

This fourth and final category consists of various other structures with the potential to modify water levels upstream of their location. They include both adaptable and non-adaptable (i.e., fixed) structures.

4.1 Ice Boom

a. Summary Description and Location: Ice booms, as the name implies, are primarily designed to control ice conditions during the winter. The ice boom prevents an excessive ice buildup in the river it is installed in, protects infrastructure (e.g., hydro-electric water intakes), and reduces shoreline erosion. They are typically installed in the late fall and removed during early spring. They partially obstruct water flow and, therefore, can increase upstream water levels. This alternative entails the prospective location of such a structure in the Upper St. Clair River and/or the St. Marys River.

b. Background: A modern design for an ice boom was developed in 1997, replacing an old timber structure installed in 1964 at the Lake Erie outfall to Niagara River. This structure, jointly owned by the New York State Power Authority (NYSPA) and Ontario Power Generation OPG), is approximately 2,700 meters (8,800 feet) long and is located approximately 300 meters (1,000 feet) southwest of the City of Buffalo water intake crib. The boom is composed of 22 spans (steel pontoons connected with steel cable). The spans are anchored to the lake bed at 122 meter (400 ft) intervals by steel cables. Installation takes place when the water temperature in Lake Erie drops to 4° degrees Celsius (39° degrees Fahrenheit) or no later than December 16th of any year. The ice boom is flexible; during periods of storms, or winds in excess of 30 miles per hour (50 km/h), the ice arch breaks and the pressure on the ice boom becomes very significant; the pontoons submerge to allow the ice to flow over it. When the pressure returns to normal, the boom pontoons return to the floating position.

The ice boom at the Little Rapids Cut on the St. Marys River was monitored by USACE between 1975 and 1980. The boom, installed just upstream of the Sugar Island Ferry crossing, consisted of a west arm (122 m or 400 feet) and an east arm (1000 feet or 305 m). The structure was installed to stabilize and reduce ice cover in the Soo Harbor and alleviate impacts on ferry operations. A channel opening of 76m (250 ft) was provided in the middle for ship passage. The study used water level recordings (i.e., Soo Harbor, Little Rapids Cut, lower St. Marys River) to determine impacts (if any) of the boom upstream and downstream of its location. Over a distance of less than one mile (from immediately upstream of the boom to Island One), the water levels varied between 1.5 and 2.5 inches (3.8 and 6.3 cm), well within the expected range. It was concluded that the ice boom at Little Rapids Cut has no significant impact on water levels.

Figure 15. Niagara River Ice Boom During Winter and Spring Removal (courtesy Environment Canada and Lake Erie Times [*http://www.forterietimes.ca/2015/04/15/removal-of-ice-boom-delayed*](http://www.forterietimes.ca/2015/04/15/removal-of-ice-boom-delayed)***)***

c. Strengths and Weaknesses: An ice boom can serve as a seasonal water level control technology, although it's primary design intent is to control ice and prevent flooding, erosion and/or infrastructure damage downstream. Use of such a structure in the Niagara River has been effective for its intended purpose, although its impact on upstream water levels is temporary and not significant enough to warrant further investigation.

d. Summary Statement: This alternative was not selected by AECOM for additional analysis, given the impracticality for St. Clair River and St. Marys River locations, and the fact that its primary application is for ice control as opposed to lake level control.

4.2 Park Fill and Control Gate System

a. Summary Description and Location: This alternative consists of a combined landfill and control gate system located at the mouth of the St. Clair River, immediately north of the Sarnia Yacht Club. The landfill would be a system of two constructed barrier islands along with control gates (46 and 76 m, or 150 and 250 ft, respectively) that could be closed during periods of low water (to increase upstream levels) and opened during high water conditions.

b. Background: This alternative offers a hybrid approach: the constructed islands would permanently increase water levels upstream (to some degree) by reducing conveyance, while the adjustable control gates would allow the impact to be modified depending upon water level conditions. In order to mitigate for potential flow velocity increases in the downstream St. Clair River main channel, this alternative can be used with in-stream kinetic turbines to be provided near the Blue Water Bridge. As an ancillary benefit, the system of islands could be designated as a natural park system to provide recreational benefits.

c. Strengths and Weaknesses: This alternative represents a partially adjustable technology with the potential to control lake levels while adapting to climate conditions. The constructed islands would have positive environmental benefits (e.g., aquatic habitat) while recognizing disruptions/adverse impacts during the construction process. As noted above, the project would offer water-based recreational opportunities.

   Several disadvantages are associated with this alternative. Significant open lake bottom fill will be required, and mitigative actions will likely need to be taken. Regulatory approvals could prove challenging as well, given the construction of islands and associated control gates. As proposed, the structures would not adversely impact commercial navigation channels but would have some impact on recreational boating traffic. Finally, as a newly proposed "hybrid" structure that has not been previously studied, the potential impact on upstream water levels has not been quantified.

d. Summary Statement: As an innovative approach not previously studied, this alternative was found by AECOM to have sufficient positive attributes to warrant additional analysis, as provided in Section V.

C. Evaluation Criteria: Applications and Outcome

All of the alternatives discussed in the preceding section have some degree of capability to control water levels. The estimated performance of each alternative ultimately depends on location, footprint, and other structural/operational attributes. Intuitively, longer and higher structures produce the most significant lake level control capability, as do upstream locations on the St. Clair River. However, alternatives with the largest footprint also have a comparatively greater potential to adversely impact such factors as natural processes (e.g., sediment transport), fish migration and spawning, and commercial and/or recreational navigation.

In the interest of focusing on a subset of these alternatives, AECOM evaluated each on the basis of available data and information, and in light of seven criteria, all weighted equally for purposes of this analysis:

- *Performance:* Evidence that the alternative is likely to be capable of contributing to lake level controls.

- *Implementation:* The extent to which the installation and operation of the alternative is feasible from an engineering standpoint, based upon similar experiences elsewhere.

- *Cost:* The anticipated cost of installation as well as operations and maintenance, based upon research to date or extrapolating from similar structures in other locations.

- *Regulatory:* The extent to which the structure is likely to be subject to regulatory/permitting requirements and the anticipated complexity/challenge of the approval process.

- *Climate Resiliency:* The ability of the structure to adapt to climate uncertainties (i.e., adjustable mechanisms) in light of lake level fluctuations.

- *Environmental:* The extent to which the structure may have positive and/or negative impacts (permanent or temporary) on the aquatic ecosystem, water quality and related considerations.

- *Social/Cultural:* The extent to which structure installation and operation may have a positive and/or negative impact on the user community (e.g., First Nations, commercial navigation, recreational boating, shoreline residents, water-based recreation).

Each alternative was evaluated on its own merits; combinations of alternatives were not considered during this process, but will be relevant when a subset of the alternatives is subjected to detailed design.

A qualitative ranking process, based upon available data/information and best professional judgement, was conducted for the alternatives by AECOM in consultation with GBF Board members. The following ratings were used on a comparative basis:

- Very Good (VG): Compares very favorably to other alternatives; meets the evaluation criterion.

- Good (G): Compares favorably to other alternatives: meets or has the potential to meet the evaluation criterion.

- Poor (P): Does not compare favorably to other alternatives: unlikely to meet the evaluation criterion.

The following table presents the rankings for the multiple alternatives considered. Based on the outcomes and, as noted in the preceding section, three alternatives were selected for additional analysis in Section V: in-stream turbines, inflatable dams, and a park fill/control gate system.

Table 3. Structural Alternatives for Lake Level Controls

Category	Alternative (and Previous Studies)	Description/Location	Performance	Implementation	Cost		Regulatory	Climate Resiliency	Environmental	Social/Cultural
					Capital	O&M				
1. Compensatory Structures	1.1 Submerged Sills (IJC, 2012)	Submerged stone weirs-Upper St. Clair River.	S	VG	VG	S	VG	P	P	S
	1.2 Weirs, Jetties (IJC, 2012)	Parallel stone dikes and weirs-Lake Huron, mouth of St. Clair River.	S	VG	S	S	S	P	S	S
	1.3 River Training (Walls, Wing Dikes) (IJC, 2012)	Stone Dikes connected to land-Fawn Island and Stag Island (west channels), St. Clair River.	VG	VG	VG	S	S	P	S	P
	1.4 River Training (Wing Dikes) (NEW)	Stone dikes connected to land-Niagara River main channel, approx. 600 ft downstream of Peace Bridge.	VG	VG	VG	S	S	P	S	P
2. Power Generating	2.1 Conventional Hydroelectric Dam (JBE, 1926)	St. Lawrence River, St. Clair River.	S	P	P	P	P	S	P	P
	2.2 In-stream Turbines (IJC, 2012)	River bed mounted power turbines, Upper St. Clair River.	S	S	P	S	S	S	VG	S
	2.3 In-stream Turbines (NEW)	River bed mounted power turbines, upstream of Sault Ste. Marie Compensation Works.	S	S	P	S	S	S	VG	G
3. Adaptive Management	3.1 Inflatable Flap Gates (IJC, 2012)	Inflatable gates, river mounted-Fawn Island and Stag Island, St. Clair River.	S	S	P	S	S	S	S	P (S)
	3.2 Inflatable Dams (IJC, 2012)	Inflatable rubber dam, no location specified. St. Clair River a possibility.	VG	S	P	S	P	VG	S	S
	3.3 Inflatable Dams (NEW)	Inflatable rubber dam, Fawn Island and/or Stag Island (west channels), St. Clair River.	VG	S	P	S	P	VG	S	S
	3.4 Control/Sector Gates (NEW)	Controlled sector gate system at Stag Island (west channel), St. Clair River.	VG	S	P	S	P	VG	S	P

4. Other Structures	4.1 Control Structures/Dikes (LRSB, 1993)	Two gated control structures downstream of Peace Bridge-Niagara River.	VG	S	P	S	P	S	S	P
	4.3 Ice Booms (Ex. Niagara)	Niagara River mouth.	S	VG	VG	S	VG	P	VG	P
	4.5 Park Fill and Control Gate System NEW)	Lake Huron/St. Clair River mouth-north side of Sarnia Yacht Club. Proposed park fill with adjustable flow control structures.	VG	S	S	VG	P	VG	S	S

Note: VG=Very Good, G=Good, P=Poor.

D. User Community Perspectives

As a means to augment the review of existing data and information, AECOM engaged in a series of conversations with individuals representing agencies, organizations and communities with an interest in lake level fluctuations and the prospect of additional structural controls. This included individuals drawn from public entities (i.e., state and federal agencies, First Nations) as well as those drawn from the private sector (i.e., commercial shipping industry, shoreline property owners). The conversations were informal, characterized by broad questions designed to elicit overall opinions on the prospect of additional structural controls for lake levels and the types of alternatives that might be considered. It was agreed that outcomes would be summarized without attribution, and that consideration of any specific structural alternatives should involve formal consultations with the broad arrange of interested parties.

Key outcomes resulting from the several conversations are as follows. They are not placed in any particular order, and provide a “selective snapshot” of perspectives that can be kept in mind as further efforts to investigate lake level control alternatives are considered. In presenting these outcomes, it is emphasized that they reflect the views of a modest subset of all stakeholders. While these views provide valuable insights into the issue, they are not comprehensive and do not necessarily reflect the entire range of viewpoints on the subject.

- Among those interviewed, interest varied relative to the study of additional lake level control mechanisms on the Great Lakes-St. Lawrence River System. Any such study, at the minimum, must address a number of key considerations that include engineering feasibility, economics (e.g., installation and operating costs), environmental impact, and public acceptability. A complicating factor is that there is no true “average” lake level, nor is there consensus agreement on what an “optimal” lake level should be.

- The question of “who should pay” must be addressed and resolved if additional measures are to be implemented. This is particularly challenging at present because there are so many other pressing issues (e.g., navigation dredging, infrastructure repair/replacement) that require large amounts of funding. Many interested parties are likely to be favorably disposed to additional structural measures provided that the costs are borne elsewhere.

- Should consideration of prospective structural measures move forward in additional detail, all interested parties must be promptly engaged, and a formal consultation process conducted, to ensure full and open discussion. In such an instance, established consultation protocols must be followed. Any further development that could elevate a disconnect between government and First Nations due to a lack of consultation will be problematic.

- If the issue is to move forward in policy dialogue and ultimately garner funding support, it needs to be embraced and advocated by a broad community of Great Lakes-St. Lawrence River System interests that goes well beyond shoreline owners alone. This is a challenging task given that the issue is highly polarized: many such interests either support or oppose the idea as a matter of principle, irrespective of the merit of any given alternative.

- "Adaptive management" is a priority interest of governments at present and, therefore, lake level control structures that are "climate resilient" (i.e., adjustable to accommodate changes in climate and resultant lake level implications) are of greater potential interest than permanent, fixed structures that do not have adaptive properties.

- To enhance prospects for its approval and installation, any proposed structure must accommodate the requirements and concerns of many different sectors of the Great Lakes-St. Lawrence River System community. Thus, frequent and open consultation from the earliest stages of consideration is critical.

- Ambitious three and five lake regulation measures have has been studied in detail over the years and summarily dismissed based, in large part, on the prohibitive cost. It is recognized that the categories of structural alternatives identified in this study are relatively modest in scale and, consequently, are likely to have a more modest impact than the more ambitious proposals.

- The IJC continues to look at non-structural adaptive management measures designed to accommodate, as opposed to control, lake level fluctuations. If consideration of structural measures is to move forward, it should do so in concert with non-structural measures.

- Governments have historically focused on "traditional" control mechanisms such as submerged sills, dams, weirs, jetties and control gates. However, newer ideas that have ancillary benefits (e.g., in-stream turbines) and creative financing opportunities (i.e., Public Private Partnerships) have particular appeal, provided that detailed analysis is favorable.

- Support for/opposition to any new structural measure will likely have two dimensions: the nature of the interested parties (e.g., commercial navigation, shoreline owners, water-based recreation, environmental interests); and the geographic location affected by the measures (e.g., upper lake shoreline residents may be impacted differently than lower lake shoreline residents). Both dimensions must be acknowledged and addressed.

- The two federal governments have worked together successfully on past lake level reference studies under the auspices of the IJC and, should a study of additional structural control measures be initiated, that relationship will continue.

- The IJC seeks to operate by consensus when addressing sensitive policy matters. Given the nature of the lake levels issue and associated debate, it has historically been difficult to secure IJC interest in/ support for new measures and approaches.

- The regulatory implications of any structural measure will be formidable, given that installation and operation are likely to affect the bottomlands of a river or lake, the levels and flows of the system, and an array of water-based uses. Additionally, the regulatory process in shared waters must involve the two federal governments and, specifically, the U.S. Department of State, and Foreign Affairs, Trade, and Development Canada. Further, the prospective installation and operation of one or more additional structural measures may require revisions to established binational lake level control plans.

- Advocates for additional permanent structures in the St. Clair River as a means to raise water levels in Lake Michigan-Huron (i.e., Compensating Works) base their argument on a long-standing Congressional authorization for construction. However, concerns associated with that alternative include levels and flows implications, navigability (i.e., channel depth implications), sedimentation behind structures, and prospective environmental impacts, among others.

- There is a tendency for society to view lake level fluctuations as a problem, and to focus exclusively on how to modify fluctuations rather than on how to adapt to them. Thus, we need to identify additional, modest adaptation measures that can be readily implemented (e.g., installing docks and other shoreline infrastructure than can accommodate fluctuations).

- It is essential that we better understand the nature of lake level fluctuations and the system in general: this includes hydrologic, environmental, and social/cultural dimensions. Until that time, consideration of any new/additional structural mechanisms is ill-advised and will not be favorably received by many. Also, modifying a system that is not well understood may result in unintended adverse consequences. Limited funds are better spent on educating communities about how to adapt to lake level fluctuations.

- First Nations view the waters of the system as “sacred” and, generally speaking, would look unfavorably on the installation and operation of any structure that would affect those waters. In particular, concerns would be expressed over any measure that would have the potential to adversely affect water quality, exacerbate an oil/hazardous material spill or re-suspend toxic sediments. Of those considered, the inflatable dam alternative would be looked upon less unfavorably than other alternatives provided that it could be demonstrated that the anchoring system would not adversely affect sediments and water quality.

V. Concept Level Analysis: Selected Alternatives-Summary

A. Introduction

The results of the evaluation process provided general guidance to AECOM in its selection of three structural alternatives for further analysis. Each of those alternatives is presented below, and includes discussion of concept level design, preliminary layout plan, regulatory requirements, estimated capital and operating costs; climate resiliency assessment, environmental assessment, and social/cultural assessment.

B. Alternative 1: In-stream Turbines

1. Concept Level Design: These units would be installed on the river bed at two locations: Upper St. Clair River by the Blue Water Bridge and upstream of the St. Marys River Compensation Works. As they provide an obstruction to the moving river flow, they will impact river hydrodynamics and increase water levels upstream. The turbines upstream of the St. Marys River Compensation Works will be able to produce electricity to be used by the hydro plant during peak demands. This will provide the plant with flow release control (i.e., gate opening and closing operations) when the turbines are on. By reducing the gate flow releases during low Lake Superior water levels, a water level control mechanism is provided. It is expected that the extremes (high and low) water levels (upstream and downstream) will be reduced, allowing for more moderate level variation.

2. Preliminary Layout Plan: The plan views of the proposed locations are shown in Figure 16 (St. Marys River Compensation Works) and 17 (Blue Water Bridge, St. Clair River).

Figure 16. Turbines at the Compensation Works (Aerial courtesy USACE)

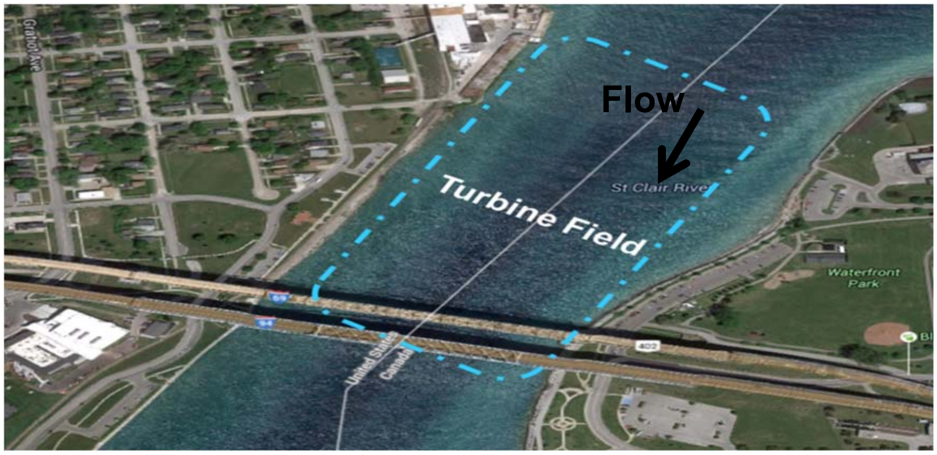

Figure 17. Turbines-Blue Water Bridge (Aerial courtesy Google Maps)

The number of turbines needed will be selected based on the target water level control. The impact on water levels was previously studied (National Research Council, 2011) for the St. Clair River near the Blue Water Bridge. A hydrodynamic modeling simulation determined that the deployment of 56 large turbines (diameter of 6.5 m, or 21 ft), under average flow conditions, would raise upstream water levels by 9 cm (3.5 in) while collectively producing 1.3 MW of power. If the number of turbines totaled 151 in that general location, upstream water levels (under average flow conditions) would increase by 19 cm (7.5 in) while collectively producing 2.5 MW of power. (Note: Energy production does not linearly scale with the number of turbines to be used. This is due to the two-way interaction between the turbine array and the river flow; each river-mounted turbine generates a "wake" zone with high turbulence and reduced flow velocity that reduces power producing capability of other turbines located in the "wake" zone.)

If 150 turbines of the same size were installed downstream where velocity is significantly lower, water levels upstream would increase by three to seven cm (one to 2.8 in) under average flow conditions, while collectively producing up to 1.1 MW of power. Power production capability will vary based on the configuration of the turbines. Figure 18 shows the computer modeling results for the Upper St. Clair simulation.

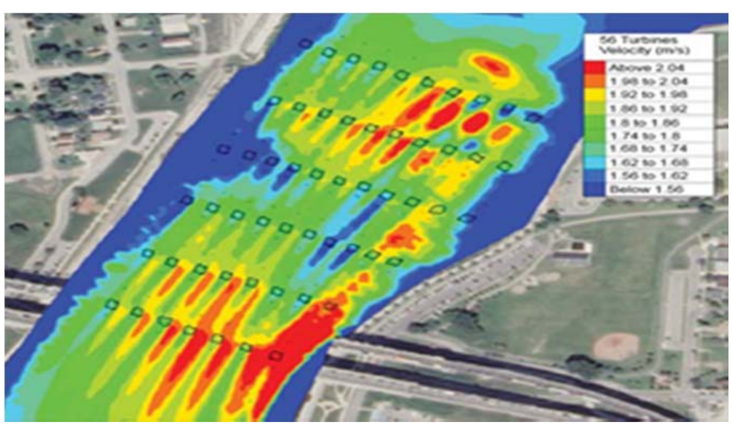

Figure 18. Upper St. Clair River Turbines Simulation

The number of units required for each location is unknown at this time. For the St. Clair River location, it is assumed that the minimum number is 56. Detailed analysis for each location (including numerical analysis of the Compensation Works gate operations) is required to determine the optimal number of turbines.

2. Regulatory Requirements: The units are mounted on the river bottom and, while the construction impacts are of short duration and the required footprint for each unit is small, the affected area could be quite extensive depending on the number of units installed.

   Detailed environmental studies for similar projects have shown minor or no significant impacts, suggesting that regulatory approvals may not be insurmountable. At a minimum, it is anticipated that environmental impact and monitoring studies will be required in support of regulatory approvals.

3. Preliminary Cost Estimates: For the St. Clair River location, the preliminary estimated costs range from $37M to $100M (56 and 150 turbines, respectively). Annual operations and maintenance costs are estimated to be 1.5% of the initial capital cost, or between $.55M and $1.5M.

4. Climate Resiliency Assessment: This alternative features adjustable technology, as the turbines can be turned on or off depending upon water level control requirements.

5. Environmental Assessment: Specialized environmental studies conducted for the large-scale RITE project suggest that the adverse environmental implications of installing and operating large turbines, as described above, would not have a significant adverse environmental impact.

6. Social/Cultural Assessment: This alternative has several attributes that, in comparison to other alternatives, suggest a favorable social/cultural assessment. These include minimal environmental concerns (as noted above); few or no aesthetic concerns (due to below surface installation and operation), and the prospective appeal of ancillary benefits associated with power generation and associated revenue. Given the "untested" nature of this alternative, this assessment remains speculative.

C. Alternative 2: Inflatable Dams

1. Concept Level Design: These units would be installed in the St. Clair River at Stag and/or Fawn Islands- see Figure 19.

2. Preliminary Layout Plan: While previous studies indicate the wide applicability of inflatable dams, it was unknown if they apply to the St. Clair River, due to the deep water conditions. The tallest existing dam (Ramspol, Netherlands) consists of three sections, 74 m (243 feet) long, 13 m (43 feet) wide, and 8.35 m high (27.4 feet) above the foundation. Typical water depths vary between 22 and 28 feet at LWD at Stag and Fawn Islands, and the east channels are 366 m (1,200 feet) and 152 m (500 feet) wide, respectively.

Figure 19. Inflatable Dams Stag/Fawn Island
(Aerial Google Maps, https://www.google.com/maps)

Given the above, St. Clair River site conditions were discussed with Dyrhoff, a design engineering firm and distributor of the Sumimoto, Japan rubber inflatable dams. It was concluded that an inflatable dam is possible at the Stag and/or Fawn Island locations, with the following draft specifications:

- Sumitomo can manufacture a five m (16.4ft) inflatable dam; if a six m (19.7 ft) dam is needed, the product will be manufactured in China.
- The height of the inflatable part of the structure should be not more than 16.4 ft (approximately 5.0 m). A concrete foundation could be provided with a stone sill structure, 14 ft high. While the concrete foundation acts a permanent sill, it expected that it will have little, if any, impact on recreational boating navigation, given typical drafts of less than eight ft (2.5 m) for recreational vessels.
- The cross-section shape of the inflatable dam would likely need to be almost semi-circular to prevent vibrations.
- The concrete foundation would need to incorporate a "house" for the deflated membrane for long periods. Suction would be required to pull the membrane into position.
- The maximum length of the inflatable dam sections would likely be approximately 200 ft (60.0 m) at the base. Concrete piers would need to be constructed between different sections of inflatable dam. These would need to have side slopes constructed at an angle of approximately 45 degrees.
- The dam would be composed of EPDM rubber body material, require a minimum three layers of nylon fabric, and have a nominal thickness of .75 in.
- The bottom rubber sheet would be EPDM rubber outer layer material, require a minimum two layers of nylon fabric, and have a nominal thickness of 5/16 in.
- The Inflation package would include six air blower units, with a total inflation time of less than two hours.

- Construction time is estimated at four to six months.

3. Preliminary Cost Estimates: Estimated construction costs are: $81.5M (Stag Island) and $30.1M (Fawn Island). The estimated unit prices are $68,000/LFT (Stag Island) and $60,000/LFT (Fawn Island). They are both lower than the Ramspol unit price ($101,000). This may be due to the lower inflatable rubber dam height (five m above the base compared to 8.35 m for Ramspol). Annual operations and maintenance costs are assumed to be 2.5% of capital construction costs ($2M and $750,000, respectively). Every 10 to 12 years, the inflatable membrane needs to be replaced ($17M and $7.3M, for Stag and Fawn Islands, respectively). Note that the estimated construction costs do not include any necessary mitigation measures (if required) in the west channel.

The water level impacts of an inflatable dam at Stag and/or Fawn Island are assumed to be similar to alternative 1.3 (river training-wing dikes): 9 cm (3.5 in), increasing to 16 cm (6.3 in) with the addition of the training walls at Stag Island; and one cm (0.4 in), increasing to five cm (two in) with the addition of the training walls at Fawn Island. The combined effect of the inflatable dams at both locations islands is estimated to be 21 cm (8.3 in).

Figures 20 and 21 present plan view and typical cross-section details of the proposed inflatable dams.

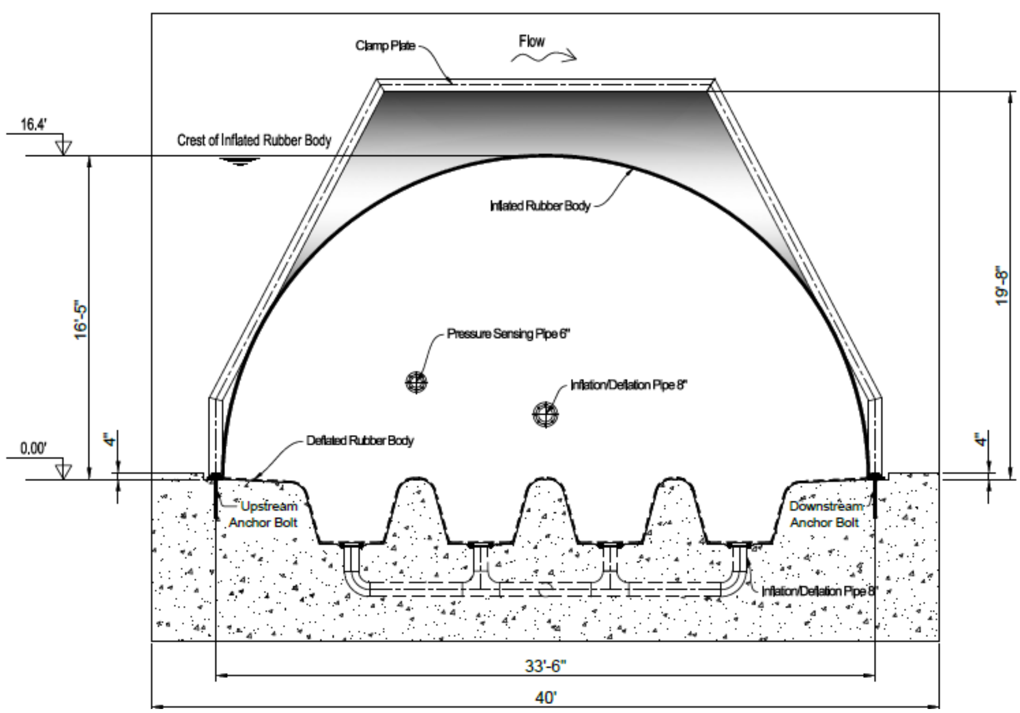

Figure 20. Typical Details Inflatable Dams Stag/Fawn Island (image courtesy Dyrhoff)

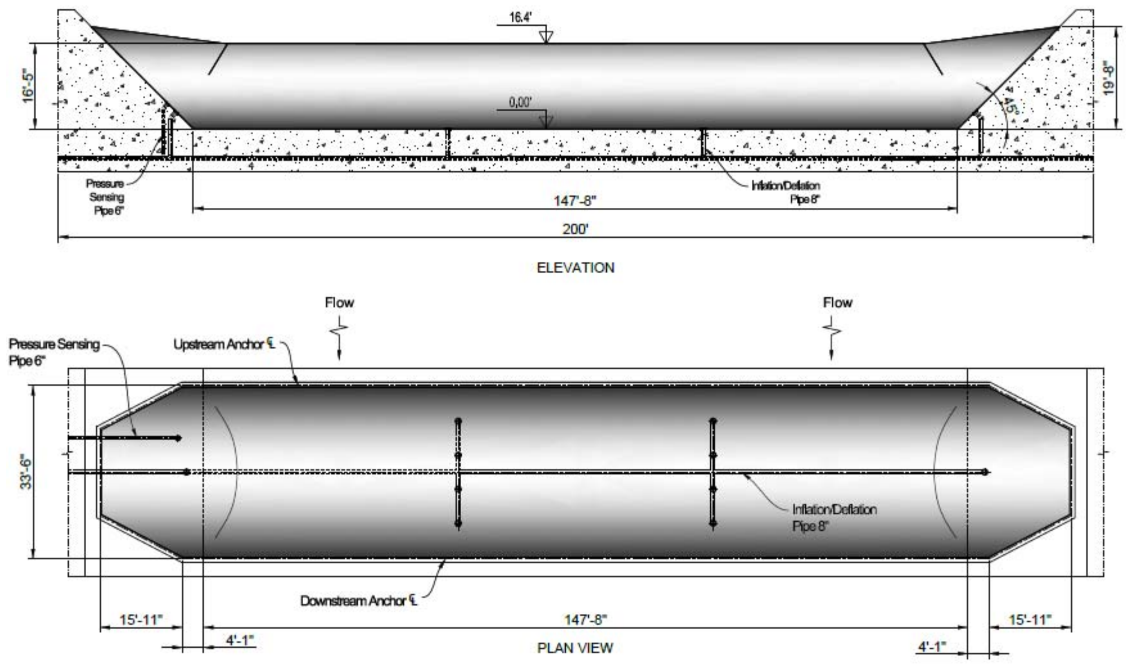

Figure 21. Typical Details Inflatable Dams Stag/Fawn Island (image courtesy Dyrhoff)

4. Regulatory Requirements: These structures will require a permanent footprint in the east channel and, possibly, compensation measures in the west channel. Even though this is a semi-adjustable alternative and the dam can be deflated during periods of high water levels, the permanent infrastructure suggests that substantial regulatory/permitting requirements will result.

5. Climate Resiliency Assessment: This is a semi-adjustable technology and, therefore, can be adapted at any time as a function of target water levels. The concrete foundation acts as a permanent submerged sill, and will slow the water velocity in the east channel. It is expected that the west channel flow velocity will increase.

6. Environmental Assessment: The primary adverse environmental impact is due to the permanent foundation and its likely impact on fish migration. The foundation will also likely impact sediment transport, trapping sediment on the upstream/updrift side and requiring periodic maintenance dredging. On the positive side, the foundation will likely create habitat opportunities at the toe of the armor stones.

7. Social/Cultural Assessment: Despite the adjustable nature of the inflatable dam, the foundation requirements will likely raise concerns over environmental disruptions, as well as impacts on recreational fishing and boating access, even when the dam is deflated. Aesthetic concerns are relevant when the dam is fully inflated.

D. Alternative 3: Park Fill and Control Gate System

1. Concept Level Design: This alternative features a proposed park fill at the mouth of St. Clair River (north of the Sarnia Yacht Club), accompanied by control structures, as summarized below:

    - Approximately four acres of fill will be used to create two islands (stone revetment, sand fill, topsoil and landscaping). The two islands will serve as upland habitat and also offer recreational opportunities. Further, the stone revetment will provide fish spawning opportunities.
    - Sand fill will create three beach cells for public recreational opportunities and protect over 1,200 feet (365 m) of current underutilized and eroding shoreline.
    - A submerged aquatic fish spawning reef will be an additional benefit of the fill.
    - Two flood control gates will be installed, and will be opened during high water levels and closed during periods of low levels. In addition, the gates will be temporarily opened to provide adequate near-shore circulation ("flushing") as needed.
    - The source of fill could include material from federal maintenance activities, as well as well as Sarnia Yacht Club maintenance dredging. This may result in substantial construction cost savings.

2. Preliminary Layout Plan: Figure 22 shows the proposed park fill alternative. As the proposed fill reduces the available flow area at the mouth of the St. Clair River, compensatory mitigation structures may be required to reduce the flow velocity. One alternative that appears to be feasible for such mitigation is the bottom mounted turbines (see alternative 2.2).

   The impact on water levels is largely undetermined at this time, given that this is a newly developed alternative. However, it is estimated that the alternative will achieve at least the level of control level provided by alternative 2.2 (turbines at the Blue Water bridge), raising the water level between nine cm and 19 cm (3.5 and 7.5 in, respectively). Detailed modeling is required to determine water level control capabilities with a degree of precision, as well as the optimal number turbines for flow mitigation.

3. Regulatory Requirements: This alternative requires a significant footprint on the river bottom, both for the constructed islands and the infrastructure for the control gates. This suggests the likelihood of significant regulatory/permitting requirements.

4. Preliminary Estimated Costs: Construction costs are estimated at $100.3M, with annual O&M costs assumed to be 2.5%, for a total of $2.5M.

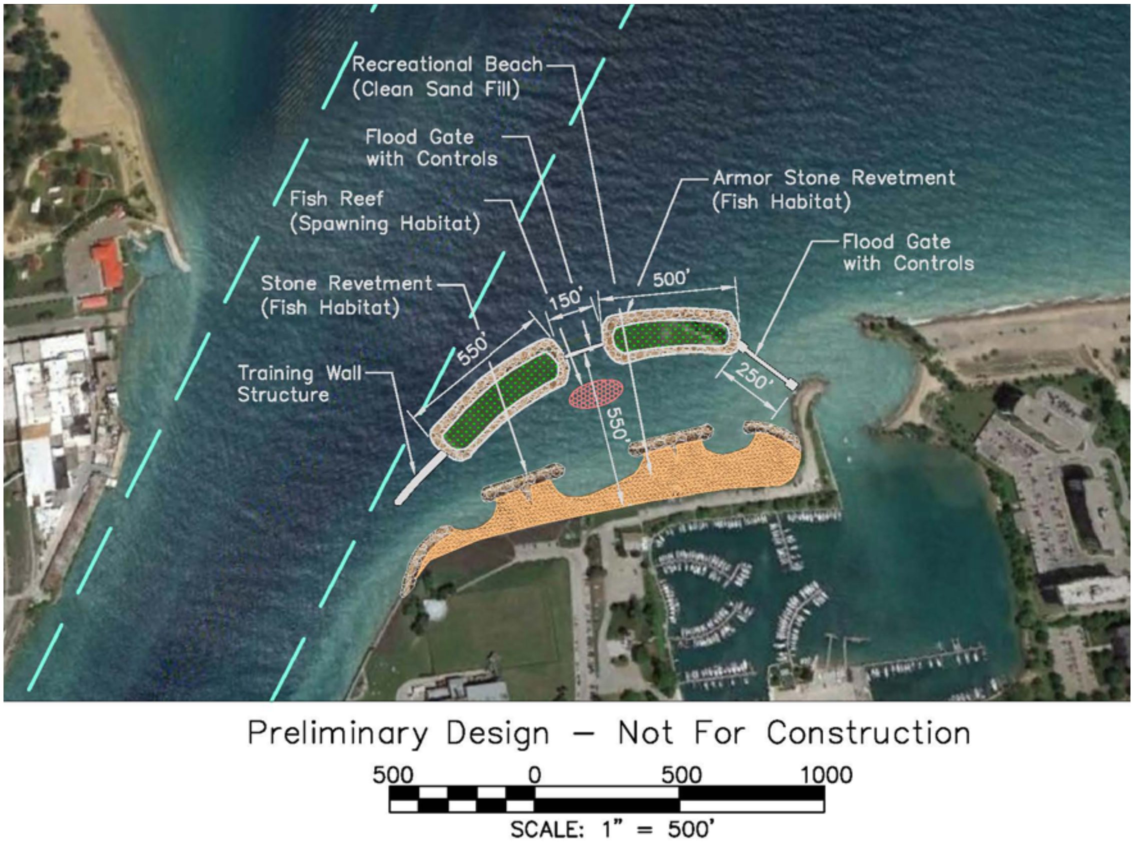

Figure 22. Park Fill and Control Structures

5. Climate Resiliency Assessment: This is a semi-adjustable technology that can adapt to climate-induced lake level fluctuations, and can also be implemented in combination with in-stream turbines (see Alternative 1).

6. Environmental Assessment: Adverse impacts will be experienced during construction due to the extent of fill requirements for the islands and infrastructure installation for the control gates. Environmental benefits will be substantial post-construction (e.g., fish and aquatic habitat, upland habitat), and an additional benefit is the ability of the control gates to periodically "flush" the near shore area to improve circulation.

7. Social/Cultural Assessment: Given that this is a newly developed alternative, its receptivity from a social/cultural standpoint is open to conjecture. The footprint is substantial and its aesthetic impact could be perceived as a negative by some. Further, it is in close proximity to a yacht club and, therefore, recreational boating considerations may be an issue. On the positive side, substantial ancillary benefits (e.g., parkland and enhanced fish, aquatic and upland habitat) will have appeal. Given that this alternative's impact on water levels has yet to be determined in detail, social/cultural receptivity will also likely be a function of its anticipated effectiveness for lake level control.

VI. Study Outcomes and Next Steps

The three structural alternatives subjected to a "concept level" analysis have a climate resilient potential to "take the edges" off pronounced lake level fluctuations. Two of the three are emerging technologies not yet implemented in the Great Lakes-St. Lawrence River System (i.e., in-stream turbines, inflatable dam), and the third is a newly devised technology specific to a St. Clair River application (i.e., park fill and control gate system). *Based on available data and information and the multi-faceted evaluation process embodied in this study, it is concluded that each of these three alternatives merits additional analysis (i.e., detailed design). Such an analysis is required to definitively determine whether these alternatives are fully viable from the standpoint of performance, implementation, cost, regulatory requirements, climate resiliency, environmental impacts, and social/ cultural considerations.*

In the interest of moving one or more of these alternatives forward to detailed design, the following steps are recommended:

1. Design and implement a strategic plan to introduce study outcomes to key decision makers/opinion leaders, generating support for continued consideration of the alternatives;

2. Secure requisite governmental support (and necessary funds) for conduct of detailed design, and select project consultant;

3. Develop and implement a detailed methodology focusing on multiple evaluation criteria (as noted above) to ensure that all key design aspects are considered;

4. Initiate formal consultations with all interested parties at study outset, and maintain meaningful engagement for the entirety of the detailed design process;

5. Conduct an "All Hands" pre-permit application meeting, convening relevant U.S. and Canadian regulatory agencies to identify/discuss all potential requirements;

6. Undertake all bathymetric and topographic surveys, as well as geotechnical investigations, to provide needed data input for modeling purposes;

7. Undertake hydrodynamic and sediment transport modeling to determine water level control potential as well as identify prospective environmental impacts;

8. Optimize design to achieve desired water level control targets;

9. Undertake detailed cost estimation for the installation and operation of each alternative, and refine, as needed, through value engineering;

10. Undertake a detailed comparative analysis of the alternatives designed, and select a preferred alternative (or combination of alternatives) to recommend for implementation.

APPENDIX A: BIBLIOGRAPHY

Alaska Center for Energy and Power, University of Alaska Fairbanks: "River, Tidal, and Ocean Current Hydrokinetic Energy Technologies: Status and Future Opportunities in Alaska", November 2010.

Atlantis Resources Limited, http://atlantisresourcesltd.com/projects.html

Bridgestone Industrial Products America, Inc., http://www.bridgestoneindustrial.com/products/

Bruxer, J. and Carlson, C. (Environment Canada), "Review of Past Studies on Further Regulation and Compensation in the Great Lakes-St. Lawrence River System, 2010.

Dunlop GRG/Trellebord, Inflatable Dam Brochure, http://www.trelleborg.com/upload/Dunlop/files/Dunlop%20GRG%20brochure.pdf

Dyrhoff UK Inflatable Dams, http://www.dyrhoff.co.uk/our-products/inflatable-rubber-dams/

Electric Power Research Institute, Palo Alto, CA: "Assessment and Mapping of the Riverine Hydrokinetic Resource in the Continental United States", 2012.

Florida Atlantic University, Boca Raton, FL: "Effects of EMF Emissions from Cables and Junction Boxes on Marine Species", 2013.

Franco, J.J. and Glover, J.E., "Effects of Submerged Sills in the St. Clair River, Hydraulic Model Investigation" Technical Report H-72-4, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1972.

Freeman, J.R., "Regulation of Elevation and Discharge of the Great Lakes: Designs for Gates, Sluices Locks in the Niagara and St. Clair Rivers", 1926.

Hydrosult et al., "St. Lawrence River Hydraulic Structures Analysis", Report to the Levels Reference Study Board, 1993.

Instream Energy Systems, http://instreamenergy.com/projects/yakima-washington/

International Great Lakes Levels Board "Regulation of Great Lakes Water Levels", Report to the International Joint Commission, 1973.

International Joint Commission, "Lake Ontario-St. Lawrence River Plan 2014, Protecting Against Extreme Water Levels, Restoring Wetlands and Preparing for Climate Change", 2014.

International Joint Commission, "Methods of Alleviating the Adverse Consequences of Fluctuating Water Levels in the Great Lakes-St. Lawrence River Basin", 1993.

International Lake Erie Regulation Study Board, "Lake Erie Water Level Study", 1981.

International Upper Great Lakes Study, "Options for Restoring Lake Michigan-Huron Water Levels: An Exploratory Analysis", Final Report to the International Joint Commission, 2011.

International Upper Great Lakes Study, "Impacts on Upper Great Lakes Water Levels: St. Clair River Summary Report", Final Report to the International Joint Commission, 2009.

International Upper Great Lakes Study, "Lake Superior Regulation: Addressing Uncertainty in Upper Great Lakes Water Levels", Final Report to the International Joint Commission, 2012.

International Waterways Commission, "Report of the International Waterways Commission of the Regulation of Lake Erie", 1910.

Instream Energy Systems, http://instreamenergy.com/projects/yakima-washington/

Joint Board of Engineers, "St. Lawrence Waterway Project", 1926.

Jonathan Colby and Mary Ann Adonizio, Verdant Power, "Hydrodynamic Analysis of Kinetic Hydropower Array", http://www.theriteproject.com/uploads/VP_HydrodynamicAnalysisKHPS.pdf

J.P.F.M. Janssen, Ministry of Transport, Public Works and Water Management, Netherlands: "The Maeslant Barrier: Design, Construction and Operation".

Levels Reference Study Board, "Levels Reference Study: Great Lakes –St. Lawrence River Basin", Report to the International Joint Commission, 1993.

Lipscomb, E.B., "Plans for Regulation of Levels of Lake Erie", 1957.

Marine and Hydrokinetic Technology Database, http://en.openei.org/wiki/Marine_and_Hydrokinetic_Technology_Database

Marjolein van Breukelen, TU Delft: "Improvement and Scale Enlargement of the Inflatable Rubber Barrier Concept: A Case Study Applicable to the Bolivar Roads Barrier, Texas, USA", 2013.

Marine Renewable Energy Technology Roadmap Steering Committee, Natural Resources Canada: "Charting the Course: Canada's Marine Renewable Energy Technology Roadmap".

Moore, S., "Report on St. Clair River Compensation", 1931.

Moore, S., "Compensating Works in the Niagara and St. Clair Rivers", 1933.

National Research Council Canada, "Assessment of the Hydrodynamic Effects of the Installation of Hydrokinetic Turbines in the St. Clair River", 2011.

New York State Energy Research and Development Authority, "Roosevelt Island Tidal Energy (RITE) Environmental Assessment Project", March 2011.

New York State Energy Research and Development Authority, "Marine and Hydrokinetic Technology Background and Perspective for New York State", December 2012.

Oak Ridge National Laboratory, Oak Ridge, TN "Field Measurements at River and Tidal Current Sites for Hydrokinetic Energy Development: Best Practices Manual", 2011.

Pentland, R., "Preliminary Appraisal of the Institutional Feasibility of Potential Compensating Works in the St. Clair River", 2009.

Qingdao Huahai Rubber Dams, http://www.huahaiindustry.com/rubberdam.asp

Ruijs, M., TU Delft: "The Effects of the 'Ike Barrier' Barrier on the Galveston Bay", September 2009.

Sandia National Laboratories, http://energy.sandia.gov/energy/renewable-energy/water-power/

Tempe Town Dam Replacement Project Factsheet, http://www.tempe.gov/home/showdocument?id=23862

U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire: "Performance Survey of Inflatable Dam in Ice-Affected Waters", October, 2001.

U.S. Army Corps of Engineers, "Compensation Studies for Recent Channel Changes in the St. Clair River", October, 1962.

U.S. Army Corps of Engineers, "Hydraulic Design Memorandum, Great Lakes Connecting Channels, Effect of and Compensation of Deepening of the St. Clair River for 25-Foot and 27-Foot Projects", October, 1961.

U.S. Army Engineer Division (North Central), "Water Levels of the Great Lakes: Report on Lake Regulation", October, 1965.

U. S. Department of Energy: "Marine and Hydrokinetic Energy Research & Development", http://energy.gov/eere/water/marine-and-hydrokinetic-energy-research-development

U.S. Department of Energy, "Energy Efficiency & Renewable Energy: 2014 Water Power Program Peer Review".

Verrazano Narrows Barrier Factsheet, http://biotech.law.lsu.edu/climate/ocean-rise/against-the-deluge/15-verrazano_narrows_barrier.pdf

Vortex Hydro Energy, http://www.vortexhydroenergy.com/

W. F. Baird and Associates, "Preliminary Study of the Structural Compensation Options for the St. Clair River", 2009.

W. F. Baird and Associates, "Regime Change (Man-made Intervention) and On-going Erosion in the St. Clair River and Impacts on Lake Michigan-Huron Lake Levels", 2015.

X.Q. Zhang, P.W.M. Tam, W Zhen: "Construction, Operation and Maintenance of Rubber Dams", Canadian Journal of Civil Engineering, NRC 2002.