Ecological Evaluation of Lake Superior Regulation Plans for the International Upper Great Lakes Levels Study

St. Marys River Evaluation and Restoration

Ecosystems Technical Working Group
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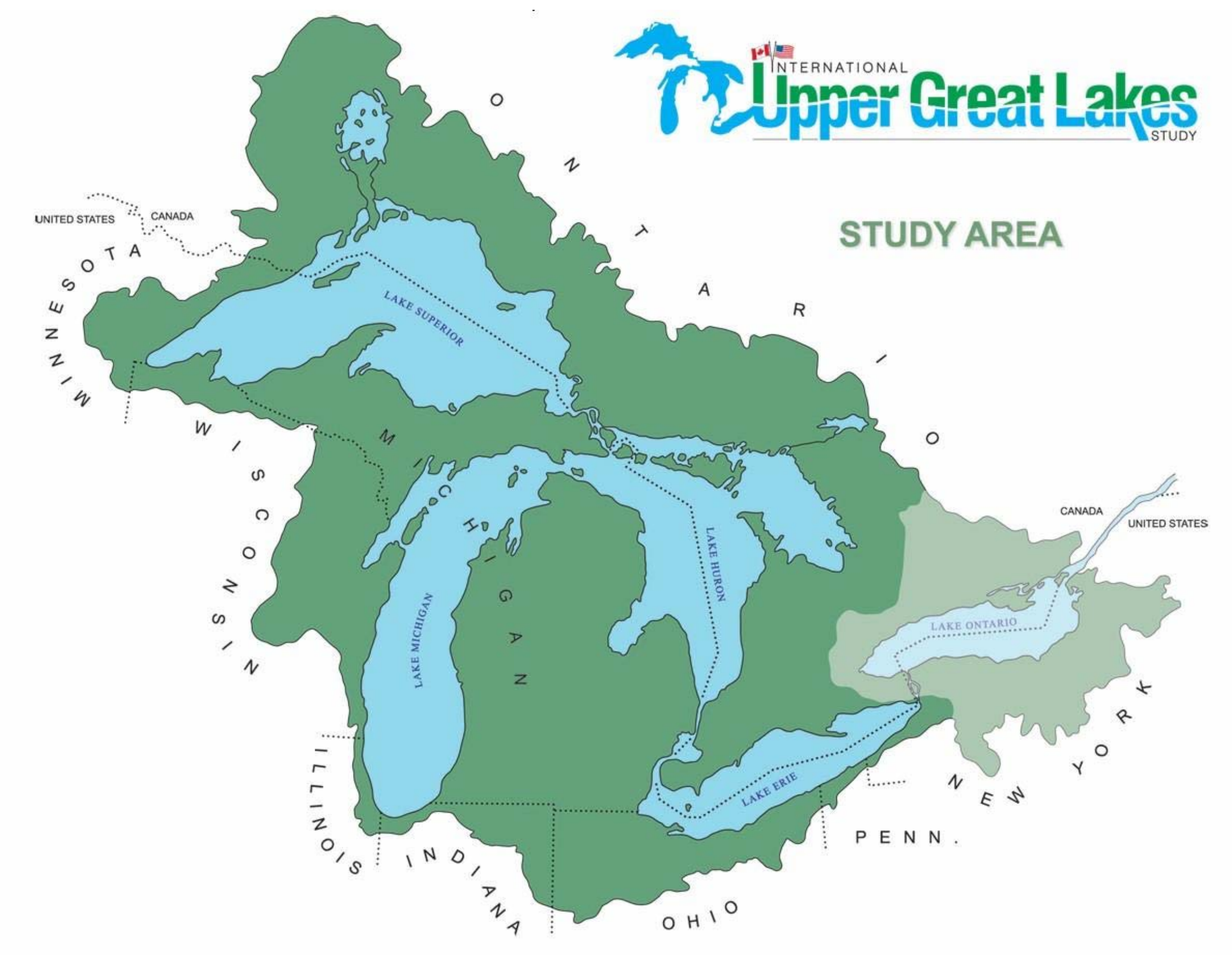

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Executive Summary

In response to the need to evaluate potential ecological impacts of changing Lake Superior water level regulation plans, the Ecosystem Technical Work Group has adopted an approach that is focused on assessing ecosystem vulnerabilities to changing Upper Great Lakes water level regimes. The objective of this approach is to identify water-level ranges and threshold criteria that minimize adverse impacts to biotic communities and ecosystem function, i.e. a range of water levels and water-level variability that supports diverse biotic communities and ecosystem functions. With respect to the overall IUGLS study, the St. Marys River work is a subset of the overall Upper Great Lakes ecological evaluation. This report is focused on the St. Marys River, compensating works, and the three hydropower plants that affect levels and flows in the St. Marys River.

The St. Marys River provides critically important wetland, fish spawning, and nursery habitat for many species in the Upper Great Lakes. The objective of this report is to identify and highlight opportunities for ecological protection and enhancement that would result from potential operational changes of the compensating works and/or hydropower plants within the St. Marys River. An environmental assessment of the St. Marys River has produced ten environmental performance indicators that were used to asses the vulnerabilities and environmental response of the St. Marys River ecosystem to changing flows and water level regimes. Ecological criteria have been developed to identify flows and water level regimes that will adversely impact the St. Marys River ecosystem and those that may enhance the St. Marys River ecosystem. During this evaluation, considerable effort has been made to protect or enhance vulnerable habitat areas and species, including vulnerable Lake Sturgeon spawning habitat.

Several opportunities have been identified to improve the St. Marys River ecosystem by manipulating flows and/or implementing operational changes at the compensating works and/or at the St. Marys River hydropower plants.

1) Approximately 90% of the sea lamprey in the Upper Great Lakes spawn in the St. Marys River. Based on data collected by the Great Lakes Fishery Commission, sea lamprey are attracted to high flow and operational changes at the hydropower plants may increase trapping efficiencies (thus eliminating more sea lamprey) and allowing GLFC control agents to better assess the number and distribution of sea lampreys in the Rapids and St. Marys River.
2) Significant environmental benefits may result from operational changes at the Compensating Works. By slowing the rate of water level change to less than 10 cm/hour, flushing and dewatering effects in the St. Marys Rapids are minimized. This would enhance fish production within the St. Marys Rapids.
3) Even though additional data and analyses are required, exploratory calculations indicate that it may be possible to increase the wetted surface area of the Rapids with a relatively minor increase in the minimum discharge or a minimum gate setting. By increasing the minimum wetted surface area, recruitment of species that use the Rapids for incubating their young during the late fall, winter, and early spring months will be improved.

Additional adaptive management opportunities may exist to further enhance environmental conditions in the St. Marys River.

Table of Contents

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St. Marys River Evaluation and Restoration

1.0 Introduction

This document briefly summarizes the overall strategy and methods that will be used by the International Upper Great Lakes Study (IUGLS) to assess and consider the ecological implications of new sets of rules for regulating the release of water from Lake Superior. A more detailed description of the Ecosystems Technical Working Group (ETWG) Strategy Approach is available in a document that was peer-reviewed and finalized in 2009 (ETWG 2009). A description of the Integrated Ecological Response Model (IERM2) and associated PIs are provided in a peer-reviewed development report that was finalized in June 2011 (ETWG 2011).

The St. Marys River report is focused on the St. Marys River, compensating works, and the three hydropower plants that affect levels and flows in the St. Marys River. The St. Marys River provides critically important wetland, fish spawning, and nursery habitat for many species and Appendix A of this report describes in the detail the ecological importance of the St. Marys River to the Upper Great Lakes.

The objective of this report is to identify and highlight opportunities for ecological protection and enhancement that would result from potential operational changes of the compensating works and/or hydropower plants within the St. Marys River (and potentially affecting the Upper Great Lakes). However, operational changes made at the compensating works and/or hydropower plants are constrained by the requirements of overall Lake Superior water level regulation and other uses of the St. Marys River such as navigation and hydropower generation.

With respect to the overall IUGLS study, the St. Marys River work is a subset of the overall Upper Great Lakes ecological evaluation. Using an approach similar to that developed for the overall Upper Great Lakes ecological analyses, the St. Marys River coping zones were developed to ensure that changes in flow and/or water level regimes due to a regulation plan would not adversely affect the St. Marys River ecosystem. The St. Marys River PIs and coping zone concepts were incorporated into the IERM2 and Shared Vision Models (ETWG 2011) and used to evaluate proposed water level regulation plans in order to 1) protect and maintain the existing ecological functions and biological communities of the St. Marys River, and 2) identify vulnerabilities and potential adaptive management opportunities as a function of resulting changes in flow/water-level regimes in the St. Marys River.

The St. Marys River ecological performance indicators described in this document were developed and applied in order to protect and maintain existing ecological conditions and biological communities in the St. Marys River. In fact, six of the PIs are not directly related to flow but rather to St. Marys River water levels which are in essence, controlled by Lake Michigan-Huron water levels. In general, due to rapid downstream damping effects, these six PIs and the St. George Channel flushing flow PI can only be enhanced by direct manipulation of Lake Michigan-Huron water levels or by other types of intervention (e.g. site-specific enhancement of hydraulic connectivity, restoration of wetland plant communities and functions, site-specific restoration/enhancement of fish spawning and nursery habitats) that are beyond the scope of this Study.

The ETWG has worked collaboratively with the St. Marys River BPAC to identify other potential restoration opportunities to address these PIs, and the BPAC has submitted habitat restoration proposal to U.S. EPA in response to the 2011GLRI RFP. The BPAC considers our work at the Rapids and at the Hydropower plants to be complimentary to their work on the lower portion of the St. Marys River.

1.1 Geographic Study Area

Figure 1. Overall IUGLS geographic study area showing the location of the St. Marys River.

The overall study area is the Great Lakes drainage basin including lakes Superior, Michigan, Huron and Erie and the connecting channels down to Niagara Falls (Figure 1). The focus of this assessment is on the St. Marys River and potential ecological impacts (or benefits) to the River resulting from operational changes in the regulation of outflows from Lake Superior.

The St. Marys River is one of five connecting channels in the Great Lakes, and the only water connection between Lake Superior and the lower Great Lakes. Lake Superior influences many physical properties of the St. Marys River including flow, water level, temperature, and chemistry. While discharges from Lake Superior have shown tremendous variability over more than 100 years of record keeping, the smallest discharge consistently occurs around March, when Lake Superior water levels are lowest, and the highest discharge occurs in September, when lake levels are highest. Seasonal water-level fluctuations of approximately 0.3 meters in the St. Marys River are driven by precipitation, evaporation, and run-off, and are compounded by regulated monthly flows through the compensating works at the headwaters of the St. Marys Rapids. In addition to seasonal water-level changes, long-term fluctuations changes in water levels and flow occur over periods of years to decades, and short-term fluctuations in water levels and flows occurring over periods of minutes to days.

Figure 2. Map of the St. Marys River (Source TNC, 2009)

1.2 The St. Marys River

The St. Marys River has a total length of 112 kilometers beginning at the headwaters at Whitefish Bay and terminating at the river mouth at the DeTour Passage in Northern Lake Huron. St. Marys River can be characterized by three distinct reaches.

Upper River - A 24 kilometer reach beginning at Whitefish Bay, flowing eastward towards the St. Marys Rapids. Water depth and channel width decreases significantly downstream, and flows will vary as a function of hydropower releases and gate openings at the Compensating Works. The upper river reach contains rocky shoals, sand, gravel, and cobble substrates, and in protected areas coastal and riverine wetlands that provide spawning habitat for Northern Pike, Longnose Suckers, White Suckers, and other species of interest.

St. Marys Rapids - A 1.2 kilometer reach of river over which the elevation drops by more than six meters. Historically, this drop in elevation created a natural barrier to navigation between the upper and lower St. Marys River. The St. Marys Compensating Works are located at the headwaters of the Rapids and are used to regulate water levels on Lake Superior and to a lesser extend, water levels on Lakes Michigan-Huron. The Soo Locks connect the St. Marys River with Lake Superior and enable commercial navigation to bypass the Rapids. Three hydropower plants use the head difference created by the Rapids to generate electricity. The substrates in the St. Marys Rapids include large boulders, cobble, exposed bedrock interspersed with patches of sand and gravel. The Rapids provides valuable spawning and nursery habitat for Atlantic salmon, Chinook salmon, pink salmon, rainbow trout, Coho salmon, and Sea lamprey. Other species such as Lake herring, Lake whitefish, Lake trout, Muskellunge, Lake sturgeon, and Walleye have also been observed in the Rapids, but usage by these species is unknown.

Lower River – An 86.8 kilometer reach that extends from downstream edge of the St. Marys Rapids all the way to the river's mouth at DeTour Passage in Northern Lake Huron. Within the Lower River are four major islands - Sugar, Neebish, St. Joseph, and Drummond Islands. Below the rapids, the River is separated into two channels by Sugar Island with Lake Nicolet receiving 74 percent of the flow to the west, and Lake George receiving 26 percent of the flow to the east. Here the channels are considerably wider with reduced flows and water levels that are strongly influenced by Lake Michigan-Huron water levels. Water from Lake Nicolet and Lake George flows southward into two channels around Neebish and St. Joseph Islands. The water then flows into Munuscong Bay, and eventually into Lake Huron. In addition, some water from Lake George flows into a third channel formed by St. Joseph Island and the Ontario Mainland into the North Channel.

The three river reaches described above provide suitable habitats for a number of aquatic organisms, and the St. Marys River supports a diverse fish community. Figure 3. illustrates documented fish spawning sites in the St. Marys River from Goodyear et al. (1982) augmented by other sources. Cold, fast-moving water in the St. Marys Rapids provides high quality spawning and nursery habitat for a divers range of species including: white sucker, slimy sculpin, longnose dace, lake whitefish, steelhead, brook trout, brown trout, lake trout, and Chinook salmon. Within the Lower River, emergent nearshore marshes provide spawning and nursery habitats for a number of cool and warm water species including walleye, yellow perch, northern pike, and smallmouth bass.

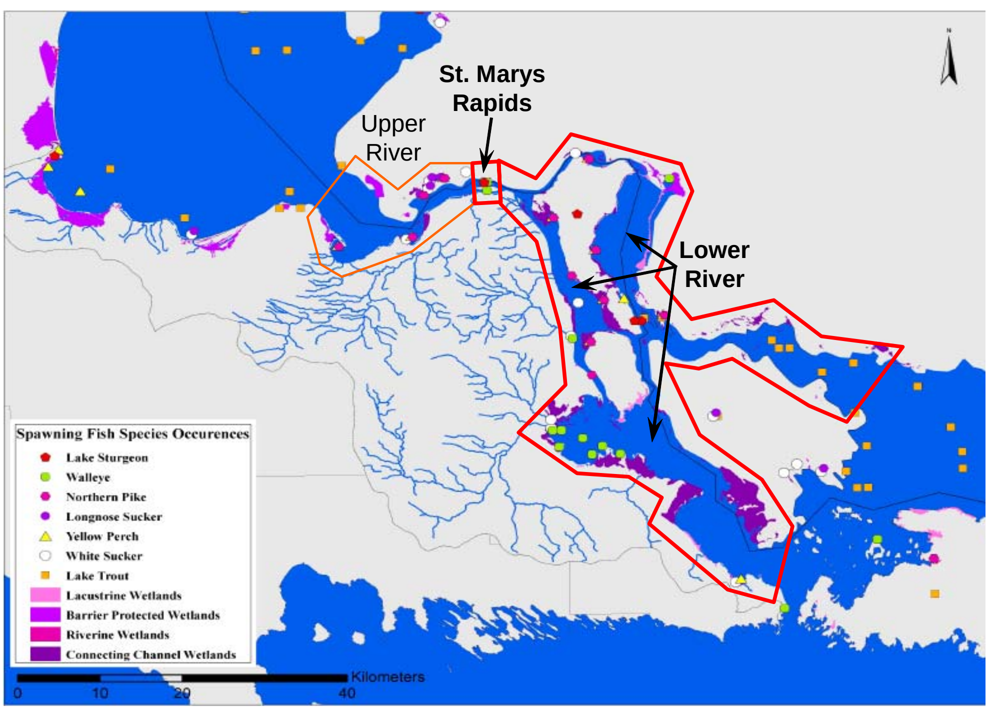


Figure 3. Location map illustrating fish spawning sites, emergent wetlands, and major reaches of the St. Marys River. This report is focused on the areas outlined in bold Red.

For the purposes of the IUGLS, the ETWG is charged with evaluating ecological responses to proposed changes in water level regimes caused by changes in Lake Superior water level regulation. Since Lake Superior water levels are controlled at the Compensating Works located at the headwaters of the Rapids, the upper river was not included as part of the St. Marys River evaluation. The ecological responses of the upper St. Marys River were evaluated separately using the more broadly based environmental Performance Indicators (PIs) developed for Lake Superior as a whole. Thus, the St. Marys River report (this document) is focused primarily on the ecological responses of the St. Marys Rapids and the Lower St. Marys River to a new Lake Superior water level regulation plan and possible operational changes at the hydropower plants and/or the Compensating Works.

2.0 Lake Superior Plan Evaluation Guidelines

The IUGLS recommendation will likely guide the IJC's choice of a new Lake Superior regulation plan, and the implementation of the new plan will have real economic, environmental and social impacts. A Regulation Plan simply codifies and quantifies, through a set of criteria and operating rules the management of lake levels to achieve the priority uses, while accommodating, to the extent possible, all the newly emergent uses and users. The regulation plans were last revised in 1979, and Plan 1977A was implemented in 1990. A set of specific operating rules are devised to ensure, to the physical extent possible, that the system is managed to deliver the services required for the priority users. For much of the time (90%), however, the management of lake levels adequately serves all the users. It is during extreme events that choices and tradeoffs must be made among the various users. The IUGLS Study Board designed its evaluation process to predict, as much as possible, the real world implications of its decisions using management guidelines based specific goals and criteria. These guidelines are a mixture of process rules (number one, for example) and decision criteria (number three). Any change to the Orders of Approval and regulation plan for Lake Superior outflows will:

1. Be based on the best assessment of impacts that can be done given the relatively small effect that Lake Superior regulation has on water levels, and size of the Great Lakes basin relative to the budget available for assessment studies.
2. Accommodate the 1909 Boundary Waters Treaty's 'order of precedence', while devising regulation plans to improve benefits for new users such as recreational boaters and the ecosystem.
3. Address to the extent possible, all the key ecological, economic, and social impacts associated with the regulation of outflows from Lake Superior, as the basis for making choices among alternative plans, and to understand the relative benefits and costs for each user within each plan.
4. Ensure that plans minimize disproportionate losses to any interest, particularly those enumerated in the 'order of precedence' or region, including disproportionate water level changes on one lake at the expense of another.
5. Be designed so that the International Lake Superior Board of Control and the IJC can respond more effectively during emergency conditions and to unusual or unexpected circumstances affecting the Great Lakes system.

2.1 Uncertainties

Under climate change, there is a high degree of uncertainty associated with future long-term water level predictions in the Great Lakes. Even though it is not possible to precisely know what future water supplies will be under climate change, extreme water level events (outside historical ranges) are plausible and we have no recent experience as to how these extreme water level events would change environmental conditions in the Great Lakes. For extreme events, we have no historical data upon which to design and validate predictive functions. Instead, best professional judgement is applied and large uncertainties means that flexibility will have to be built into the resulting decisions and resulting water level regulation plan.

The IUGLS Study Board agreed that the most effective way to manage uncertainty in future climate, economic, social and environmental conditions was to manage adaptively. There was and is no evidence that Lake Superior regulation has caused any environmental impacts due to the fact that regulation of Lake Superior has had relatively small impacts on Superior water levels and almost no impact on the water levels of the lower lakes. It is anticipated that a new Lake Superior water level regulation plan will be similar to Plan 1977A, and perhaps will be more flexible as it will incorporate an adaptive management component that would allow for future adjustments in response to unforeseen water level regimes resulting from potential climate change impacts. In fact, the Study Board is developing an adaptive management approach that will consider decisions beyond the new water level regulation plan, including a range of actions designed to deal with the anticipated effects of climate change.

3.0 Ecosystem Evaluation

3.1 General Approach

The ecosystems of the upper Great Lakes provide a broad range of ecosystem services to society and contain numerous valuable natural resources that benefit North America. Absolute water levels and fluctuations have major influences on the nearshore and coastal regions of the Great Lakes and their ability to support aquatic organisms. Hence, a primary objective of this work is to assess the extent to which water-level regulation will affect the natural variability of water levels and coastal ecosystem structure and function over time. Ecological responses to longer-term changes in water level regimes due to climate change will be evaluated using an adaptive management approach.

Resource and time limitations severely limit the ability of the ETWG to perform a comprehensive traditional scientific investigation of all ecosystem components that could be affected by changes in Upper Great Lakes water level regimes. Typically, these types of detailed studies would evaluate discrete changes in biotic communities in response to a single, or perhaps, several stressors over multiyear periods as was done in the Lake Ontario (LOSL) study (Werick et al. 2008). However, because Upper Great Lakes ecosystems are relatively unimpaired (with respect to water-level regime), it may not be necessary or practical to document all of the dynamic responses of a complex coastal ecosystem to every water-level change scenario as long as those water-levels approximate a “natural” water level regime.

The Ecosystem Technical Work Group has adopted an approach that is focused on assessing ecosystem vulnerabilities to changing Upper Great Lakes water level regimes. The objective of this approach is to identify water-level ranges and ecological conditions that minimize adverse impacts to biotic communities and ecosystem function, i.e. a range of water levels and water-level variability that supports diverse biotic communities and ecosystem functions. The fundamental approach used in this study can be summarized as follows:

- Build an expert team of Great Lakes ecologists and biologists to consider how varying water level regimes affect critical ecosystem components and functions in the Upper Great Lakes;
- Use relevant existing data (and new field data where necessary) to develop a more robust conceptual understanding of the relationships between water level regimes, ecological components, and ecological functions in the Upper Great Lakes;
- Develop environmental performance indicators throughout the upper Great Lakes drawing on conceptual relationships and data to guide indicator development. The resulting Performance indicators are functions that will have domains of water (such as levels and flows), time (such as duration or a simple time series), and an appropriate measure of ecological condition or health;
- Based on best professional judgment, identify the hydrologic conditions that disrupt, or significantly alter ecological components and functions such that an ecosystem transitions from a natural state (Zone A), to a modified state (Zone B), to a catastrophic state (Zone C). Zone C impacts are not only severe, but are irreversible as well.
- Based on the Performance Indicators, develop a model (called the Integrated Ecological Response Model or IERM2 Model) that produces a matrix of Performance Indicator values for a given a time series of water levels and flows;
- Use the IERM2 model to test hypotheses about how the ecosystem will respond to extreme water level regimes expected under future climate change scenarios. Use the model results to identify critical monitoring parameters, and determine what values trigger an adaptive or mitigation response.
- Develop a simple-to-use version of the IERM2 model to evaluate the ecological response of proposed Lake Superior water level regulation plans. The simplified IERM2 model will produce a matrix that tracks the incidence of Zone A, B and C conditions for a given time series of water levels and flows.

3.2 Ecological Thresholds and Description of Biological Degradation

To assess ecosystem vulnerabilities, it is necessary to identify those conditions or water level regimes that diverge from the natural water-level regime and to establish thresholds or transition periods where changes to the water-level regime result in significant long-term alteration of biotic communities and/or ecosystem function. More importantly these thresholds are solely a function of the underlying biotic community responses and fundamental structure of the ecosystem; knowledge of proposed water-level regulation plans and/or potential climate change induced water-level regime scenarios is not required to identify these thresholds.

To more clearly define the meaning of an ecological threshold, the ETWG has adopted a standardized description of biological condition to qualitatively assess the ecological response and vulnerabilities to changes in water level regime (Table 1). These types of descriptive frameworks are typically applied to riverine systems as part of an aquatic-life use designation process (e.g. U.S. EPA 2005).

Table 1. Description of Biological Condition

Pristine

Natural Variability

Critical Threshold

Degraded

Impact Score	Biological Condition
1	**Natural or native condition** Native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within range of natural variability
2	**Minimal changes in structure of biotic community; minimal changes in ecosystem function** Virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within range of natural variability
3	**Evident changes in structure of biotic community; minimal changes in ecosystem function** Some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but sensitive–ubiquitous taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system
4	**Moderate changes in structure of biotic community; minimal changes ecosystem function** Moderate changes in structure due to replacement of some sensitive–ubiquitous taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes
5	**Major changes in structure of biotic community; moderate changes in ecosystem function** Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased buildup or export of unused materials
6	**Severe changes in structure of biotic community; major loss of ecosystem function** Extreme changes in structure, wholesale changes in taxonomic composition; extreme alterations from normal densities and distributions; organism conditioning is often poor; ecosystem functions are severely altered

Davies and Jackson (2006), Bain (2007)

The example framework in Table 1 is derived from an aquatic classification scheme developed and used by Davies and Jackson (2006) and applied by Bain (2007) to the St. Marys River. This classification scheme provides a useful way to describe and rank the types of ecological changes that may occur as water level regimes diverge from Plan 1977A and/or pre-project "natural" water level regimes.

A similar bottom-up strategy was suggested by Dr. Casey Brown at an IUGLS Adaptive Management workshop held in Windsor, Ontario in May 2009. In his presentation, Dr. Brown suggested that it would be more efficient to perform vulnerability assessments in response to changing water-level regimes. These vulnerability assessments would establish water-level regime conditions necessary to maintain a desired state (e.g. biotic diversity and ecosystem function). Thresholds would be determined solely by the requirements of the ecosystem. Once those criteria or thresholds have been established, it would then be appropriate to ask the plan formulators and climate-change modelers which hydrologic scenarios yield water level regimes that exceed those threshold conditions.

Individual field sites have been selected based on a set of stratified criteria that include: geographic and ecoregional representation across a broad range of ecosystem types and components; sensitivity and responsiveness to changes in water level regime; available historical data and imagery; ongoing research and field activity; and socio-economic interest (Ciborowski et al. 2008 – Figure 4). A result of these analyses was the determination that the connecting channels; such as the St. Marys River, St. Clair River, Lake St. Clair, and Detroit Rivers, are hydraulically and hydrologically different than the Great Lakes, and will respond differently to altered water level and flow regimes resulting from changes in water level regulation.   These systems respond to minor changes in water level regime, are highly productive, and provide critically important habitat for fish, birds, and wildlife in the Great Lakes. The connecting channels also serve as ecologically important pathways for migratory species between the Upper and Lower Great Lakes.

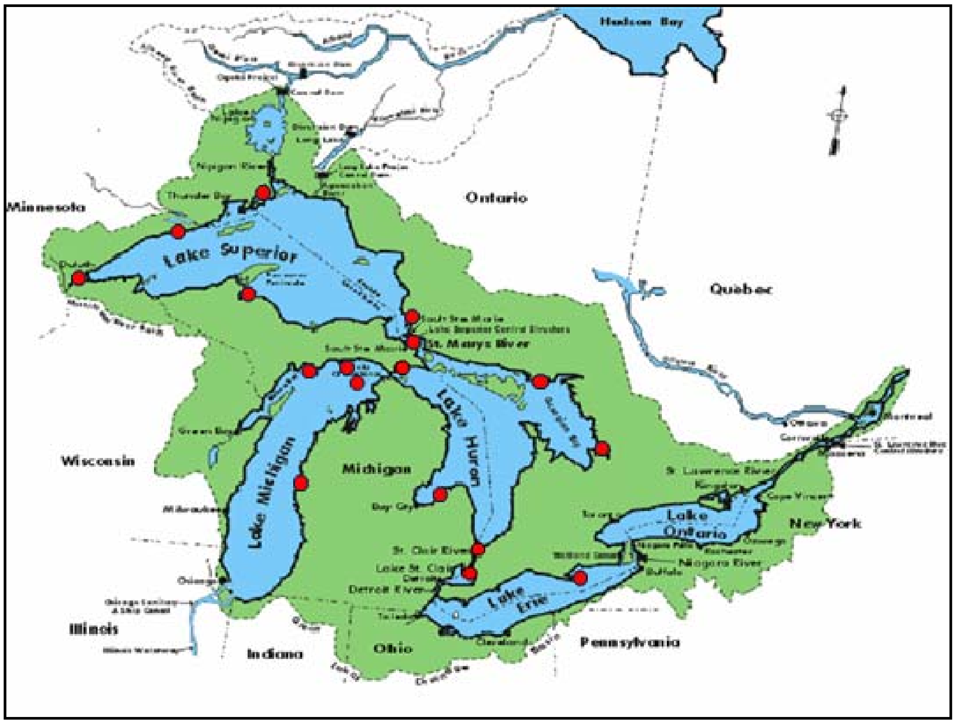


Figure 4. Map showing the locations of the final study sites.

3.3 Coping Zones

The Adaptive Management Technical Working Group (AM Group) has introduced the idea of “coping zones” based on the Description of Biological Condition shown in Table 1. The AM Group has modified Table 1 to apply to other (economic) sectors of the Study as well. As part of the adaptive management approach, the term “coping zones” are used to describe the various stages of impact or degradation to a system. For the purposes of environmental evaluation, the following definitions apply:

- <u>Coping Zone “A”</u> In Table 1 the first three conditions represent the “natural state” of the ecosystem that has historically been maintained by natural water level regimes. Water level regime changes within natural ranges and variability have minimal impact to the ecosystem, even though there will be some minor changes in biotic communities and ecosystem functions (green shaded area). For this study, detailed investigation of these types of ecological changes is generally *not* necessary as they would fall within the natural variability of the system. These conditions are assigned to Coping Zone "A".

- Coping Zone "B" The third and fourth conditions represented by the yellow and orange shaded areas in Table 1 represents progressively more substantive changes to the structure of the biotic community, which may include moderate changes in the biotic community including measurable changes in ecosystem function. At this stage, the ecosystem is starting to respond to water-level regimes that are approaching critical thresholds that when exceeded, will result in significant degradation of the ecosystem. In most cases, these types of ecological changes might be considered to be acceptable over the short term, but may lead to undesirable long-term impacts and should be avoided**.** These conditions are assigned to Coping Zone "B".

- Coping Zone "C" Biological conditions represented by the red shaded area below the double solid lines in Table 1 are ecologically unacceptable. These conditions represent substantive long-term impacts to biotic communities and disrupted ecological functions that may severely impair the Upper Great Lakes ecosystem[1]. In many cases the degradation may be permanent and irreversible. Zone "C" is an undesirable condition.

For the St. Marys River, both low-water and high-water Coping Zone criteria (Zones "A", "B", and "C") have been established for each environmental PI within the St. Marys River. It is important to note that the Coping Zone criteria not only are defined by a specific threshold water level, but by a time or duration component as well. In general, coping zone criteria were initially established for Coping Zone"C", and then test runs of the IERM2 model were used to assist the Site Coordinators when developing and calibrating Coping Zone "B" criteria.

4.0 St. Marys River Environmental Restoration

The ETWG used local knowledge and expertise to identify ecological enhancement opportunities related to flows at the compensating works and hydropower facilities that may not be related directly to Lake Superior water level regulation. For example, the sea lamprey experiments described in section 4.2 and ramping rate adjustments described in section 4.3 have minimal to no impact on Lake Superior water level regulation and can be implemented under a broad range of proposed water level regulation plans.

4.1 St. Marys River Environmental Performance Indicators

The ETWG St. Marys River Site Coordinator performed an ecological evaluation of the St. Marys River and generated water level regime response curves, thresholds, and coping zones for the St. Marys River. Eight St. Marys River PIs were identified for inclusion in the IERM2 model (Table 2).

[1] Once reaching a Zone "C" condition, if water level regimes return to Zone "A" or Zone "B" levels, the ecosystem does not return to the pre-existing state, but rather reaches equilibrium at an altered state. Thus there is a permanent change in the biological community and/or ecological functions relative to what was there before. For many Biologists, this represents irreversible damage to the ecosystem that otherwise would not have occurred, and therefore is consistent with the interpretation of Zone "C" for the other sectors.

Table 2. Summary of St. Marys River Coping Zone Criteria

Criterion Identifier	Lake Region	"Zone B" Condition	"Zone C" Condition or Range Compression Metric	PI Fact Sheet IDs	Proposed By	General Objective
SMG-01	St. Marys River (gates)	Compensating Works operated with 4 or more gates open for May-July for any given year.	*(not applicable)*	21	Bain et al.	Prevent ideal conditions for sea lamprey reproduction
SMG-02	St. Marys River (gates)	*(not applicable)*	Compensating Works operated with less than 0.5 gate open for any given month in any given year.	22	Bain et al.	Maintain sufficient habitat for native fish reproduction
SMQ-01	St. Marys River (flow)	Mean flow rate during June maintained below 1,700 m3/s for any 3 years in a 5-year window.	Mean flow rate during June maintained below 1,700 m3/s for 5 or more consecutive years.	24	Bain et al.	Provide suitable spawning area for lake sturgeon
SMQ-02	St. Marys River (flow)	Mean flow rate during May-June maintained below 2,000 m3/s for any 5 years in a 7-year window.	Mean flow rate during May-June maintained below 2,000 m3/s for 7 or more consecutive years.	25	Bain et al.	Maintain spawning habitat in Lake George Channel
SMH-01	St. Marys River (Lake Huron WL)	The water level decrease between Nov. and the following Apr. exceeds 1.00 meters for any given year.	The water level decrease between Nov. and the following Apr. exceeds 1.25 meters for any given year.	26	Bain et al.	Prevent mortality of lake herring that might be caused by water level declines
SMH-02	St. Marys River (Lake Huron WL)	Maximum change in Lake Huron water level during the Jun-Aug period is greater than 0.2 meters for any given year.	Maximum change in Lake Huron water level during the Jun-Aug period is greater than 0.3 meters for any given year.	27	Bain et al.	Avoid flooding of black tern nests
SMH-03	St. Marys River (Lake Huron WL)	Mean spring/summer/fall (May-Sep) water level in Lake Huron is less than 174.5 meters for any given year.	Mean spring/summer/fall (May-Sep) water level in Lake Huron is less than 174.5 meters for 3 or more consecutive years.	28	Bain et al.	Maintain suitable conditions for submerged vegetation
SMH-04	St. Marys River (Lake Huron WL)	Mean annual water level less than 176.0 meters for any given year.	Mean annual water level less than 175.6 meters for any given year.	30	Bain et al.	Maintain backwater habitat for fish spawning

Two of the St. Marys River PIs were found to be sensitive to many of the proposed Lake Superior water level regulation plans. The SMG-01 PI was initially established to minimize passage of sea lamprey though the compensating works into the upper St. Marys River. Follow-up discussions with GLFC Sea Lamprey Control revealed that Sea Lamprey Control does not consider multiple gate openings or high flows at the compensating works as a Zone "C" condition. The potential utilization of spawning habitat in the upper St. Marys River is currently unknown, and if multiple gate openings/high flows at the compensating works do occur, Sea Lamprey Control will incorporate the small tributaries that flow into the upper St. Marys River into their 5-year sea lamprey stream assessment protocols. The four-gate threshold is now considered to be a Zone "B" condition which can be managed adaptively by Sea Lamprey Control. The PI contains a requirement to notify Sea Lamprey Control when Zone "B" conditions do exist so that provision can be made to modify their stream assessment protocols.

The SMQ-01 PI was also found to be sensitive to many of the proposed Lake Superior water level regulation plans. The SMQ-01 PI was established to provide an adequate flow rate over important Lake Sturgeon spawning habitat areas in the St. Marys River. The minimum flow criteria were confirmed and new information received from the GLFC St. Marys River Fisheries Task Group indicated that: 1) the numbers of St. Marys River Lake Sturgeon are low (~500 individuals) and, 2) that the St. Marys River Lake Sturgeon may be a genetically distinct from other Lake Sturgeon in the Upper Great Lakes.

The Site Investigators Report and resulting Performance Indicators are provided in Appendices A and B attached to this peer-review document.

The incorporation of an adaptive management approach into a new Lake Superior water level regulation plan provides an opportunity to explore short-term operational changes that may provide additional ecological benefits to the St. Marys River. A review of the literature, discussions with the St. Marys River Fisheries Task Group, and an ecological evaluation performed by the ETWG revealed several additional opportunities to improve the St. Marys River ecosystem.

4.2 Enhance Sea Lamprey Control in the St. Marys River

The Great Lakes Fishery Commission administers the sea lamprey management program through its two control agents, the U.S. Fish and Wildlife Service (USFWS) and Fisheries and Oceans Canada (DFO). The program is a critical component of fisheries management in the Great Lakes because it significantly reduces the mortality of Great Lakes fish caused by the feeding of parasitic sea lamprey, thereby facilitating the rehabilitation of important fish stocks.

The introduction of sea lamprey into the Upper Great Lakes has had a devastating impact on the large bodied fish in the Upper Great Lakes. Before sea lampreys entered the Great Lakes, Canada and the United States harvested about 7 million kg (15 million lbs) of lake trout from Lakes Huron and Superior annually. By the early 1960's, the catch was only 136,000 kg (300,000 lbs). From 1990 to 1995, the average Lake Huron lake-wide abundance was 400,000 sea lampreys, more than was estimated other four Great Lakes combined. The first sea lampreys were detected in the St. Marys River in 1962. Surveys between 1962 and 1987 revealed larval distributions that extended from 5 km upstream of the Compensating Works to 25 km downstream on the North Channel, and 35 km downstream though Lake Nicolet and East and West Neebish Channels to the entrance of Lake Munoscong. It was estimated that up to 88% of all sea lamprey in Lake Huron were produced from the St. Marys River (GLFC 2009).

Sea lampreys use coarse substrates and rapidly flowing water as spawning habitat. Application of traditional methods to control sea lamprey (TFM or bayluscide spot treatments) is problematic in the St. Marys River due to high flow velocities, size/extent of the channels, and logistical issues treating such a large area. At the St. Marys River, the GLFC has implemented an integrated management strategy that is a combination of trapping, sterile-male release techniques, and annual granular bayluscide spot treatments to suppress sea lamprey reproduction in the St. Marys River. The integrated management strategy has resulted in a 73% reduction in larval sea lamprey in 2007 relative to pre-1999 levels (GLFC 2009). However, even though sea lamprey wounds per 100 lake trout in Lake Huron (fish greater than 53 cm or 21 inches in length) have declined, the suppression target of 5 wounds per 100 fish has not been reached (GLFC 2009). Existing control techniques have apparently reached a threshold whereby the ability to further reduce the Upper Great Lakes sea lamprey population is limited.

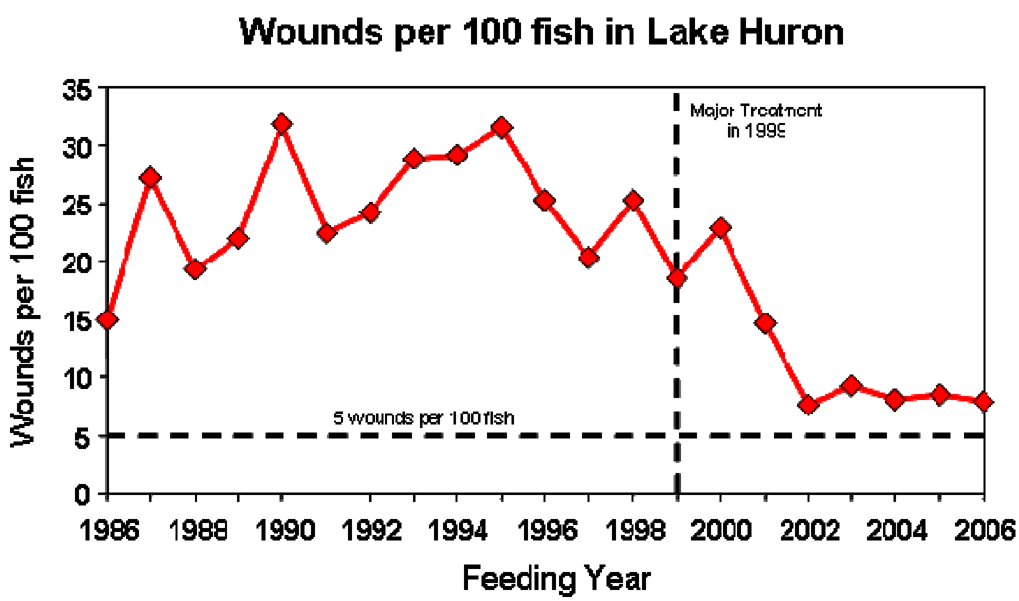
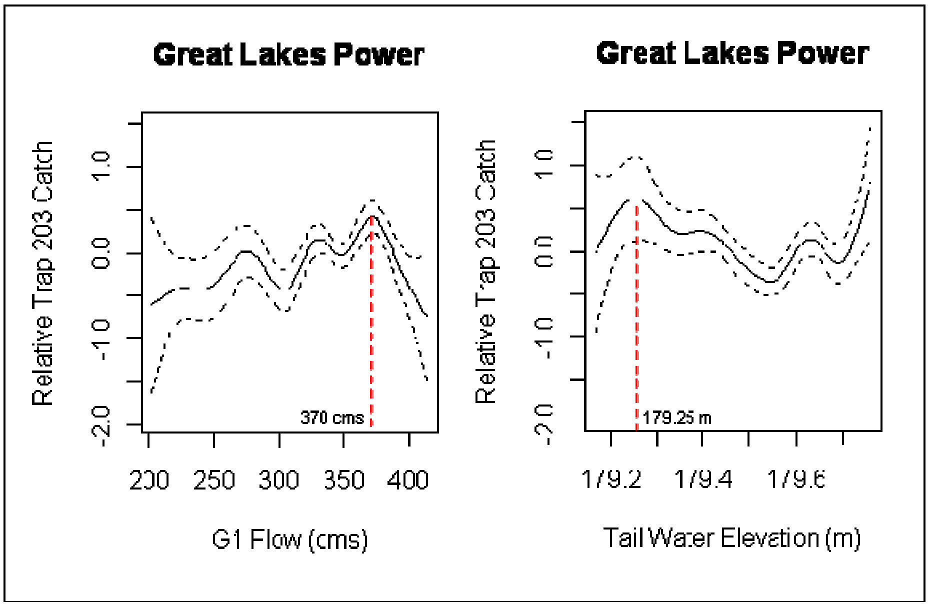


Figure 5. Time series plot illustrating the decline in fish wounding rates in Lake Huron (GLFC 2009).

Sea lamprey trapping operations are conducted in the tailwaters of the hydropower plants during June and July. Historically, trapping efficiency on the St. Marys River averages about 40%. However, a preliminary examination historical data indicate that sea lamprey are attracted to high flows (or water levels) suggesting that it may be possible through flow manipulation to concentrate sea lamprey and increase trapping efficiencies above 40%. Given the importance of the St. Marys River to sea lamprey reproduction, an increase in trapping efficiency should result in a reduction in sea lamprey populations in the Upper Great Lakes, which would benefit the Great Lakes fishery. The GLFC is currently calculating potential benefits and the economic value of increased trapping efficiencies on the Upper Great Lakes fishery.

Moreover, the hydropower plants receive a fixed monthly allocation of water for hydropower production. To operate efficiently and to meet demand, the hydropower producers manage water by peaking and ponding. For example, during the night when power demand is low, the hydropower plants reduce flows and “pond” or store water on Lake Superior. During the day when power demand is high, the hydropower plants “peak” or increase flows to generate more power. Downstream impacts of peaking and ponding are minimal as fluctuations in flow are rapidly attenuated in the upper reaches of the Soo harbor and water depths are deep enough that there are no significant ecological impacts (Bain 2007). However, during spawning season (June and July), sea lampreys migrate primarily at night between 9:00 pm and 6:00 am. But at night, the hydropower plants are reducing flows in order to store water on Lake Superior. One way to potentially increase sea lamprey trapping efficiencies would be to maintain higher flows at night in order to attract the maximum number of sea lampreys when they are most active.



Statistical plots generated by Jean Adams, USGS/WDNR

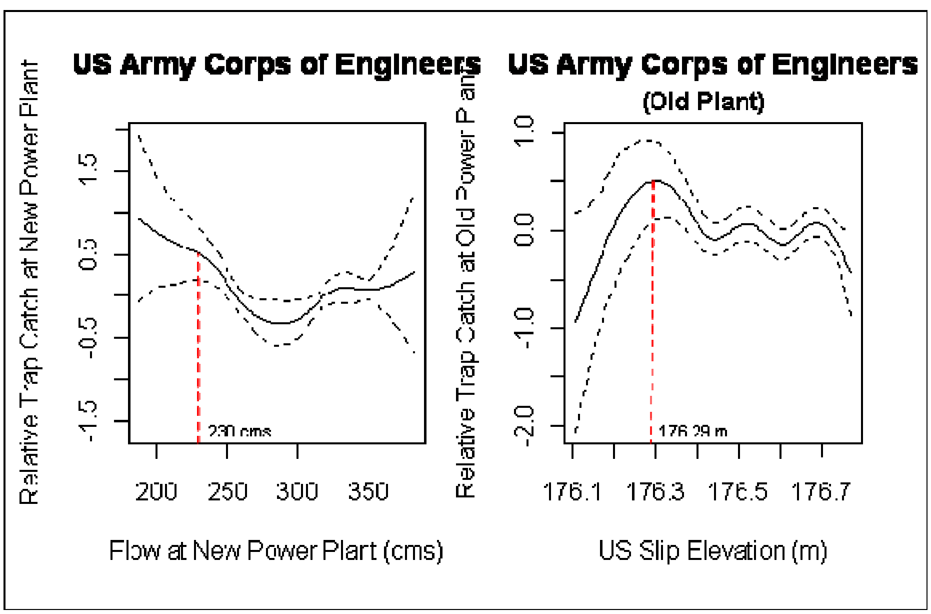


Figure 6. Plots of relative trap catch vs. flow and tail water (or U.S. Slip) elevation for Great Lakes Power (Brookfield) and the U.S. Government hydropower plants. The Cloverland (formally Edison Sault) hydropower plant did not show a statistically significant relationship with flow or tail water elevations.

As part of an ongoing study, the GLFC has been collecting and evaluating historical water level and flow data from the power plants to determine if there is a statistical relationship between water levels, flow velocities, and trapping efficiencies at the St. Marys River hydropower plants. Figure 6 shows some preliminary results from these analyses. There is a statistically significant relationship between flow and relative sea lamprey catch rate at two of the three hydropower plants. Note that these relationships were developed for flows at the hydropower plants, not at the compensating works.

It should be emphasized that these results are preliminary and tentative. The ETWG, working with the IUGLS Plan Formulation and Evaluation Group (PFEG), has facilitated meetings between GLFC control agents, representatives from the three hydropower plants currently producing electricity at the St. Marys River, and the IJC Board of Control. Based on these initial discussions, the GLFC submitted a proposal to U.S. EPA to obtain Great Lakes Restoration Initiative (GLRI) funding to perform a series of experiments to demonstrate that flow manipulations at the power plants could increase the overall effectiveness of the sea lamprey control program. This proposal was funded. Instead of peaking and ponding every day during the months of June and July, Brookfield and Cloverland will be operating at peak flows every other night (instead of ponding). The proposed methods and timeline are given in Table 3 below.

Table 3. GLFC Enhanced St. Marys River Sea Lamprey Control

Method	Proposed Timeline	Proposed Outcome
1. Analyze historic river data to explore how flow, water level, and hydropower peaking and ponding activities affect trapping efficiency; Install level loggers near trap sites to collect additional water level data	**October 2010 – March 2011; May – July 2011**	**Results used by IUGLS Team to suggest alternative to current water allocation plan in St. Marys River; Potential to manipulate discharge to increase trap efficiency**
2. Monitor behaviors using DIDSON		
Proof of concept	**September 210**	**Identify optimal settings**
Field study	**May – July 2011**	**Identify sea lamprey swimming or resting behaviors that can be exploited to increase efficiency of alternative control strategies**
3. Compensating Gate Trap	**May – July 2011**	**Assess feasibility and cost-effectiveness of placing a permanent trap at Compensating Gates**
4. Monitor location and marked sea lamprey using professional divers	**May – July 2011**	**Validate assumption that unmarked and marked sea lampreys mix in river and are equally vulnerable to assessment traps**
5. Manually remove sea lamprey using professional divers	**May – July 2011**	**Potential additional alternative control strategy**
6. Expand next surveys	**July – August 2011**	**Additional Alternative control and large sample size to asses effects of sterile male release**

The objectives of these experiments are:

1. To evaluate how flow, water level, and hydropower peaking and ponding activities affect trapping efficiency.
2. To observe the behavior of sea lamprey in the vicinity of traps, and determine behaviors that may be exploited for trapping, including whether sea lampreys remain attached to the face of the hydropower plants or turbines.
3. To evaluate the feasibility and efficiency of a trapping device placed at the Compensating Gates.
4. To observe the spatial distribution of fin-clipped sea lampreys to evaluate the assumption that all sea lampreys migrate to trap sites and have the potential to be trapped.
5. To determine the feasibility of manually removing sea lampreys from the river bottom with divers.
6. To measure how a reduction in water flow through the rapids area affects the number of nest observations completed by the control agents.

A copy of the GLFC workplan and a draft copy of the proposed flow manipulations at the hydropower plants planned for the spring/summer 2011 are attached and can be found in Appendix C. These experiments should clearly demonstrate whether or not there is correlation between peak flows at night and increased trapping efficiency. As a component of Adaptive Management, this is an excellent example of how new data and information can result in operational changes that yield potentially significant ecological benefits to the Upper Great Lakes.

Based on the results of this study, adjustments may be made in hydropower peaking and ponding operations during the months of June and July in order to maximize sea lamprey control efforts on the St. Marys River.

4.3 St. Marys Rapids Ramping Rates

Flows over the St. Marys Rapids are controlled by the number of gate openings at the Compensating Works. Adjustments are typically made once a month after water levels on Lake Superior and Lakes Michigan-Huron have been evaluated based on criteria in Plan 1977A. The once-a-month adjustments typically occur over a short period of time (generally an hour or less) and the resulting flows across the Rapids change dramatically over short periods of time as well. The rate of change in flow (and water depth) is a solely a function of the rate at which the compensating gates are opened or closed. Rapid changes in flow volume can result in significant losses of small larval fish due to increasing flows. Conversely, rapid dewatering of the Rapids strands fish and may desiccate areas that are being used as spawning or nursery habitats.

Based on the literature and recommendations found in St. Marys River PI Fact Sheet 23 (fish stranding), **gate changes that yield a maximum water level change rates of 10 cm/hour or less is recommended for the Compensating Works at the St. Marys River. Gate changes should be implemented at a rate of one-half gate per four hours or one-quarter gate per hour to achieve the desired ramping rates.** It is further recommended that gate change rates be calibrated to ramping rates as detailed bathymetry and water depths have not been adequately documented for different gate openings at the St. Marys Rapids.

Table 4 shows monthly usage of the Rapids by major species as a function of life stage. The blocks outlined in light blue indicate a species life stage that may be particularly susceptible to excessive ramping rates (flushing flows or rapid dewatering). Based on this table, **the months April through September represent the time period when many species of fish are using the Rapids as a nursery and are particularly susceptible to excessive ramping rates. Ramping rate protocols should be implemented during this time period.**

Table 4. Temporal Usage of St. Marys Rapids by Species and Life Stage

Species	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*
Atlantic salmon	Inc	Inc	Inc	Inc/Hatch	Hatch/Nu	Nu/Smolt	Nu	Nu	Nu	Sp	Sp	Inc
Chinook salmon	Inc	Inc	Inc	Inc/Hatch	Hatch/Nu	Nu	Nu/Smolt	Smolt	Sp	Sp	Inc	Inc
pink salmon	Inc	Hatch/Nu	Hatch/Nu	Hatch/Nu	Hatch/Nu			Sp	Sp	Inc	Inc	Inc
rainbow trout (steelhead)	Nu	Nu	Nu	Smolt	Sp/Smolt	Sp/Inc	Inc/Hatch	Nu	Nu	Nu	Nu	Nu
coho salmon	Inc	Inc	Inc/hatch	Hatch	Hatch/Nu	Nu/Smolt	Nu	Nu	Nu	Sp	Sp	Inc
Lake herring	*											
Lake whitefish	*											
Lake sturgeon					Stage/Sp	Sp	Sp					
Lake trout	**											
Muskellunge	***										X	X
Walleye	****											
Sea Lamprey	*****				Stage	Sp	Sp					
				Minimum Ramping Rates Implemented								

Key

Key
Maintain Max Wetted Surface Area
No Flushing Flows
Sea Lamprey Spawning

Recognizing that 14 of the 16 gates are operated manually (only two gates are automated on the U.S. side, none on the Canadian side), automating the gates would allow these manipulations to occur without having to place personnel on the Compensating Works during inclement weather conditions. Automating the gates would also provide additional flexibility to implement short-term adjustments in response to future adaptive management needs.

4.4 St. Marys Rapids Wetted Surface Area

The wetted surface area of the St. Marys Rapids has been identified as a concern of Biologists. The minimum half gate setting for the Rapids south of the fisheries berm does not allow water cover to the entire surface area of the Rapids. This fact has been discussed in numerous publications (e.g. Koshinsky and Edwards 1983; Edsall and Gannon 1993; Environmental Hydraulics Group 1995).

Based on several cross sections across the Rapids, the USACE recently performed hydraulic calculations to estimate water depths, flow velocities, and wetted perimeter over the Rapids for a range of gate settings at the Compensating Works. Based on those calculations, the ETWG plotted the wetted perimeter and discharge vs. gate openings to determine if there was an optimum gate setting that would maximize wetted perimeter for the three cross sections evaluated (Figure 7).

A gate setting of four is commonly referred to in other publications (e.g. Koshinsky and Edwards 1983; Environmental Hydraulics Group 1995) and in PI Fact Sheet 22 entitled “Available Native Fish Habitat” (see Appendix B). Ideally, a gate setting of four would be appropriate to maximize environmental benefits at the Rapids. However, a minimum gate setting of four would cause significant “spillage” of Lake Superior water that would otherwise be used to generate electricity.

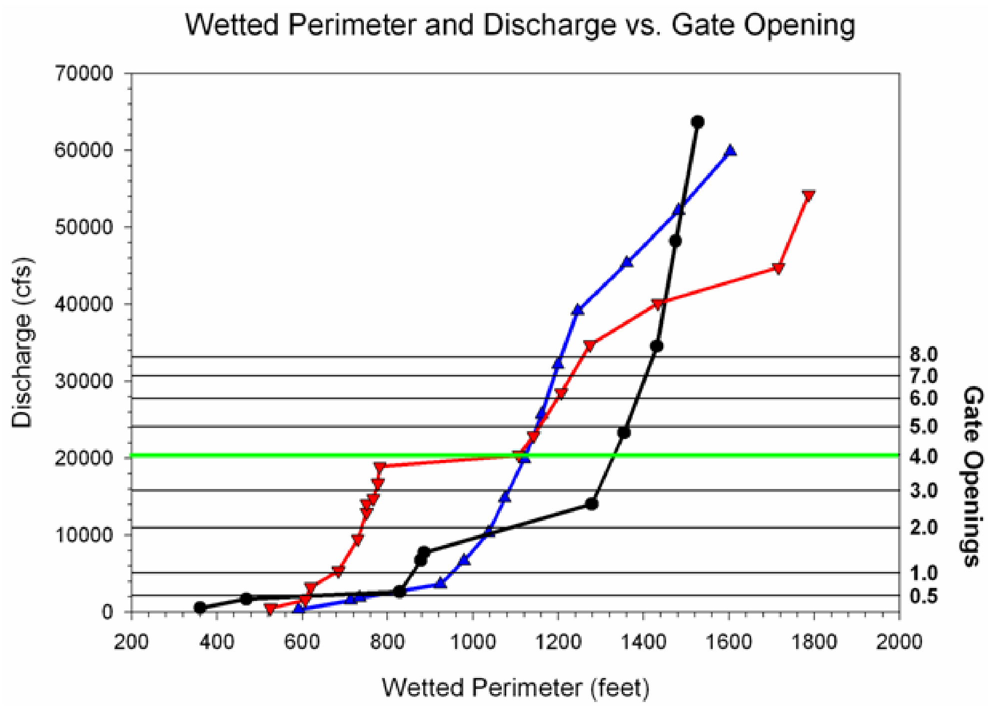


Figure 7. Graph showing plots for three cross sections across the St. Marys Rapids comparing wetted perimeter and discharge vs. number of gate openings. The green horizontal line represents a gate setting or four that maximizes the wetted perimeter in these cross sections.

Taking a step back, examination of Table 4 shows monthly usage of the Rapids by major species as a function of life stage. The blocks outlined in light green indicate a species life stage that may be particularly susceptible to changes in the wetted surface of the Rapids. Based on this table, **the months September through March represent the time period when either late fall spawners are active and/or the eggs of several important species are incubating within the Rapids. Fluctuations in the wetted surface area, especially dewatering of the Rapids during the winter months, would severely impact the Rapids fishery.**

The current half gate minimum setting may not provide enough protection during low water periods during the winter months. Figure 7 reveals that for two of the cross sections located in the middle and upper portions of the Rapids (black and blue plots), increasing the minimum setting to 0.75 or 1.0 would increase remaining the wetted perimeter by approximately 50% from the current half-gate setting. An increase in the minimum gate setting would further protect those species that are sensitive to changes in the wetted surface area during the winter months.

Figure 8 is a more detailed plot of the same data showing the range of discharge values for each gate setting. The blue colored band is the range of discharges for the half-gate setting, the light green band is the range of discharges for a one-gate setting, and the tan band is the range of discharges for the two-gate setting. For the current half-gate setting, during low water periods on Lake Superior, flows are reduced along with the wetted perimeter. Instead of using a minimum half-gate setting, **it may be more appropriate to set a minimum discharge and adjust the gates accordingly. Based on Figure 7, a minimum discharge of 80 to 100 cms (~3500 cfs) would maximize the available wetted perimeter without having to resort to a fourfold increase in the gate setting.**

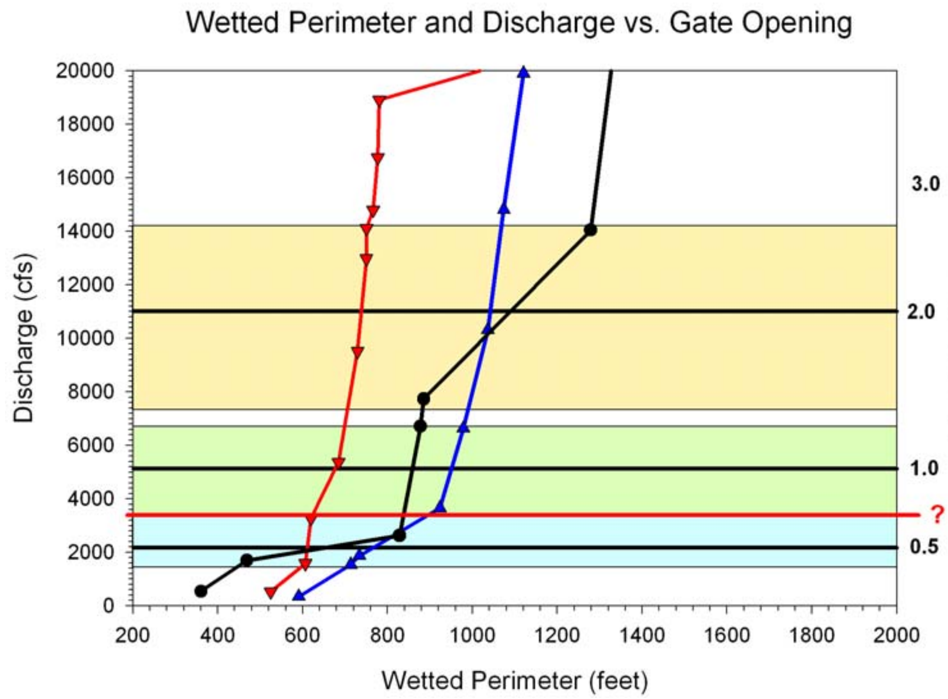


Figure 8. Graph showing more plots for three cross sections across the St. Marys Rapids comparing wetted perimeter and discharge vs. number of gate openings. A minimum flow of 100 cms or a minimum gate setting of 0.75 to 1.0 would provide additional environmental benefits without "spilling" significant volumes of Lake Superior water.

These calculations are speculative as they are based on three cross sections that may not be representative of the St. Marys Rapids. The discussion above is exploratory and suggests that with additional data, reasonable adjustments to the minimum gate setting may be possible. This is a future Adaptive Management issue, especially if low water conditions continue to exist on Lake Superior. Moreover, the IUGLS Public Interest and Advisory Group (PIAG) has expressed a strong interest in the Rapids and in any actions that would enhance the environment of the St Marys River.

5.0 Summary

The Ecosystem Technical Work Group has adopted an approach that is focused on assessing ecosystem vulnerabilities to changing Upper Great Lakes water level regimes. The objective of this approach is to identify water-level ranges and thresholds that minimize adverse impacts to biotic communities and ecosystem function, i.e. a range of water levels and water-level variability that supports diverse biotic communities and ecosystem functions.

At each of the ETWG study sites, ecological response curves relating environmental Performance Indicator (PI) responses to changes in water level regime were developed by ETWG Site Coordinators. The response curves link the descriptors of biological condition (based on environmental PIs) with descriptors of water level variability to identify possible thresholds.

A comprehensive environmental assessment has produced ten environmental performance indicators that can be used to asses the vulnerabilities and environmental response of the St. Marys River ecosystem to changing water level regimes. Ecological criteria have been developed to identify water level regimes that will adversely impact the St. Marys River ecosystem and those that may benefit the St. Marys River ecosystem.

Several opportunities have been identified to improve the St. Marys River ecosystem by manipulating flows and/or implementing operational changes at the Compensating Works and/or at the St. Marys River hydropower plants. Preliminary evidence suggests that sea lamprey are attracted to high flows and adjustments may be made to increase trapping efficiencies and allow the GLFC control agents to better assess the number and distribution of sea lampreys in the Rapids and in the St. Marys River.

Operational adjustments to the Compensating Works by slowing the speed at which gate changes are made may have significant environmental benefits. By keeping the rate of water level change less than 10 cm/hour, flushing and dewatering effects are minimized.

Even though additional data and analyses are required, exploratory calculations indicate that it may be possible to increase the wetted surface area of the Rapids with a relatively minor increase in the minimum discharge or a minimum gate setting. By increasing the minimum wetted surface area, recruitment of species that use the Rapids for incubating their young during the late fall, winter, and early spring months will be improved.

These actions are examples of adaptive management strategies that when implemented, may yield significant environmental benefits to the Upper Great Lakes ecosystem.

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APPENDIX A

Site Investigators Report

St. Marys River Biological Status and Hydrologic Performance Indicators

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St. Marys River Biological Status and Hydrologic Performance Indicators

By

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For

Environmental Working Group
International Upper Great Lakes Study

Great Lakes-Northern Forest Cooperative Ecosystem Studies Unit

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Introduction

The St. Marys River is an atypical aquatic ecosystem because it is a large (mean discharge 2,140 m^3/s) and short (112 km) river connecting large lakes. This ecosystem has been well characterized in comprehensive reviews by Duffy et al. (1987), Kauss (1991), Bray (1993), HHC (1994) and others. The river includes three distinct sections: a 22.5-km Lake Superior outlet section at lake elevation; a 1.2-km rapids (6.1 m drop) section with facilities and channels for navigation, hydropower, water regulation, and high gradient fishery support; and a 88.3-km lower river section largely at Lake Huron elevation. The lower river has the morphology of a complex strait, with substantial water turnover and current like a river, and changing water surface elevations from natural and human factors. Narrow channels, broad and wide lakes, four large islands, and many small islands are present. St. Marys River water chemistry and pelagic biota often reflect the flow through nature of the river system. Water quality in the river is generally very high and similar to the nutrient poor, cold waters of Lake Superior. Phytoplankton and zooplankton are dominated by the same taxa that characterize pelagic waters of Lake Superior. Attached, rooted, and emergent plants in shallow and shoreline waters provide much of the organic material and habitat supporting the river biota. Fish and invertebrate faunas are diverse and explained by the diversity of habitats in the system and the connections to large lakes.

The connection among lakes provided by the St. Marys River makes the river a key element in the Great Lakes system. The Soo Locks set the maximum dimensions of ships moving cargo across the Great Lakes, the river provides an ideal site for hydropower production, and the rapids have always supported productive fishing and reproduction of migratory species. The human benefits have been improved by major alterations of the river. Navigation improvements started as early as 1797 and have continued with periodic upgrading of the locks and dredging of shipping channels. Hydropower plants were first constructed in 1902 and have been rebuilt and optimized for the site with water diversion channels and regulating structures. These actions have resulted in a loss of about half the rapids habitat, altered river hydraulics and flow paths, and continuous regulation of river volume. The development of Soo Harbor, urban centers on both sides of the river, and industrial facilities has altered the shoreline in some of the river. Today the river is greatly modified but remains a key aquatic resource in the Great lakes system for a variety of human uses and ecosystem benefits.

Conservation of the St. Marys River has been priority for many agencies and groups in the US and Canada for many years. This report is a part of the International Upper Great Lakes Study (IUGLS 2010) is being conducted by the International Joint Commission under the authority of the Boundary Waters Treaty to evaluate options for regulating levels and flows in the upper Great Lakes system. This study is aimed at assessing the need for changes to the water regulation plan in the upper Great Lakes to meet the contemporary and emerging needs, interests, and preferences for sustainable management of the system. A priority focus is on the options to improve the Lake Superior outflow through the St. Marys River. US and Canadian agencies and conservation groups are looking at the history of changes in the St. Marys River and considering how the environment can be improved while maintaining the important benefits to people in both countries.

No comprehensive assessment of the St Marys River ecosystem has been reported despite multiple detailed reviews of the river's environment and conservation efforts that propose numerous remedies and actions. We developed an ecosystem scale evaluation of the current river environment using many investigations and observations by river experts and conservationists. Also, in response to the current IUGLS study of water management options for the river, we defined a set of hydrologic performance indicators for the current US and Canadian assessment of Lake Superior outflows. Our objectives are to identify the current condition of the river environment emphasizing its biological status, and identify a series of water control changes that would address some of the deficiencies in the environmental quality of the river, anf specify water management performance indicators for use in the International Upper Great Lakes Study.

Biological Condition Assessment

A descriptive model of ecosystem change in response to stressors has been developed by Davies and Jackson (2006). Called a biological condition gradient, this model organizes changes in ecosystem structure and function to characterize the overall status. The model synthesizes observations into six status classes ranging from undisturbed or natural ecosystem condition to severely altered environments with major loss of ecosystem structure and function (Figure 1). This method builds on the characteristics of stressed ecosystems described by Odum et al. (1979), Odum (1985), Rapport et al. (1985), and Cairns and Pratt (1993). The status classification communicates ecosystem condition in a form that can be used in environmental management for planning restoration and protection measures.

We applied this model to the St. Marys River using comprehensive reviews of the river environment (Duffy et al. 1987; Kauss 1991; Bray 1993), a conservation assessment using more than 40 river experts (Harris et al. 2009), and our own workshop of St. Marys River biologists (authors and those listed in Acknowledgements). Observations of change in the river ecosystem were collected, and then organized in the six classes of condition using the specification for environmental attributes in Davies and Jackson (2006). Table 1 reports ecosystem changes by environmental attributes ordered in the six status classes. This allows an informed judgement of the overall ecosystem condition using the dominant class where changes were rated.

Using the pattern of observed and reported changes relative to the ecosystem status classes, we concluded that the St. Marys River currently has moderate changes in the structure of the biotic community and some change in ecosystem function (Class 4). Some changes were rated minimal or evident (Classes 2 and 3), and a fair number of observations indicate major change in the ecosystem. However, all environmental attributes showed change in the class 4 level and the changes noted cluster around this level. Class 4 is marked by moderate change in ecosystem structure and minor functional change. Changes in community structure involved replacement of some sensitive and specialized taxa by more tolerant taxa and nonnative species (Table 1). However, the presence of sensitive taxa has been generally maintained although in some cases at low levels. Small fishes, some birds, wetland plants, and salmonid fishes have shifted toward more tolerant taxa and nonnative species that are more generalized in environmental needs. The altered community compositions indicate some significant change in ecosystem structure and function such as altered food webs and benthic invertebrate composition.

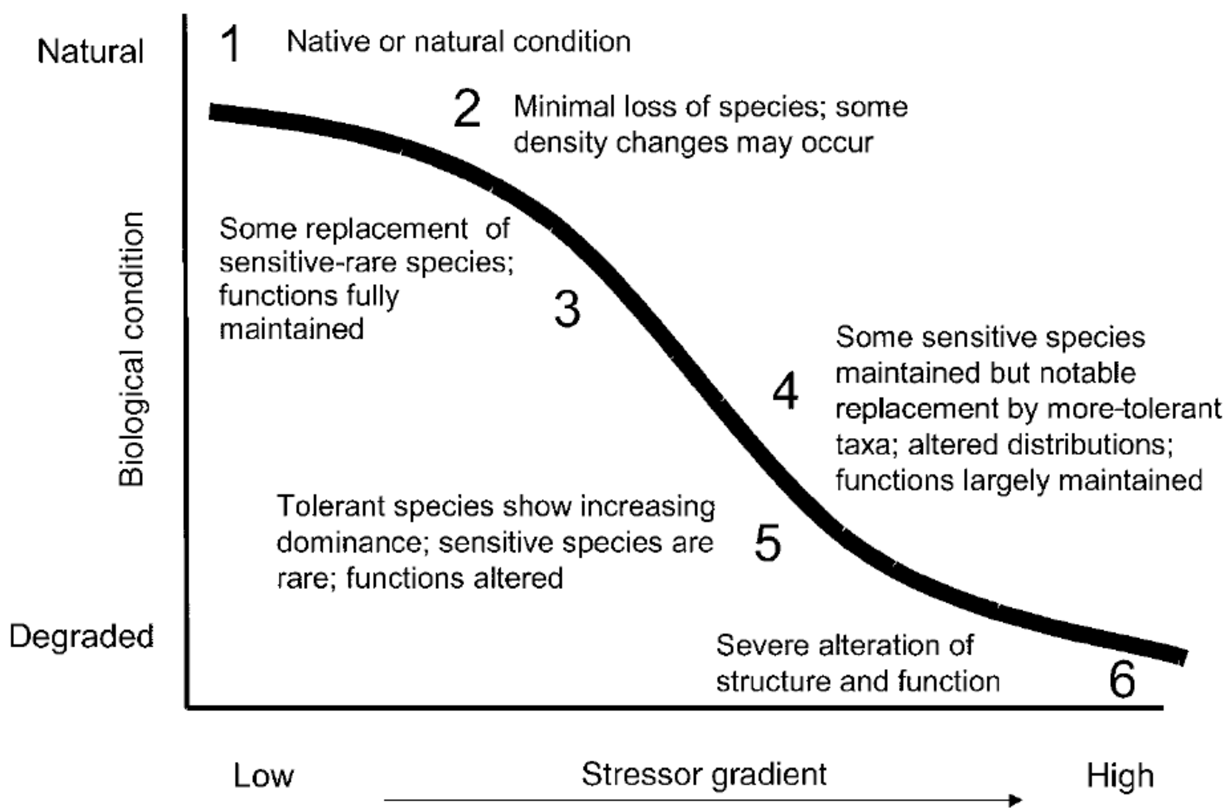

Figure 1. The biological condition gradient organized into 6 stressor classes (from Davies and Jackson 2006).

Table 1. Observed changes in the St. Marys River ecosystem tabulated using the biological condition assessment method of Davies and Jackson (2006).

Ecosystem attribute	1 Natural condition	2 Minimal changes in biotic structure	3 Evident changes in biotic structure and minimal changes in ecosystem function	4 Moderate changes in biotic structure indicating some change in ecosystem function	5 Major changes in biotic structure and moderate changes in ecosystem function	6 Severe changes in biota and ecosystem
Sensitive regional or rare taxa			Lake sturgeon sharply reduced, no evidence on spawning success.	Sandhill crane and lake trout now rare.	Brook trout was common and now absent.	
Sensitive ubiquitous taxa				Local walleye stocks sharply down and vulnerable to loss; northern pike and burrowing mayflies declined from high abundance.	Markedly diminished species include cisco, burbot, black tern, eagles, and osprey.	
Intermediate tolerant taxa				Increasing abundance: double-crested comorants, white pelicans, and freshwater drum.		
Tolerant taxa			White perch colonizing river.	Undesirable indicator bacteria, *Escherichia coli*, now abundant. Ring-billed gulls and herring gulls increasingly abundant.		
Nonnative, introduced taxa		Colonizing river: round goby, zebra mussels, spiny water flea, rusty crawfish, and phragmites.	Now common: three spine stickleback, rainbow smelt, alewife.	Rainbow trout and Pacific salmon species greatly increased in river. Rainbow trout now dominant in rapids habitat.	Very common: sea lamprey, purple loosestrife, reed canary grass.	

Table 1. Continued.

Ecosystem attribute	1 Natural condition	2 Minimal changes in biotic structure	3 Evident changes in biotic structure and minimal changes in ecosystem function	4 Moderate changes in biotic structure indicating some change in ecosystem function	5 Major changes in biotic structure and moderate changes in ecosystem function	6 Severe changes in biota and ecosystem
Organism condition			Morphological anomalies observed in white sucker.	Pacific salmon hybrids common, VHSv and BKD diseases in salmon.	Sea lamprey wounding and mortality common for large fish.	
Ecosystem functions			Sediment contamination effecting benthic organisms in some areas. Wetland and aquatic vegetation changes from dredging, ship traffic, and hydrologic alteration.	Altered food web through reduction of cisco and replacement by smelt and alewife. The change has been associated with thiamine deficiency in some large fishes.		
Spatial-temporal effects			Localized water pollution and contaminated sediments.	Wetland losses and littoral-shore modification (bulkhead and hardening) in much of upper section of lower river. Water temperatures have increased allowing species colonization of river.	Rapids habitat greatly reduced to one limited area, altered hydrodynamics by navigation structures and channel dredging in much of the lower river.	
Ecosystem connectance			Dominant water pathway changed from north to south channels by navigation works.	Compensating Works is a partial barrier. Water level controls isolate some embayments periodically.		

A key consideration of the fourth status class is that most sensitive taxa are maintained at a reduced level but still commonly detected in the system. Large changes in abundance may be seen in some taxonomic groups such as bacteria, some birds, and a variety of non-native species. At present, major changes in ecosystem function have not been reported although physical alteration of the river in terms of water flows, hydrologic regime, and water barriers have been profound.

Our conclusion is that the St. Marys River has experienced moderate biological structure change without major ecosystem functional breakdown. However, many species of different taxonomic groups are in the process of colonizing the river and increasing in abundance. We feel that the St. Marys River is approaching a point where major ecosystem functional change can occur given the strong alteration of water flows and paths combined with increasing water temperatures. These observations are consistent with the class 4 biological condition. Therefore, we want to emphasize the unique nature of the St. Marys River in the Great Lakes system, and draw attention to the need to constrain and possibly reverse ecosystem changes that could easily transform the river to a new ecosystem with much different characteristics.

Hydrologic Considerations

The International Upper Great Lakes Study (IUGLS 2010) is a currently active opportunity to address the management of St. Marys River levels and flows. We considered which changes in the river ecosystem that are shown in Table 1 can be improved by different management of river flows and levels. Not all changes that define the St. Marys River biological condition can be addressed by water management but many can be influenced by changes in river regulation and Lake Huron water level management. We review these grouped by related ecosystem attributes shown in Table 1. Our purpose is to identify water control changes that would address some of the deficiencies in river condition, and identify benefits that would come from changes in water regulation.

Sensitive Species

Lake sturgeon were once abundant in the Great Lakes and the St. Marys River, but the population is suspected to be 1% of its original size (Harkness and Dymond 1961). This fish species is a conservation priority in the Great Lakes Basin (Holey et al. 2000; Great Lakes Fishery Commission 2008; Harris et al. 2009). The lake sturgeon is now listed as threatened, endangered, or a species of concern in Michigan, Ontario, Illinois, Indiana, Ohio, Wisconsin, and Minnesota, and as a globally rare species by The Nature Conservancy (Goforth 2000). Thus the species is a conservation priority in the Great Lakes Basin (Holey et al. 2000; Great Lakes Fishery Commission 2008, Harris et al. 2009). The St. Marys River has an estimated population size of around 500 individuals that appear genetically distinct from other lake sturgeon populations in the Great Lakes (Gerig et al. *in press*). A major barrier to lake sturgeon recovery is the lack of suitable spawning sites (Daugherty et al. 2008). Lake sturgeon spawn in areas with moderate flow (Seyler 1997; Manny and Kennedy 2002; Friday 2006) and hard substrate (Auer

1996; Seyler 1997; Bruch and Binkowski 2002). The St. Marys River has several sites that meet these requirements (Goodyear et al. 1982), but maintenance of these spawning habitats is linked to flow regime to maintain adequate water velocities. In the St. Marys River, sufficient river flow must be maintained for lake sturgeon spawning to ensure adequate spawning success and recruitment.

Cisco have been important commercially and are still a popular sport fish, but their abundance has declined across the Great Lakes (Fielder et al. 2002; Mohr and Evener 2005). They are now listed as threatened in Michigan, a restoration priority in Lake Huron (Lake Huron Technical Committee 2007), and a conservation priority across the Great Lakes Basin (Great Lakes Fishery Commission 2008). The decline in cisco has altered the prey fish assemblage that is now dominated by species rich in thiaminase (Fitzsimons et al. 1998) causing thiamine deficiency complex in predator fishes (Ketola et al. 2000). In addition, cisco grow to larger sizes than many current prey fishes, which makes them a more energetically advantageous prey for lake trout (Lake Huron Technical Committee 2007). Therefore, maintaining or increasing the current cisco population may help restore a threatened species, but also may help restore lake trout. The St. Marys River is one of the few areas where cisco have persisted (Fielder 1998, 2002), making it a critical area for the collection of gametes for reintroduction elsewhere in the Great Lakes. Cisco are broadcast spawners that deposit eggs in shallow water in late fall with hatching in the spring. The eggs are sensitive to water elevation changes that occur during winter (Greeley and Bishop 1932). Furthermore, cisco eggs may hatch prematurely when exposed to light or physical disturbance, both of which may be associated with water elevation changes that disturb surface ice (Colby and Brooke 1970).

Many species of migratory birds nest in emergent vegetation of marshes along the Great Lakes shorelines. Black terns are one of most prominent of these migratory, emergent wetland nesting birds (Currier 2000) and we use black tern as a representative species for promoting control of water level changes. Black tern is a designated species of concern in Ontario, Wisconsin, Michigan, and Ohio because populations have been decreasing since the 1960s (Peterjohn and Sauer 1997). Specific hydrologic conditions are needed for black tern habitats; especially stable water levels during the breeding season (Mortsch et al. 2006). Black terns build nests from dried reeds, stalks, and grasses on mounds of vegetation often dominated by cattails (*Typha* sp.) or bulrushes (Scirpus sp.; Cuthbert 1954; Dunn 1979). Nesting sites are usually at the interface of emergent wetlands and open water where both vegetation and open habitats are about equally common (Hickey and Malecki 1997). Nesting sites are selected by black terns within a very limited range of water depths (Mazzocchi et al. 1997; Alsop 2001; Maxson et al. 2007). Nests are vulnerable to flooding and destruction by wave action, conditions that are often associated with increases in water level or its variability during the breeding and nesting seasons (Shuford 1999; Naugle 2004; Mortsch et al. 2006).

Nonnative and Tolerant Species

Sea lamprey is a nonnative species and a lethal parasite of the larger fishes in the Great Lakes (Bergstedt and Schneider 1988; Kitchell 1990). Sea lamprey have caused major changes in the fish communities, fisheries, and ecosystem characteristics in the Great Lakes. The St. Marys River produces more sea lamprey than all the Great Lakes tributaries combined (Great Lakes Fishery Commission 2000) and this results in the highest attack rate on large fishes in Lake

Huron compared to the other lakes (Johnson 1988). The size and volume of the St. Marys River makes the traditional lamprey control methods impractical; treatment with lampricides that kill lampreys in their larval stage (Brege et al. 2003). The Great Lakes Fishery Commission coordinates an integrated program to reduce lampreys in the St. Marys River using spot treatment with lampricide, trapping adults, and releasing of sterile male adults (Great Lakes Fishery Commission 2000). The St. Marys River rapids have an abundance of gravel and rubble substrate with flowing water that provides the prime spawning area for lamprey (Manion and Hansen 1980; Eshenroder et al. 1987; Schleen 1992) in the St. Marys River. Efforts to increase fish habitat in the rapids with control of rapids flow from gates on the Compensating Works would also increase the spawning habitat supporting lamprey production.

Ecosystem Functions

The structural complexity and reduced wave action provided by submerged aquatic vegetation (SAV) beds are important functions of nearshore ecosystems (Strayer and Findlay 2010). SAV beds reduce erosion and thus turbidity by stabilizing clay sediment (Liston et al. 1986). SAV beds are highly productive areas that support diverse assemblages of macroinvertebrates and fishes, and contribute to the majority of primary productivity in the St. Marys River (Liston et al. 1980; Williams and Lyon 1991). They are an important source of food for decomposers (Liston et al. 1980) and cover for a diverse and abundant macroinvertebrate community (Liston et al. 1980 [and references therein]; Duffy et al. 1987; Edsall and Charlton 1997). SAV also provide spawning and nursery habitat to a high proportion of Great Lakes fish species (Liston et al. 1980; Lane et al. 1996a,c) and resident habitat to warmwater fishes (e.g., centrarchids; Lane et al. 1996b). As such, SAV support the larger St. Marys River fish community by serving as an important link in lower food web material exchange (Liston et al. 1980). In the st. Marys River, SAV bed area is determined primarily by water depth (Williams and Lyon 1991), but also substrate, slope, water clarity, and water velocity (Liston et al. 1980; Liston et al. 1986; Duffy et al. 1987). Changes to water elevation will impact the availability of suitable habitat along and extending into the St. Marys River channel from the shoreline.

Emergent wetlands in the Great Lakes are important habitats supporting birds, mammals, fishes, invertebrates, and high biological productivity. They serve as key spawning, nursery, and feeding areas for 44 fish species of the river. Because the river has a very high water turnover rate, pelagic productivity by phytoplankton and zooplankton is minimal (Duffy 1987). The complex structured habitat formed by emergent wetlands provide more than 90% of the rivers overall dry weight biomass production (Kauss 1991). Benthic invertebrate productivity on a per unit area basis exceeds all other habitats types (Kauss 1991). Also, emergent wetlands are important to migratory waterfowl such as mallard, blue-winged teal, and the American black duck. Emergent wetlands are sensitive to water level change. The area of these wetlands has been photographed and mapped in Lake Nicolet for a half century; a large water body in the St. Marys River. A strong relationship exists between water level and the area of emergent wetlands for the St. Marys River (Kauss 1991), the Great Lakes (Kelsall and Leopold 2002; Ciborowski et al. 2008; Mortsch et al. 2006, 2008), and waterways in general (Harris and Marshall 1963; Dabbs 1971; Spence 1982).

Spatial-temporal Changes

The St. Marys River main rapids drops over 6 m in a 1.2-km reach, resulting in fast-flowing water dominated by cobble, boulder, and bedrock substrate. Large and diverse substrates and fast flows are lacking throughout the remainder of the 112-km river, which makes the rapids an important area for biotic production. The fish community in the rapids is unique and dissimilar to communities in other habitats of the river. Historically, the rapids provided high quality spawning habitat for several native species, and the rapids continue to provide spawning and feeding habitat for numerous game species and important forage fishes (Gleason et al. 1981; Goodyear et al. 1982; Steimel 2010). Macroinvertebrate composition and productivity in the rapids also differ substantially from other habitats in the river, and were dominated by net-spinning caddisfly larvae (Duffy et al. 1987; Kauss 1991). Reduction of the rapids habitat has occurred due to the construction of shipping locks and hydropower facilities and their canals. However, habitat is also reduced by flow regulation from the Compensating Works; a 16-gate structure regulating flows through the rapids. An average of about 5% of Lake Superior outflows pass through the rapids under rules of the Boundary Waters Treaty (Koshinsky and Edwards 1983).

Previous studies of rapids habitat and hydraulics (e.g., Hough et al. 1983, Koshinsky and Edwards 1983) have indicated that reduced flows result in considerable drying of rapids habitat. Increases in flow through the Compensating Works is a feasible strategy to enhance fish and benthic macroinvertebrate production in the rapids. Current flow regulation impacts biota by reducing habitat, stranding fish and invertebrates, drying and freezing of fish eggs, and alteration of spawning and nursery conditions. Changes in water regulation rules could enhance habitat available for fish and macroinvertebrate production and improve conditions for migratory fish spawning, rearing, and foraging.

The speed of water level change in the rapids caused by gate operations on the Compensating Works has been a concern of fisheries management (Godby 2006) and river conservations organizations (Harris et al. 2009). The speed of gate adjustments and changes in water releases is an issue that is limited to the rapids. Quick flow rate and water level changes on fishes can be severe and result in loss of a substantial portion of small, young fishes: a rate of 60 cm/hr change has been associated with 22% mortality of small salmonid fishes in similar rivers (Halleraker et al. 2003). The rate of fish losses due to abrupt declines in water level has been carefully studied to develop standards for mitigating this threat to river fishes. Salmonid fishes less than 100 mm length are most vulnerable to stranding. Protection criteria were developed for the speed of change that does not pose a threat to river fishes: less than a decline in water level of 10 cm/hour (Salveit et al. 2001; Halleraker et al. 2003, 2007). A change in Compensating Works operations to meet this water level rate of decline would reduce loss of young fishes considerably and could improve resident fish populations in the rapids.

The accumulation of sediment in habitats previously swept clear of fine sediment can make channels narrower and shallower, reduce formation of bars, and cover valuable spawning habitat (Reiser et al. 1989; Poff et al. 1997). These changes have obvious negative consequences for boating, vegetation, and fishes. Without flushing flows, eggs and larvae of many amphibians, fishes, and invertebrates may suffer high mortality rates (see references in Wiley et al. 1995). A lack of flushing flows can be especially important in areas where sediment input is high, as is the case in many of the low-gradient, clay and sand-dominated tributaries that flow into the St.

Marys River. A variable river flow regime influences sediment transport, which in turn affects channel morphology, habitat, and biota (Reiser et al. 1990; Poff et al. 1997; Kondolf and Williams 1999). Controlled water releases may be used to flush sediment in a manner approaching conditions prior to river regulation to maintain a more natural and productive environment. Proper implementation of flushing flows is necessary to maintain ecological integrity (see Table 2 in Poff et al. 1997) while allowing for control of flow for other purposes during the remainder of the year.

Ecosystem Connections

Backwater habitats include barrier protected and connecting channel wetlands and embayments. Along with other nearshore wetlands, backwater habitats are of high quality relative to Great Lakes wetlands overall (Harris et al. 2009). Backwater habitats are accessible to the river, enabling exchange of materials (e.g., nutrients) and organisms with the main river. Riverine and Great Lakes fishes depend on these areas as warmwater refuges in the spring (Brazner and Beals 1997; Edsall and Charlton 1997) and for important spawning and rearing habitat (Goodyear et al. 1982; Harris et al. 2009). These habitats are an important conservation priority because they provide essential habitat for waterfowl, migratory bird species, and native fishes that rely on wetlands for at least one life history stage (Harris et al. 2009). SAV beds in backwaters provide cover and complex habitat for macroinvertebrates and small fishes (Jude and Pappas 1992; Gore and Shields 1995; Randall et al. 1996; Brazner and Beals 1997). Finally, backwater habitats support submerged and emergent marsh communities composed of species that require slow water movement and reduced wave action (e.g., herbaceous species, species with long-floating propagules, and shallow submerged aquatic vegetation, SAV; Nilsson et al. 2002). River shoreline wetland habitat loss was a listed impairment in the designation of the St. Marys River area of concern (Selzer 2007). Maintaining connectivity between backwater habitats and the open river is vital for species that use these habitats during different life stages. Backwater habitat connectivity with open waters of the St. Marys River is determined by water elevation. Lower water elevations can result in hydrologic separation of backwaters through exposure of sand bars or other bathymetric features above the surface of the water column. Low water elevations also can cause loss of backwater habitat through dewatering of shallow areas.

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APPENDIX B

St. Marys River Environmental Performance Indicators

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Fact Sheet ID: 21

Performance Indicator (PI) Name/Short Description: Sea Lamprey – spawning habitat suitability index (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Mark Bain

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is an inverse suitability index for sea lamprey spawning habitat in the St. Marys River rapids, with higher suitability indices reflecting lower spawning habitat availability for sea lamprey.

The St. Marys River rapids have an abundance of gravel and rubble substrate with flowing water that provides sea lamprey (*Petromyzon marinus*) spawning habitat. These conditions are limited in all other areas of the river, making the rapids a prime spawning area for lamprey (Manion and Hansen 1980; Eshenroder et al. 1987; Schleen 1992). A survey of larval lamprey abundance across the St. Marys River indicated the zone including the rapids, power channels, and Soo Harbor is the third most productive area for the species, annually supporting an estimated 736,912 larvae (ammocoetes) in the 1980s (Eshenroder et al. 1987). Efforts to increase fish habitat in the rapids with control of rapids flow from gates on the Compensating Works (16-gated control structure used to control Lake Superior water level) would also increase the habitat supporting lamprey spawning. Therefore, a PI was developed to relate rapids aquatic habitat with suitability for reducing lamprey spawning success. This indicator is limited to the main rapids because the Fishery Remedial Works (flow diverting berm - raised barrier separating two areas) on the Canadian shore of the rapids was designed and built to maintain aquatic habitat at a specific volume of flow and gate setting. There is little flexibility to change conditions north of the berm; however, flow changes and habitat area in the main rapids are still being considered (see main rapids wetted habitat performance indicator).

Ecological Importance/Niche: Sea lamprey are a non-native species and a lethal parasite of the larger fishes in the Great Lakes (Bergstedt and Schneider 1988; Kitchell 1990). They have caused major changes in the fish communities, fisheries, and ecosystem characteristics in the Great Lakes (Smith and Tibbles 1980). In the 1980s, damage to Great Lakes fisheries was estimated at $2.6 million a year and about 70% of the fishery value of the most parasitized fishes (Eshenroder et al. 1987). The St. Marys River produces more lamprey than all the Great Lakes tributaries combined (Great Lakes Fishery Commission 2000) and this results in the highest attack rate on large fish in Lake Huron compared to the other lakes (Johnson 1988). The success of lamprey control for Lake Huron depends mainly on controlling lamprey in the St. Marys River (Eshenroder et al. 1995; Schleen et al. 2003).

The size and flow volume of the St. Marys River makes traditional lamprey control methods impractical, such as treatment with lampricides that kill lampreys in their larval stage (Brege et al. 2003). The lack of efficient control methods for lamprey in the St. Marys River has resulted in this river remaining a major source of the parasite. The Great Lakes Fishery Commission coordinates an integrated program to reduce lampreys in the St. Marys River using spot treatment with lampricide, trapping adults, and release of sterile male adults (Great Lakes Fishery Commission 2000). This combination of control measures has reduced lamprey productivity by 90% in the river (Schleen et al. 2003). Increasing the productive capacity of the St. Marys River to produce other fish and aquatic biota will likely serve to assist with lamprey reduction efforts. Changes in rapids flow, habitat area, and the Fishery Remedial Works have not been evaluated for effects on lamprey spawning production (Young et al. 1996). Without specific data, we developed an approximate relation between rapids aquatic habitat area, water flow, gate openings, and lamprey production to consider this important water management effect for the St. Marys River.

Temporal Validity: The PI applies to spawning habitat in the rapids for the spawning period: June and July. This is the general spawning period for sea lamprey in the Upper Great Lakes (Manion and Hanson 1980).

Spatial Validity: The PI was designed to represent flow changes, gate openings on the Compensating Works, and wetted habitat in the main rapids. The main rapids constitute the best and large majority of suitable spawning habitat in the St. Marys River (Eshenroder et al. 1987; Krauss 1991; Schleen 1992; Young et al. 1996). Also, consideration of changing rapids aquatic habitat area by modifying gate opening rules for fish and aquatic biota will have an effect on lamprey spawning area in the rapids.

Hydrology Link: The area of aquatic habitat in the St. Marys River rapids is based on the volume of flow released by the Compensation Works. Studies of rapids flow and watered habitat have been reported in terms of the number of gates open. The specific volume of flow varies by open gates because of the elevation of Lake Superior. Therefore, it is easier and more direct to measure volume in terms of gate openings. For this PI, both the number of open gates and rapids flow volume are reported. Flow volume is based on gate discharges reported in Hough et al. (1981) for a lake elevation of 183.0 m.

Algorithm: The PI plot below (Figure 1) was based on a similar wetted habitat and flow relationship plot in Koshinsky and Edwards (1983). This study and all data on flow and habitat area were developed prior to the Fishery Remedial Works in 1985 and 1986. A berm starts at the Compensating Works and roughly follows the Canadian shore down the rapids. Its purpose is to maintain water released from Gate #1 (normally 1/2 open) along the Canadian shore and fill side channels in the area. The berm effectively isolates the Canadian shore from the main rapids that extend to the US shore; it elevates the water surface north of the berm. Prior to the construction of the Fishery Remedial Works, studies of flow and wetted habitat along the Canadian shore calculated that four to six gates need to be open to have sufficient flow to inundate the Canadian shore and side channels (ILSBC 1974; Hough et al. 1981; Koshinsky and Edwards 1983). The plot in Koshinsky and Edwards (1983) shows the increase in wetted habitat from one-half gate to four gates and does not include habitat in the area maintained by the Fishery Remedial Works. This information shows the increase in wetted area primarily in the main rapids. Figure 1 also shows there is aquatic habitat when no gates are open. This aquatic habitat is expected because as much as 14 m^3/s of water leaks through the Compensating Works (ILSBC 1974) and standing water pools exist at this minimum flow.

The suitability index for lamprey spawning reduction in the rapids would be optimal at zero flow because this would be the minimum support for lamprey spawning - no habitat. However, we assigned the optimal condition to be a one-half open gate to maintain the current habitat for other fishes. A suitability index score of one would be the highest flow that would inundate the main rapids from the highest US shore to the Fishery Remedial Works berm along the Canadian shore. Four gates open would cause inundation and is the worst case for lamprey control.

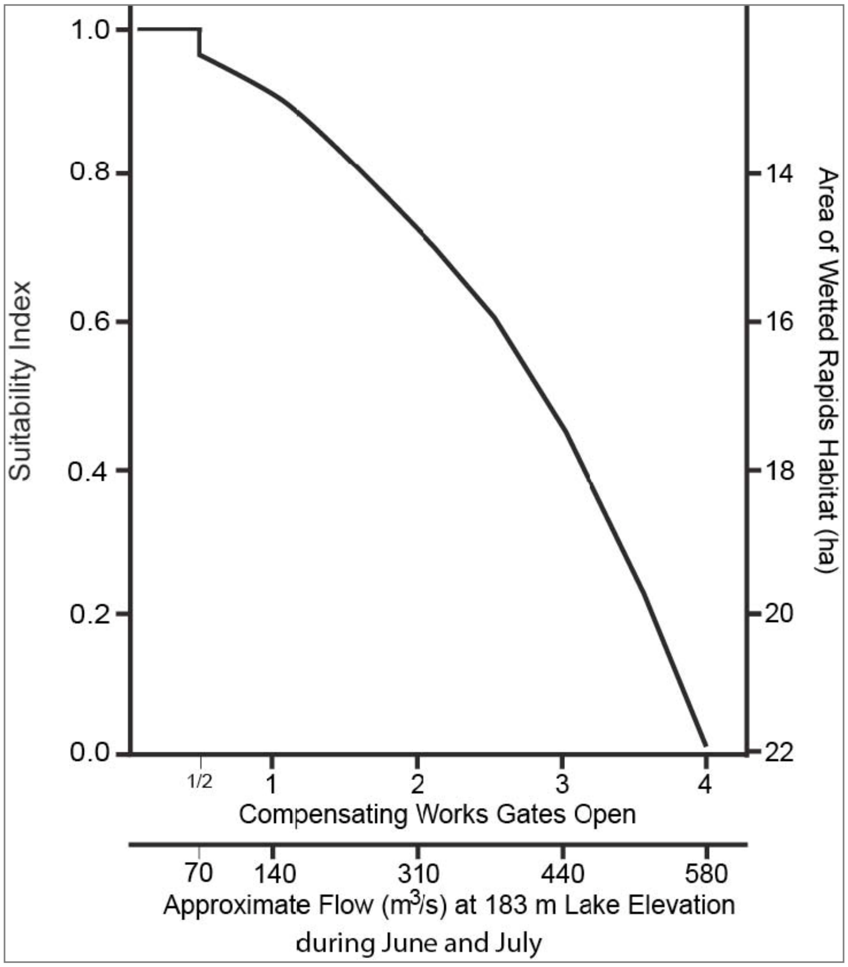

Figure 1. Relationship between flow and habitat area to determine a suitability index value for sea lamprey spawning habitat.

Coping Zone Criteria: The relationship between open gates, flow, and wetted habitat is gradual so there is no clear threshold level to be identified. However, four gates open would provide essentially all possible habitat area in the main rapids for lamprey spawning and four open gates could be considered a threshold with an assigned suitability index score of zero:

- **SMG-01**:
    - Zone C: Compensating Works operated with 4 or more gates open for the May-July period for any given year.

Calibration Data: Data used to develop this relationship and serves as the basis for the PI was reported in Koshinsky and Edwards (1983); they used data, study results, and air imagery at different flows to compile their plot. These are the best data and information available at this time. Repeated assessments of habitat, flows, and gate openings were conducted prior to the final decision and design of the Fishery Remedial Works. After this structure was built, there have been no similar analyses of the rapids area.

Validation Data: The model or relationship provided is based on multiple studies and assessment by fishery experts. However, testing of the relationship developed has not been conducted nor has a quantitative study of lamprey spawning habitat been conducted in the rapids. The rapids are difficult to survey and measure because of variable topographic structure, high velocities in watered area, and the width of the channel.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. The relationship between flow and wetted rapids habitat represents the main rapids area at flows under four open gates.
2. The area of aquatic habitat in the rapids is an indicator of lamprey spawning habitat support.
3. Flowing water over gravel and rubble substrates provides lamprey nesting habitat.

These basic assumptions are used to project lamprey spawning habitat area in the St. Marys River rapids and to target control measures. Thus, confidence can be considered high for the general relationship developed here.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

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Fact Sheet ID: 22

Performance Indicator (PI) Name/Short Description: Native Fish – available habitat area in St. Marys River rapids (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)
Researched by: Ashley Moerke

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: This PI metric describes the total surface area of native fish habitat available in the St. Marys River rapids.

The St. Marys River (SMR) rapids drop over 6 m in a 1.2 km reach, resulting in fast-flowing water dominated by cobble, boulder, and bedrock substrate. Large and diverse substrates and fast flows are lacking throughout the remainder of the 112 km river, which makes the rapids an important area for biotic production. The rapids provides habitat for native fishes. Although this habitat was historically, construction of the Compensating Works (16-gated control structure used to control Lake Superior water level) and hydropower facilities diverted over 90% of the Lake Superior outflow and dewatered over 25 hectares of the rapids (Duffy et al. 1987). In 1981, a berm (Fishery Remedial Works, flow diverting berm - raised barrier separating two areas) was constructed to reduce dewatering of the main rapids at lower flows; however, available habitat still varies with Compensating Works gate operations.

The remaining rapids provides critical habitat for fish and benthic macroinvertebrates, but the habitat is limited to the area inundated by flows through the Compensating Works. Therefore, this PI was developed to relate the wetted area of the main rapids to changes in water elevations associated with the Compensating Works gates. Current water elevation regulations may lead to decimation of biota by reducing water flows over the rapids habitat which may strand fish and invertebrates, freeze fish eggs deposited in the substrate, and eliminate spawning and nursery habitat. Future water elevation regulations via Compensating Works gate operations could be altered to enhance habitat available for macroinvertebrate production and fish spawning, rearing, and foraging.

This indicator is limited to the main rapids because the area north of the berm (Fishery Remedial Works) is isolated from the main rapids and remains wetted with gate operation consistently open at 20 cm. Operational changes to the Compensating Works gates would largely influence the main rapids.

Ecological Importance/Niche: The fish community in the rapids is unique and dissimilar to communities in other habitats of the river. Historically, the rapids provided high quality spawning habitat for native species, including white sucker (*Catostomus commersonii),* slimy sculpin (*Cottus cognatus),* lake whitefish (*Coregonus clupeaformis),* brook trout (*Salvelinus fontinalis),* and lake trout (*Salvelinus namaycush).* The rapids continue to provide spawning and feeding habitat for numerous game species, including steelhead (*Oncorhynchus mykiss)*, brown trout (*Salmo trutta),* and chinook salmon (*Oncorhynchus tshawytscha),* and important Great Lakes forage fishes such as longnose dace (R*hinichthys cataractae*), alewife *(Alosa* *psuedoharengus)* and rainbow smelt *(Osmerus mordax)* (Gleason et al. 1981; Goodyear et al. 1982; Steimel 2010). The rapids may also provide critical spawning habitat for lake sturgeon (*Acipenser fulvescens*), a threatened species in Michigan. Macroinvertebrate composition and productivity in the rapids also differs substantially from other habitats in the river, and are dominated by net-spinning caddisfly larvae (Trichoptera: Hydropsychidae) (Duffy et al. 1987; Kauss 1991) due to the faster flowing waters and larger substrate. These hydropsychids likely serve as a valuable food source for benthic fishes such as sculpin, pelagic forage fishes such as longnose dace, and juvenile fishes. Reduction of the rapids habitat has occurred due to the locks, the Compensating Works, and hydropower generation. Currently, less than 10% of Lake Superior outflows flow through the rapids; flows are now regulated by Compensating Works gates at the head of the rapids. Previous studies (e.g., Hough et al. 1983; Koshinsky and Edwards 1983) have indicated that the flows experienced at three open gates or less result in considerable drying of rapids habitat, which limits habitat available for biotic use and production. Regulation of flow through the Compensating Works is a feasible strategy to enhance fish and benthic macroinvertebrate production in the rapids.

Temporal Validity: Annual - the rapids are used throughout the year for fish spawning, egg incubation, and larval rearing. For example, many salmonids spawn in the rapids in the late spring (May-June) or fall (August-November), but their eggs incubate over the winter months. The rapids also provide nursery habitat for species throughout the entire year.

Spatial Validity: This indicator applies to the main rapids of the SMR (south of the berm) where changes in the Compensating Works gate operations will alter wetted area and available habitat for biota. The area north of the berm (Canadian side) is isolated from the main rapids and remains wetted with gate operation consistently open at 20 cm.

Hydrology Link: The wetted area of the rapids was related to flow volume released through the Compensating Works gates. Koshinsky and Edwards (1983) reported river discharge based on the number of gates open and then related this to wetted area in the rapids.

Algorithm: Data used in development of this PI are summarized as a plot in Koshinsky and Edwards (1983). Flow volume is based on gate discharges for a lake elevation of 183.0 m. This and other existing studies relating flow and habitat area in the rapids were conducted prior to the Fishery Remedial Works in 1985 and 1986. This structure is a berm that starts at the Compensating Works and roughly follows the Canadian shore down the rapids. Its purpose is to maintain water released from Gate #1 (normally open 20 cm) along the Canadian shore and fill side channels in the area. The berm effectively isolates the Canadian shore from the main rapids that extend to the US shore; it elevates the water surface north of the berm. Prior to the construction of the Fishery Remedial Works, studies of flow and wetted habitat along the Canadian shore calculated that four to six gates needed to be open to have sufficient flow to inundate the Canadian shore and side channels (ILSBC 1974; Hough et al. 1981; Koshinsky and Edwards 1983, and others). The plot in Koshinsky and Edwards (1983) shows the increase in wetted habitat from one-half gate open to four gates open. The plot does not include habitat in the area maintained by the Fishery Remedial Works. This information shows the increase in wetted area primarily in the main rapids. Figure 1 also shows aquatic habitat exists when no gates are open. This is expected because as much as 15 m^3/s leaks through the Compensating

Works (ILSBC 1974) and standing water pools would exist at this minimum flow.

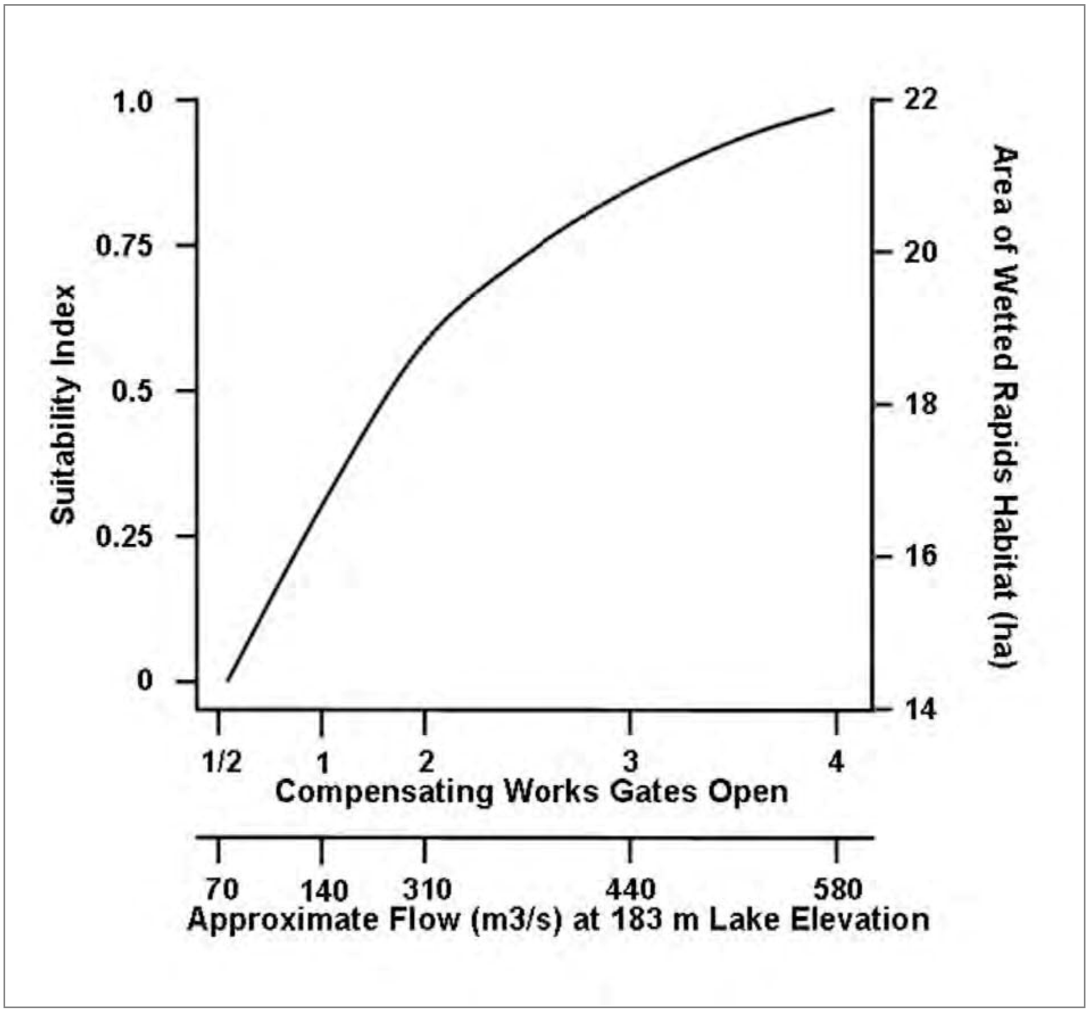

Figure 1: Relationship between flow and area of wetted rapids to determine a suitability index for native fish habitat area.

The suitability index for wetted area in the rapids would be optimal at 1.0 when four gates are open because this would provide maximum inundation of the rapids and increase availability of habitat for macroinvertebrates and fishes. A suitability index score of zero would be when only one-half gate is open in the rapids. A reduction in gates open from four to one-half would result in a loss of over one-third of the existing rapids wetted habitat.

Coping Zone Criteria: The coping zone criterion developed for this PI reflects expert opinion that the St. Marys Rapids should never experience flows below the ½ gate opening. This is a the minimum flow set between the US and Canada in current plan. Any duration of lower flow would dry the rapids more than now and strand fish, desiccate invertebrates, and set a new lower flow condition. Therefore, the critical condition applies to any length of time, as reflected in the description provided below:

- **<u>SMG-02</u>**:
  - <u>Zone C</u>: Compensating Works operated with less than 0.5 gate open for any given month in any given year.

Calibration Data: Data used to develop this PI are from Koshinsky and Edwards (1983). This is the best information currently available, but the relationship was developed prior to the final decision and design of the Fishery Remedial Works. After this structure was built, there has been no similar analysis of the rapids area.

Validation Data: The model provided is based on multiple studies; however, no test of the relationship developed has been conducted since the construction of the Fishery Remedial Works.

Risk and Uncertainty Assessment: The following are the main assumptions of PI model:

1. The relationship between flow and wetted rapids habitat represents the main rapids area at flows under four gates open.
2. The relationship between flow and wetted rapids habitat, based on data prior to the construction of the Remedial Fishery Works, is similar to the relationship between flow and wetted rapids habitat after construction of the berm.
3. The area of wetted habitat in the rapids is an indicator of benthic macroinvertebrate and fish production.

These basic assumptions are used to project wetted areas in the SMR based on flow volume released from the Compensating Works. Confidence can be considered relatively high for the general relationship developed here.

Confidence, Significance, and Sensitivity: See discussion in preceding sections.

Documentation and References:

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Steimel, N. 2010. Effects of temperature, rainfall events, and time of year on fish use of the St. Marys River Rapids. Senior Thesis, Department of Biological Sciences, Lake Superior State University.

Fact Sheet ID: 23

Performance Indicator (PI) Name/Short Description: Fish Stranding in Rapids - ramping rate suitability index (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Mark Bain

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: A PI is presented that relates potential fish losses, via fish stranding, to the speed of change in gate openings and flow volume to address this concern in reconsidering the operation of the Compensating Works.

The speed of water level change due to gate changes on the Compensating Works (16-gated control structure used to control Lake Superior water level) above the rapids of the St. Marys River has been a concern of fisheries management (Godby 2006) and river conservations organizations (Harris et al. 2009). The speed of gate adjustments and changes in water releases are often called 'ramping rates' and usually apply to hydroelectric plant discharges. For the St. Marys River, this issue is limited to the rapids and does not involve the hydropower plants; the rapids were maintained to support the river's famous salmonid fishery. Rapid ramping rates can impact fish resulting in the loss of a substantial portion of small, young fish. This loss adds to natural mortality and can greatly diminish populations. The rate of rapid flow volume changes associated with changes in the Compensating Works gate openings have been judged too erratic and damaging on fish in the rapids (Harris 2009).

Ecological Importance/Niche: Observations of fish stranding under rapidly declining river water levels have been reported below many hydroelectric facilities. The rate of fish losses due to abrupt declines in water level have been primarily studied in Norway, which relies entirely on hydropower for its electric supply and has very important salmon and trout fisheries in its broad, boulder dominated, cold rivers. These studies are applicable to the St. Marys River: same kinds of fish, boulder strewn habitats, and cold climate. Studies have been done in the US and in other countries, but the Norwegian research has been the most thorough. A series of conclusions from experiments on fish losses from rapid and gradual water level changes are reported in Salveit et al. (2001) and Halleraker et al. (2003, 2007). Salmonid fish losses primarily occur because of stranding during rapidly falling water levels. Salmonid fishes less than 100 mm in length are most vulnerable to stranding. Higher rates of standing occur in coarse substrates with high current speeds. Finally, criteria were developed for the speed of change that does not pose a threat to river fishes.

Temporal Validity: The fish stranding and ramping rate PI applies to gate and flow changes in any season for the rapids. Salmonid fishes are present year round so quick changes in water levels are a potential threat at any time.

Spatial Validity: The PI applies only to the St. Marys River rapids below the Compensating Works south of the Fishery Remedial Works - the main rapids. All of the St. Marys River hydroelectric plants discharge directly into deep channel waters where the ramping fish standing/ramping rate issue does not exist.

Hydrology Link: The rate of water level change is central to this PI. The Norwegian research on ramping rate impacts was summarized to develop protection criteria in Halleraker et al. (2003), which gives specific guidance for minimizing losses of salmonid fishes by stranding.

> *Dewatering slower than 10 cm an hour drastically decreased stranding of young trout, the most vulnerable group of fishes. For rivers dominated by coarse substrate, these slow ramping rates (<10 cm/hr) must be achieved. Gentle drops in discharge after long stable flow periods are recommended.*

I present a PI (Figure 1) that was developed with the < 10 cm/hr change rate defining optimum conditions (Suitability index = 1). In Halleraker et al. (2003) a fast rate of change was a measure for fish losses: 60 cm/hr with 22% mortality of small salmonid fishes. This rate of change was considered unacceptable and labeled with a suitability index of zero. The rate of fish loss was considered linear between these points; an intermediate change rate of 13 cm/hr was computed and fell directly on the straight line in the plot.

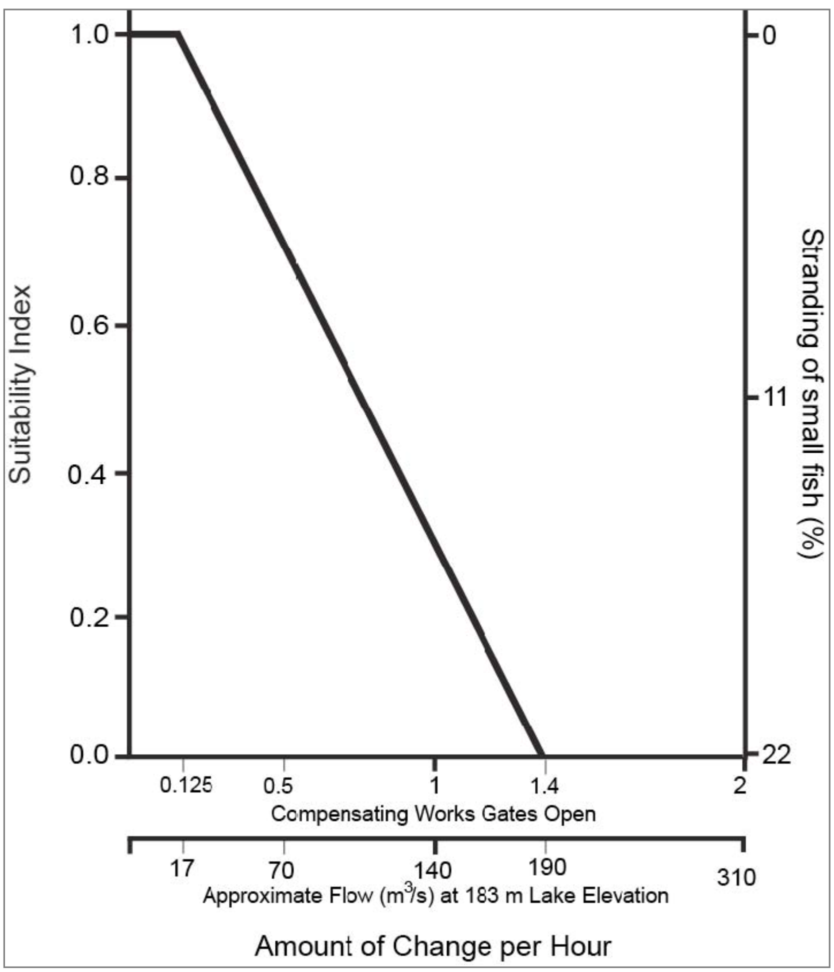

Figure 1. Relationship between flow and stranding of small fish to determine a suitability index for ramping rates.

Algorithm: The key rates of change (10 and 60 cm/hr) were converted to main rapids flow and gate opening (at a common lake level 183 m, Houke et al. 1981) using a set of calculations based on standard hydraulic properties of river channels. Hydraulic rules in Leopold and Maddock (1953) and Dunne and Leopold (1978) provide the computations for this conversion. The conversion to a rate of change in Compensating Works operations started with the basic formula:

$$\mathbf{d = cQ}^{f}$$

Where **d** is the average channel depth (ft), **Q** is the flow in ft^3/s, ***f*** is an exponent, and **c** is a numerical constant. Leopold and Maddock (1953) and Dunne and Leopold (1978) have parameterized this formula in English units for many river channels around the World. The exponent ***f*** was set to 0.40, which is an average value for many rivers. The numerical constant **c** was calculated using data extracted from International Lake Superior Board of Control (ILSBC 1974, see p. 86) and St. Marys Rapids Working Group (1983, see Table 2). The formula above was rearranged to compute an estimate of **c** using rapids flow and average depths:

$$\mathbf{c = d/Q}^{f}$$

Six flows with average rapid water depths were used to compute **c,** ranging from 2,500 to 46,000 ft^3/s. The estimates of c ranged from 0.06 to 0.16 and an average of these values was used (0.10). Any flow can then be inserted in the first formulae using ***f*** = 0.40 and **c** = 0.10 to calculate average water depth. Estimations were done to define the amount that rapids flow can be changed to match the 10 and 60 cm/hr rate of change. The results were then converted to metric units and plotted on the PI plot (Figure 1). The x-axis flow is in units of m^3/s for gate openings and is based on a common gate flow reported in Houke et al. (1981) with Lake Superior elevation at 183 m. The final PI plot shows a suitability rating of gate and volume change per hour with an estimate of potential fish losses.

A one half open gate is the common opening equivalent on the Compensating Works for the current flow rate for the rapids. There are 16 gates on the Compensating Works and a change of one half open gate should be done in no less than four hours to meet the suitability index of 1. A rate of change in rapids flow should be $\leq 17\ m^3/s$ per hour to maintain a rate of water surface change of no more than 10 cm/hr. Because one half open gate releases approximately 70 m^3/s water, this amount of gate change needs to be spread over four hours to approximate a flow rate of change of 17 m^3/s.

Coping Zone Criteria: Based on the above discussion the rate of change in St. Marys Rapids water depth should always be maintained at less than 60 cm/hr, keeping in mind that the ideal rate of change is less than 10 cm/hr. Therefore, "Zone C" conditions are encountered when the rate of change in water depth is greater than or equal to 60 cm/hr. This criterion is operational in nature, and therefore it is not represented directly in the IERM2 model or the accompanying

Coping Zone calculator, which operate on monthly mean water level time series.

Calibration Data: Calibration data were scarce because of the need for both rapids volume and an estimate of average depth. Data were found for six widely varied rapids flows in ILSBC (1974, see p. 86) and St. Marys Rapids Working Group (1983, see Table 2). The resulting computations provided a narrow range of values used in the formula to relate volume and depth in the rapids. The exponent of this formula was a central value reported in standard river hydraulics references (Leopold and Maddock 1953; Dunne and Leopold 1978).

Validation Data: There are no validation studies available for fish losses under varying water levels in the St. Marys River rapids. However, thorough research in Norway was done to identify rates of change associated with near zero fish losses and high losses. These were combined with standard hydraulic formulas to predict rates of change in the St. Marys River.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. The standards for fish loss, under varying water levels, apply to the St. Marys River.
2. Parameterization of St. Marys River rapids hydraulic properties is realistic.
3. The resulting standards will improve conditions for fish with modified Compensating Works operations.

Although many theoretical and approximate calculations were done to estimate operating standards, there are no alternatives at this time to address the issue of rapid flow changes and fish losses in the rapids.

Confidence, Significance, and Sensitivity: See discussion in preceding sections.

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Fact Sheet ID: 24

Performance Indicator (PI) Name/Short Description: Lake Sturgeon – spawning habitat area (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Geoffrey Steinhart

Modeled by: LimnoTech (Redder, DePinto)

PI Metric/Niche: The PI metric is the percent increase in lake sturgeon spawning habitat area. It is based on the relationship between SMR discharge and the percent increase in suitable velocities for lake sturgeon spawning habitat.

Lake sturgeon (*Acipenser fulvescens*) are an ancient fish species that were once abundant in the Great Lakes and the St. Marys River (SMR), but the population is suspected to be 1% of its original size (Harkness and Dymond 1961). The SMR has an estimated population size of around 500 individuals that appear genetically distinct from other lake sturgeon populations in the Great Lakes (Gerig et al. in press). Lake sturgeon spawn in areas with a moderate flow (Seyler 1997; Manny and Kennedy 2002; Friday 2006) and hard substrate (Auer 1996; Seyler 1997; Bruch and Binkowski 2002). The SMR has several sites that meet these requirements (Goodyear et al. 1982), but maintenance of these spawning habitats is linked to flow regime to maintain adequate water velocities.

Ecological Importance/Niche: While once an abundant resource for the Ojibwe living near the SMR (Cleland 1982) and abundant throughout the Great Lakes (Harkness and Dymond 1961), lake sturgeon are now listed as threatened in Michigan and Ontario, including the area of the SMR. In addition, lake sturgeon are listed as endangered in Illinois, Indiana and Ohio, as a species of concern in Wisconsin and Minnesota, and as a globally rare species by The Nature Conservancy (Goforth 2000). The precipitous decline in lake sturgeon populations has made them a priority in the Great Lakes Basin (Holey et al. 2000; Great Lakes Fishery Commission 2008). In the SMR, lake sturgeon restoration is a conservation target for the SMR Conservation Action Plan (Harris et al. 2009). Two potential barriers to lake sturgeon recovery are the lack of suitable spawning sites (Daugherty et al. 2008) and intermittent spawning (Becker 1983). Male lake sturgeon may spawn as frequently as every other year, but females typically spawn every 4-8 years (Becker 1983; Threader et al. 1998). Therefore, to ensure adequate spawning success and recruitment, sufficient habitat and flows must be maintained for lake sturgeon spawning.

Temporal Validity: Lake sturgeon begin to stage, in preparation for spawning, around water temperatures of 9°C (Friday 2006). Spawning occurs at water temperatures ranging from 12-18 °C (Becker 1983; Threader et al. 1998). In the SMR, these temperatures typically occur in June (unpublished data from 1982-2007; Roger Greil, Lake Superior State University Aquatic Research Laboratory). We defined the period from June 1 through June 30 as the period of concern for lake sturgeon spawning in the SMR.

Spatial Validity: Our lake sturgeon PI is tuned for the SMR with an emphasis placed on putative (or assumed) spawning areas. Lake sturgeon typically spawn in water depths less than 5 m (Becker 1983; Threader et al. 1998). They prefer hard substrates and a moderate current for spawning (Auer 1996; Seyler 1997; Bruch and Binkowski 2002; Manny and Kennedy 2002; Friday 2006). The area between Sugar Island and East Neebish Island is a historic spawning area for lake sturgeon (Goodyear et al. 1982). Recent work by Gerig et al. (in press) has shown lake sturgeon moving from Lake George to this area. It is unknown whether lake sturgeon spawn in the Lake George Channel; however, telemetry studies have found that they commonly frequent these areas (Gerhig et al. in press) and that suitable substrate and depths exist, so spawning may occur if velocities were appropriate. The SMR rapids are a historic breeding area for lake sturgeon (Goodyear et al. 1982), but the flow in the rapids was not considered since they are under separate hydrologic control (via the Compensating Works – a 16-gated control structure used to control Lake Superior water level) than the rest of the potential spawning areas (e.g., flow through the three hydroelectric plants).

Hydrology Link: Lake sturgeon spawn in areas with a distinct current (Threader et al. 1998). Typical velocities in lake sturgeon spawning areas range from 0.46-1.1 m/s (Seyler 1997; Manny and Kennedy 2002; Friday 2006), but can be as low as 0.2 m/s and as high as 1.4 m/s (LaHaye et al. 1992). Maintaining proper flows during the staging and spawning period has clear consequences for lake sturgeon reproductive and recruitment success (Brousseau 1987).

Algorithm: We estimated current velocity using transects to estimate cross-sectional area along putative lake sturgeon spawning areas. Sites included in the analysis were the area between Sugar Island and East Neebish Island (5 transects, 0.2km apart), the eastern end of the Lake George Channel, from the Garden River to Lake George (10 transects, 0.5km apart), and mid-way along the Lake George Channel (7 transects, 0.25km apart). The first three sites, all in or below the Lake George Channel, were assumed to receive 30% of the total SMR flow (ILSBC 2002). Average water velocity for each transect was estimated by dividing the total flow (m^3/s) by the cross-sectional area of the transect (m^2). All transects with a flow between 0.46-1.1 m/s were summed after weighting. Weighting was done by calculating the amount of suitable habitat in each site (i.e., the area with water depths less than 5 m), and dividing by the sum of all suitable habitat in all sites. The PI was created for total SMR flows ranging from 1600-2400 m^3/s (Figure 1).

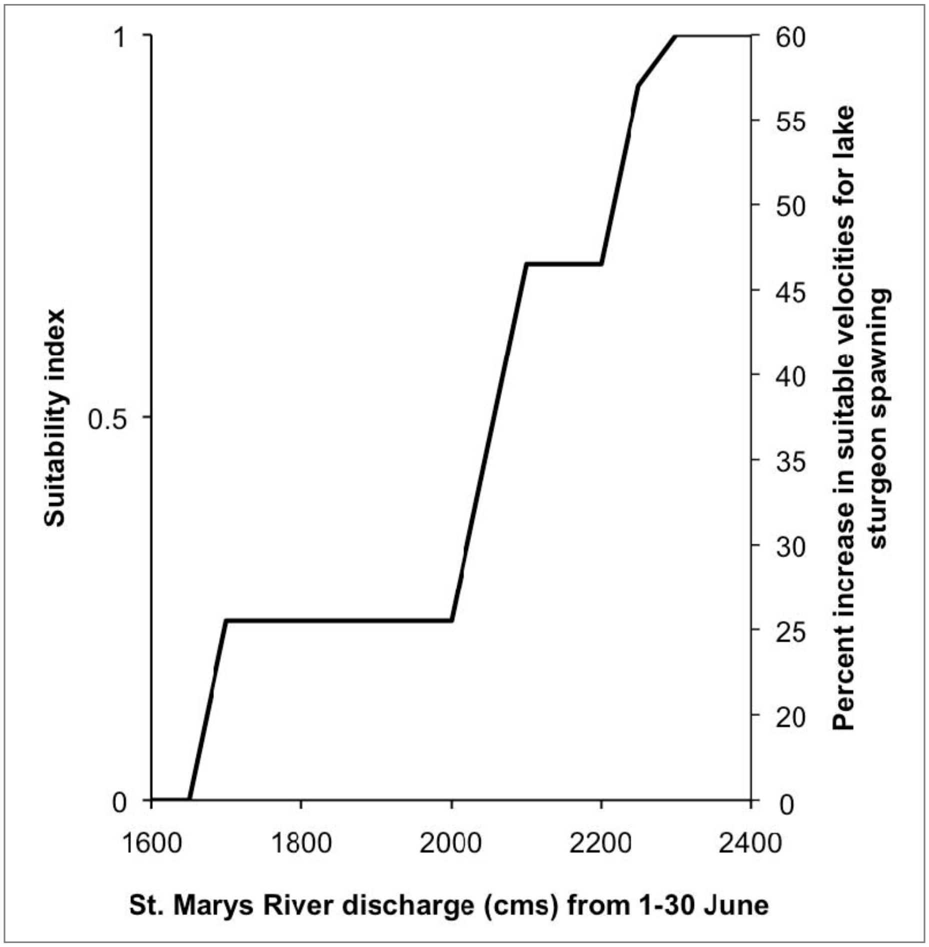

Figure 1. Relationship between St. Marys River discharge flow and suitable velocities for lake sturgeon spawning to determine a suitability index value.

Coping Zone Criteria: A threshold for this PI is at a flow of 1700 m^3/s, which increases the number of transects with suitable spawning velocities by 25% of the transects examined. The specific coping zone criterion developed for lake sturgeon spawning is as follows:

- **SMQ-01:**
  - Zone B: Mean flow rate during June maintained below 1,700 m^3/s for any 3 years in a 5-year window.
  - Zone C: Mean flow rate during June maintained below 1,700 m^3/s for 5 or more consecutive years.

This threshold was chosen because of the need to restore lake sturgeon populations and, thus, a need to increase reproductive and recruitment success. Peak suitability occurs at 2300 m^3/s. It should be noted that extreme velocities may interfere with lake sturgeon spawning, so discharge in excess of 2800 m^3/s may be detrimental for lake sturgeon spawning (data not shown).

Sturgeon can experience years that are poor for reproduction, and this long-lived fish has the ability to withstand poor years of recruitment. However, this species is not known to be spawning in the river at favorable levels currently, and it is considered a priority conservation species in many Great Lakes states and Canada. Thus, violation of the threshold should be minimized and occur only sporadically through time.

Calibration Data: Study results reporting lake sturgeon spawning locations, habitat requirements, and temperature were used to create the spatial and temporal validity of this PI.

Validation Data: Model validation data do not exist for this PI as many lake sturgeon spawning sites are known only from historical records or estimated from seasonal movements. Current velocity has not been recorded in the SMR while lake sturgeon were actively spawning. Future work should confirm these putative spawning sites and determine the flow in which specific aggregations of lake sturgeon spawn.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. Lake sturgeon may move to other spawning areas, or find different velocities within a site, if velocities are not appropriate.

2. Egg survival is related to juvenile and adult abundance.

3. The simplification of velocity estimates (i.e., average velocity across transects) adequately reflects the true velocities across heterogeneous transects, at least within the accepted range of velocities.

Although where lake sturgeon spawn in the SMR today or how many spawn in tributaries to the SMR is still unknown, this PI uses one known spawning area and other putative spawning locations. Furthermore, because these sites contain suitable depth and substrate, they should be representative of other spawning locations. Therefore, this is the best approach for calculating this PI.

Confidence, Significance, and Sensitivity: See discussion in preceding sections.

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Fact Sheet ID: 25

Performance Indicator (PI) Name/Short Description: Sediment Flushing Flows – suitability index (St. Marys River, Lake George)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Geoffrey Steinhart

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is based on the velocities needed to erode or transport 1 mm diameter sand particles. A suitability index is calculated from the relationship between St. Marys River (SMR) discharge and the percent of transects in the Lake George Channel with sand transport.

Stream flow regime influences sediment transport, which in turn affects channel morphology, habitat, and biota (Reiser et al. 1990; Poff et al. 1997; Kondolf and Williams 1999). When structures or diversions reduce flow, the amount of sediment transport may be reduced, leading to sediment aggradation (to fill and raise the level of the bed of a stream by deposition of sediment) (Reiser et al. 1989). To simulate a more natural environment, controlled releases may be used to flush sediment in a manner approaching conditions prior to implementation of control structures or diversions (Poff et al. 1997). These controlled releases are often called flushing flows. Proper implementation of flushing flows is necessary to maintain ecological integrity (see Table 2 in Poff et al. 1997) while allowing for control of flow for other purposes during the remainder of the year.

Ecological Importance/Niche: The accumulation of sediment in areas previously swept clear of fine sediment can make channels narrower and/or shallower, reduce formation of bars, and cover valuable spawning habitat (Reiser et al. 1989; Poff et al. 1997). These changes have obvious negative consequences for boating, vegetation, and fishes (respectively). Without flushing flows, eggs and larvae of many amphibians, fish, and invertebrates may suffer high mortality rates (see references in Wiley et al. 1995). A lack of flushing flows can be especially important in areas where sediment input is high, as is the case in many of the low-gradient, clay and sand-dominated tributaries that flow from the Eastern Upper Peninsula into the St. Marys River (SMR).

Temporal Validity: Natural flushing flows typically coincide with spring runoff. Furthermore, unnaturally changing flows during periods of ice cover may lead to early ice-out, which may influence the hatch timing of fishes (e.g., cisco - *Coregonus artedi*; Colby and Brooke 1970; Næsje et al. 1995). Therefore, flushing flows are recommended to occur around the time of spring runoff, the typical date of ice-out, and before most spring-spawning fishes reproduce. Because high flows may attract lake sturgeon (*Acipenser fulvescens*) to suitable spawning areas (Seyler 1997; see lake sturgeon PI), high flow before lake sturgeon spawn may serve two beneficial roles. We defined the time for flushing flows as between May 15 and June 15, which corresponds to the staging and start of the lake sturgeon spawning season (based on spawning temperature preferences and unpublished temperature data from 1982-2007; Roger Greil, Lake Superior State University Aquatic Research Laboratory).

Three continuous days of flushing flow velocities per year are recommended, based on recommendations for other ecosystems, like the Colorado River (U.S. Department of the Interior 2002)

Spatial Validity: With the modifications to the SMR to facilitate shipping, some flow has been diverted away from the Lake George Channel to the shipping canal and through Lake Nicolet (ILSBC 2002). For this reason, we defined the spatial extent of this PI to include the Lake George Channel because it is an area that historically experienced natural flushing flows, but due to channel and flow modifications, flow has been reduced. In addition, the Lake George Channel is likely spawning habitat for key fishes.

Hydrology Link: Sediment resuspension and transport is a function of current velocity (Hjulström 1935; Leopold 1994). With the creation of the shipping channel and various upstream engineering projects, discharge through the Lake George Channel is now reduced and more seasonally stable than in the past (ILSBC 2002).

Algorithm: For the Lake George Channel, our goal was the mobilization and transport of 1 mm diameter sand particles. We constructed depth profiles using 17 transects across the Lake George Channel (approximately 1km apart). We assumed the Lake George Channel received 30% of the total SMR flow (ILSBC 2002). Average water velocity for each transect was estimated by dividing the total flow (m^3/s) by the cross-sectional area of the transect (m^2). The velocities needed to erode or transport particles were determined from Hjulström's curve (Hjulström 1935). Each transect was then given a score based on the mean velocity: 1 if the velocity met or exceeded the minimum velocity needed to mobilize the target particle size (0.35 m/s) and 2 if the velocity was able to mobilize a particle 85% larger than the target size (0.5 m/s). The latter computation was performed because the velocity needed for erosion of sediment may be impeded at depth or over rough substrate (Reiser et al. 1990).

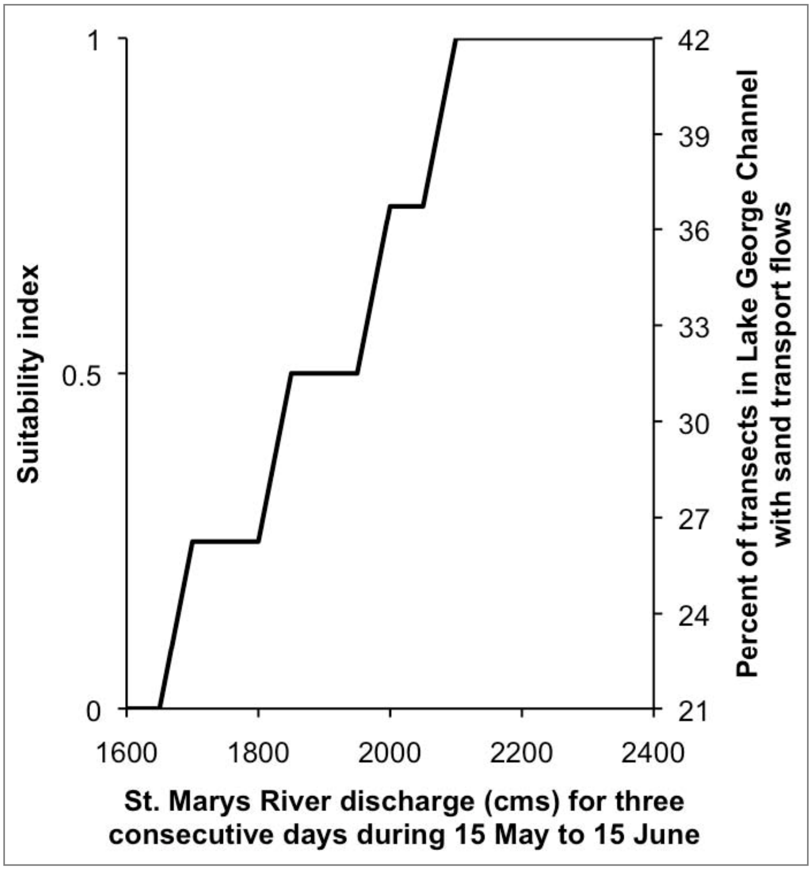

Figure 1. Relationship between St. Marys River discharge and the percent of transects in the Lake George Channel with sand transport flow to determine a suitability index.

Coping Zone Criteria: A threshold for this PI occurs at a flow of 2000 m^3/s, which results in roughly 40% of the transects in the Lake George Channel having suitable mean velocities to mobilize and transport sand. It should be noted that these flow rates also should produce adequate flows to transport smaller, clay particles within Lake George (data not shown). The final criteria is identified as "SMQ-02" in the IERM2 Coping Zone Calculator:

- **<u>SMQ-02</u>:**
    - <u>Zone B</u>: Mean flow rate during May-June maintained below 2,000 m^3/s for 7 or more consecutive years.
    - <u>Zone C</u>: Mean flow rate during May-June maintained below 2,000 m^3/s for any 5 years in a 7-year window.

Calibration Data: Well documented physical hydrology studies were used to determine the critical velocities needed for this PI. However, the depth and composition of the substrate were assumed to be homogenous and to represent the typical values used to generate Hjulström's curve.

Validation Data: The flushing flow PI should be field verified as the magnitude, timing, and frequency of flushing flows are unique for every system. In addition, data on substrate composition and depth would add additional detail.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. Local current velocities are influenced by depth, rugosity (measure of small-scale variations or amplitude in the height of a surface), and channel morphology data, which were not available for developing this PI.

2. The model focuses on the magnitude of flow required. Duration and frequency of flushing is based on ecosystem objectives for the Colorado River and may be different for the SMR.

3. Increased flows could mobilize potentially contaminated sediments from some locations in Lake George and the Lake George Channel.

Confidence, Significance, and Sensitivity: See discussion in preceding sections.

Documentation and References:

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Fact Sheet ID: 26

Performance Indicator (PI) Name/Short Description: Cisco (lake herring) **–** spawning habitat suitability index (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Geoffrey Steinhart

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: Cisco *(Coregonus artedi*; formerly called lake herring) have been a traditional component of the native fish community in the Great Lakes. Cisco are broadcast spawners that deposit their eggs in relatively shallow water. Because cisco, and other coregonids (e.g., lake whitefish), spawn in late fall and do not hatch until spring, they are sensitive to water elevation changes that occur during winter (Greeley and Bishop 1932). Furthermore, cisco eggs may hatch prematurely when exposed to light or physical disturbance, both of which may be associated with water elevation changes that disturb surface ice (Colby and Brooke 1970).

The PI metric is based on the relationship between Lake Huron water elevation and the percent change in cisco habitat area to determine a suitability index value for cisco spawning habitat in the St. Marys River (SMR).

Ecological Importance/Niche: Cisco have been a commercially important fish and are still a popular sport fish, but their abundance has declined across the Great Lakes (Fielder et al. 2002; Mohr and Evener 2005). They are listed as threatened in Michigan, and are a priority for restoration in Lake Huron (Lake Huron Technical Committee 2007) and across the Great Lakes Basin (Great Lakes Fishery Commission 2008). Cisco restoration is being pursued because the current prey fish community lacks diversity and is dominated by species that are rich in thiaminase (enzyme that breaks down thiamine) (Fitzsimons et al. 1998), the cause of thiamine deficiency complex (TDC; Ketola et al. 2000). TDC may be impeding efforts to restore lake trout in the Great Lakes. In addition, cisco grow to larger sizes than many current prey fishes, which makes them a more energetically advantageous prey for lake trout (Lake Huron Technical Committee 2007). Therefore, maintaining or increasing the current cisco population not only may help this threatened species, but also may help restore lake trout. The SMR is one of the few areas where cisco have persisted (Fielder 1998, 2002), making it a critical area to preserve and for the collection of gametes (a reproductive cell - male (sperm) or female (egg)) for reintroduction elsewhere in the Great Lakes. Furthermore, other fall spawning fishes (e.g., lake whitefish, *Coregonus clupeaformis*) may be similarly affected by declines in water elevation.

Temporal Validity: Cisco typically spawn in November in the SMR and peak larval abundance usually occurs in May, coinciding with typical ice-out (Colby and Brooke 1970; Liston and McNabb 1986; Fielder 1998, 2000). We defined November 1 through May 15 as the period of concern for water elevation change in the SMR.

Spatial Validity: Our cisco PI is tuned for the SMR with an emphasis placed on known spawning areas. Fielder (1998, 2000) documented the locations of gravid (advanced stage of pregnancy), ripe (ready to spawn), partially spent (partially spawned), and spent (spawned out) cisco in the SMR. With this information, Fielder hypothesized that cisco spawned in areas of the Lake George Channel, Lake George, Baie de Wasai, and downstream from the Rock Cut. However, using transport models, eggs deposited in the Rock Cut were suspected to be carried downstream by currents (Fielder 1998) and Lake George may only be a staging ground for cisco. Therefore, we limited our analyses to the Lake George Channel and Baie de Wasai, the latter being the focal site of recent efforts to collect spawning cisco (Chuck Madenjian, USGS, Ann Arbor, personal communication) and repeatedly cited as an important spawning area (Behmer et al. 1979; Gleason et al. 1979; Jude et al. 1988).

Hydrology Link: Cisco eggs may be vulnerable to desiccation if water elevations drop. Furthermore, eggs may be vulnerable to dislodgement, destruction, or early hatching if ice-out is accelerated by dropping water elevations (Colby and Brooke 1970; Fielder 1998, 2000). Because these areas are driven more by Lake Huron water elevations than discharge through the Compensation Works (16-gated control structure used to control Lake Superior water level) and hydroelectric facilities (ILSBC 2002; Bain 2007), changes in Lake Huron water elevation could lead to undesirable effects on cisco egg survival.

Algorithm: Cisco have been documented to spawn in water as shallow as 1 m (Cahn 1927), but more frequently between 3-6 m in depth (Smith 1956; Smith 1985; Savino et al. 1994). We assumed that eggs may be deposited in water depths ranging from 1-6 m. We constructed depth profiles using transects at 10m intervals across the known spawning area in Baie de Wasai (six transects approximately 0.5km apart) and a putative (or assumed) spawning area in the Lake George Channel (seven transects approximately 0.25km apart). Our base water elevation was 176.4 m in Lake Huron. We then used change in Lake Huron water elevation to predict new depth profiles across these transects. Any locations between 1-6 m that were later found to be less than 1m deep (following a drop in water elevation) were assumed to be no longer suitable for incubation because there are no records of cisco spawning shallower than 1 m. We did not model an increase in water elevation because it was assumed that any temporary increase in depth would not affect incubation (cisco eggs have been found in 18 m deep water in Lake Superior; Dryer and Beil 1964). Under each water elevation change examined (-0.25, -0.5, -0.75, -1, and 1.25 m), the number of suitable 10-meter sections were summed for each transect and, subsequently, scaled to create a suitability index.

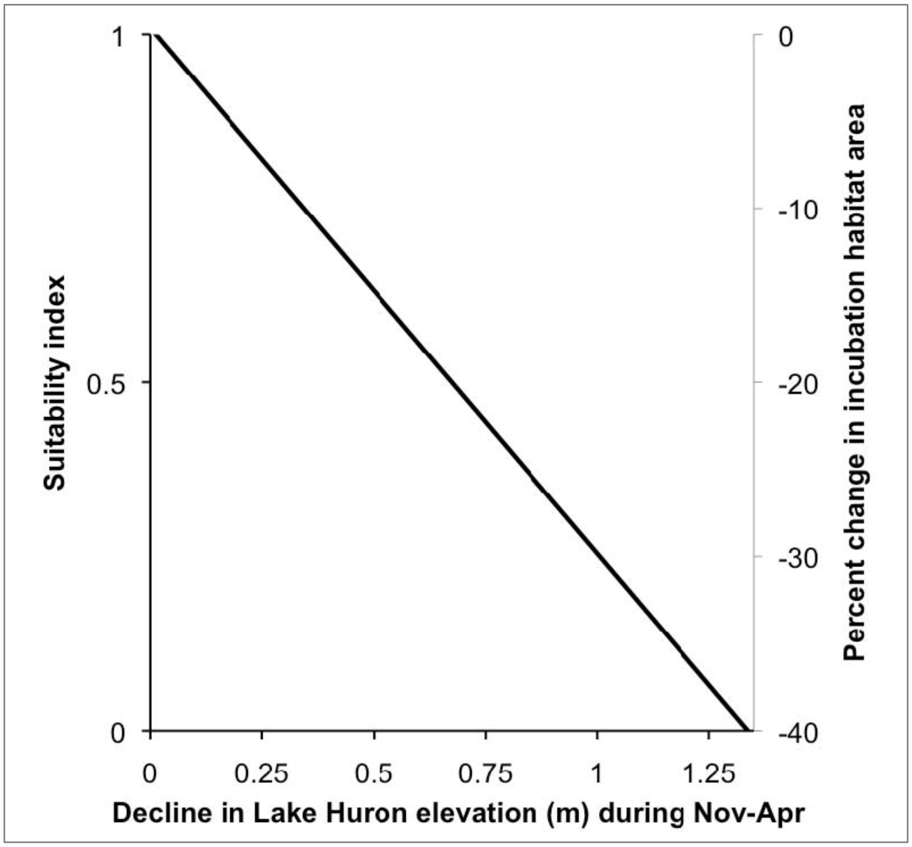

Figure 1. Relationship between Lake Huron water elevation and the percent change in cisco habitat area to determine a suitability index value.

Coping Zone Criteria: A threshold for this PI is zero on the suitability index: a drop of 1.25 m in Lake Huron would result in approximately 40% of the cisco spawning habitat decreasing in depth to less than 1 meter. Because cisco are listed as threatened, and their annual recruitment is notoriously variable (S. Greenwood, Ontario Ministry of Natural Resources, personal communication), any loss of cisco incubation habitat could be seen as detrimental. The "Zone B" and "Zone C" rules for this criterion are as follows:

- **SMH-01 Criterion**:
    - Zone B: The water level decrease between November and the following April exceeds 1.00 meters for any given year.
    - Zone C: The water level decrease between November and the following April exceeds 1.25 meters for any given year.

Calibration Data: Study results reporting cisco spawning locations and timing were used to create the spatial and temporal validity of this PI.

Validation Data: Model validation data do not exist for this PI. In fact, people are still investigating the reproductive behavior and success of cisco in the SMR. Better validation data could be obtained with a more focused and intensive effort towards determining the exact depths at which cisco spawn in the SMR, the percent of eggs deposited at different depths and the amount of egg movement after deposition.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. Eggs, once deposited, are not carried away from the spawning site by currents.
2. Egg survival is related to juvenile and adult abundance.
3. Baie de Wasai and the Lake George Channel are suitable representative areas for other putative spawning areas in the SMR.

Modeling results suggest eggs are not flushed from Baie de Wasai (Fielder 1998, 2000), but no such modeling has been completed for the Lake George Channel. Furthermore, the link between egg survival and adult abundance has rarely been demonstrated conclusively, possibly due to density-dependent effects. Much speculation exists about the extent of cisco spawning areas in the SMR. Baie de Wasai is a known spawning area, but other areas may receive some eggs. Finally, cisco are not the only fall spawning fishes, and we believe this algorithm is the best approach to predicting the potential loss of incubation habitat for fall spawning fishes in the SMR.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

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Fact Sheet ID: 27

Performance Indicator (PI) Name/Short Description: Black Tern **–** nesting success suitability index (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Mark Bain

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is based on Lake Huron water levels, which is used to determine a suitability index for black tern nesting success.

Black terns (*Chlidonias niger*) are one of most prominent of the migratory birds that nest in marshes and emergent wetlands along the coast of the Great Lakes (Currier 2000). They build nests from dried reeds, stalks, and grasses on mounds of vegetation often dominated cattails (*Typha* sp.) or bulrushes (*Scirpus* sp.; Cuthbert 1954, Dunn 1979). Nesting sites are usually at the interface of emergent wetlands and open water where both vegetation and open habitats is about equally common (Hickey and Malecki 1997). Nesting sites are selected by black terns within a very limited range of water depths (Mazzocchi et al. 1997; Alsop 2001; Maxson et al. 2007). Nests are vulnerable to flooding and destruction by wave action, conditions that are often associated with increases in water level, or water level variability during the breeding and nesting seasons (Shuford 1999; Naugle 2004; Mortsch et al. 2006). When evaluating the implications of water levels on the black tern, the bird's nesting success and survival needs require direct consideration.

Ecological Importance/Niche: Many species of migratory birds nest in emergent vegetation of marshes along the Great Lakes shorelines: Pied-billed Grebe (*Podilymbus podiceps*), American Bittern (*Botaurus lentiginosus*), Least Bittern (*Ixobrychus exilis*), Yellow Rail (*Coturnicops noveboracensis*), King Rail (*Rallus elegans*), Virginia Rail (*Rallus limicola*), Sora (*Porzana carolina*), Common Moorhen (*Gallinula chloropus*), American Coot (*Fulica americana*), Forster's Tern (*Sterna forsteri*), Black Tern (*Chlidonias niger*), Marsh Wren (*Cistothorus palustris*), Mallard (*Anas platrhynchos*), and Swamp Sparrow (*Melospiza georgiana*; Peck and James 1983, Timmermans 2001, Poole and Gill 2002). We will use the black tern as our representative species for evaluating the impact of water level changes on this important ecological guild (groups of species that exploit the same resources in the same way) of birds.

The black tern is designated as a Vulnerable Species by the Ontario Ministry of Natural Resources and endangered or a species special concern in many Great Lakes states, including Wisconsin, Michigan, and Ohio. It has been a candidate for federal listing under the US Endangered Species Act. In the upper Great Lakes region, black terns occur mainly along the shorelines of Lakes Michigan, Huron, and eastern Lake Superior (Brewer et al. 1991; Chu 1994; Currier 2000). Black tern populations have been decreasing since the 1960s (Peterjohn and Sauer 1997). Specific hydrologic conditions are needed for black tern habitats, especially stable water levels during the breeding season (Mortsch et al. 2006).

Temporal Validity: Black terns nest in the upper Great Lakes region from mid-May through early to mid-August (Chu 1994; Currier 2000). However, in northern Michigan, nesting has been observed to begin in late May and early June and extend to late July (Cuthbert 1954; Bergman et al. 1970). Eggs are incubated for 17 to 22 days, and young fledge (bird is old enough to fly away from the nest) 19 to 25 days after hatching. We define from June 1 through August 15 as the period of concern for water level change for the St. Marys River.

Spatial Validity: Our black tern PI is timed for the St. Marys River area but can be applied more broadly to lakes Michigan and Huron with an expansion of the temporal validity period.

Hydrology Link: Nests are vulnerable to flooding and destruction by wave action, conditions that could be exacerbated by increases in water level or its variability during the breeding and nesting seasons (Shuford 1999; Naugle 2004; Mortsch et al. 2006).

Algorithm: Black terns have been documented to build nests in water ranging in depth from 0.2 to 1.2 m (Dunn 1979; Currier 2000; Alsop 2001; Maxson et al. 2007). Average water depth at nest sites is about 0.5 to 0.6 m deep (Mazzocchi et al. 1997; Zimmerman 2002). Stable water levels during nesting are critical for nesting success. Using an average nest water depth of 0.6 m and the maximum range of 1.2 m, we estimate that a rise in water level of 0.6 m would impact nesting success because of flooding resulting in water depths higher than normally used. Thus, an increase in water level during the nesting period (June 1 -August 15) of 0.6 m would be unsuitable for nesting and no change in water level would be optimal. The PI plot below shows this relationship and links Lake Huron water levels and black tern nesting success.

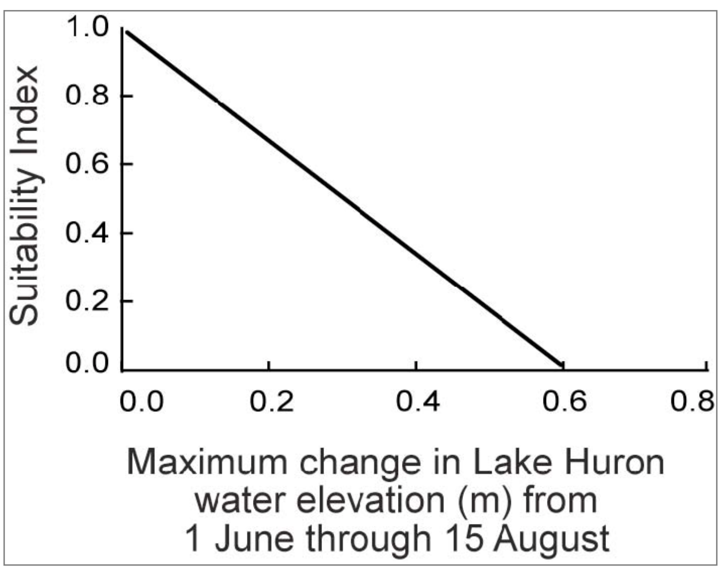

Figure 1. Suitability index for black tern nesting success based on Lake Huron water level.

Coping Zone Criteria: A threshold for this PI is 0.5 on the suitability scale, which corresponds to a maximum change in Lake Huron water level of 0.3 m. This threshold was selected to minimize any loss of nesting habitat. The black tern is a conservation priority in the multiple states and in Ontario, and its represents other marsh nesting bird that are also conservation priorities. The “Zone B” and “Zone C” rules for this criterion are defined as follows:

- **<u>SMH-02 Criterion</u>**:
    - <u>Zone B</u>: Maximum change in Lake Huron water level during the June-August period is greater than 0.2 meters for any given year.
    - <u>Zone C</u>: Maximum change in Lake Huron water level during the June-August period is greater than 0.3 meters for any given year.

Calibration Data: Study results reporting microhabitat conditions of black tern nesting sites were used to parameterize the PI. References cited provide the source of water depths used for nest site selection.

Validation Data: The model provided is based on multiple published studies; however, a test of the relationship developed has not been tested with measured nesting success.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. Nesting success has a major influence on species abundances.
2. Nesting success declines with water level changes beyond the average conditions and maximum range used by the species.
3. Black terns select nesting sites based on the water depth ranges and emergent wetland conditions early in the nesting period.

We consider this PI very sound and reliable because it was developed from multiple publishes studies with similar water level values. Also, the threat of nest flooding and wave impacts brought on by water level changes has been repeated in multiple accounts of causes for the species decline.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

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Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, North Dakota.

Fact Sheet ID: 28

Performance Indicator (PI) Name/Short Description: Submerged Aquatic Vegetation (SAV) – habitat suitability index (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Kristin Arend and Pariwate Varnakovida

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is based on the relationship between Lake Huron water levels and the percent change in area suitable for SAV growth to determine a suitability index for SAV habitat.

SAV beds primarily occur on clay substrate throughout the St. Marys River (SMR) system at water depths of 2.0 to 7.0 m (Duffy et al. 1987). Clay substrate dominates within these depth ranges throughout the SMR (Liston et al. 1980; Liston et al. 1986), providing a substantial amount of suitable habitat for SAV communities (Liston et al. 1986). The spatial distribution, species composition, and biomass of SAV beds in the SMR have been relatively stable since 1935 (Liston et al. 1986; Williams and Lyons 1991). Total wetland area in the SMR has changed only 1.6% (Williams and Lyons 1991), with interannual fluctuations driven by variation in water elevation across a range of 1.04 m (Williams and Lyon 1991; Bray 1996). Intra- and interannual fluctuations in water elevation are thought to help maintain these nearshore, wetland habitats in an early successional state (Williams and Lyons 1991; Bray 1996).

Ecological Importance/Niche: The structural complexity and reduced wave action provided by SAV beds are important functions of nearshore ecosystems (Strayer and Findlay 2010). SAV beds reduce erosion and turbidity by stabilizing clay sediment (Liston et al. 1986). SAV beds are highly productive areas that support diverse assemblages of macroinvertebrates and fishes. SAV contributes to the majority of primary productivity in the SMR (Liston et al. 1980; Williams and Lyons 1991). They are an important source of food for decomposers (Liston et al. 1980) and of food and cover for a diverse and abundant macroinvertebrate community (Liston et al. 1980 [and references therein]; Duffy et al. 1987; Edsall and Charlton 1997). Macroinvertebrates are more than five times as abundant outside of the navigation channel compared to within the navigation channel (Liston et al. 1980). SAV beds in the SMR also provide spawning and nursery habitat to a high proportion of Great Lakes fish species (Liston et al. 1980; Lane et al. 1996a,c) and resident habitat to warmwater fishes (e.g., Centrarchids; Lane et al. 1996b). SAV support the larger SMR fish community by serving as an important link in lower food web material exchange (Liston et al. 1980).

Temporal Validity: SAV beds begin to develop in early spring (at 5°to 6° C), with peak biomass in late August or early September (Liston et al. 1986). We define from May 1 through September 31 as the period of concern regarding water elevation change effects on SAV in the SMR.

Spatial Validity: Our SAV PI is specific to the cooler thermal regime and higher water clarity of the SMR and Upper Great Lakes. The PI includes the lower SMR starting below the main rapids at Sault Ste. Marie, Ontario, and extending through the north channel ending at the head of Lake George,the main channel through Lake Nicolet and its east and west branches ending at the head of Lake Munuscong. This area includes much of the area included in Liston et al (1986) and Williams and Lyon (1991) and some of the area included in Bray (1996). Lake George was not included in our PI due to data limitations (see below) and because the primary sediment in Lake George is sand, which does not support SAV (S. Greenwood, Ontario Ministry of Natural Resources, personal communication; K. Arend, personal observation). This PI directly applies to lower reaches of the SMR included in our analysis. The indicator also can be applied more broadly to the upper SMR, Lakes Superior and Huron, and northern Lake Michigan by modifying the temporal period (to account for effect of different thermal regimes on length of growing season) and depth range (to account for SAV occurrence at greater or shallower depths under conditions of greater or lower light penetration).

Hydrology Link: SAV bed area is determined primarily by water depth (Williams and Lyon 1991), but also substrate, slope, water clarity, and water velocity (Liston et al. 1980; Liston et al. 1986; Duffy et al. 1987). Changes to water elevation will impact the availability of suitable habitat along and extending into the SMR channel from the shoreline through direct or indirect effects on these additional factors.

Algorithm: Deep SAV beds have been documented to extend away from the river shoreline from a 2.0 m minimum depth to a 7.0 m maximum depth in the lower SMR (Liston et al. 1986). SAV primarily occupies clay substrate, which is the dominant substrate type in the SMR. Bray (1996) similarly determined areal of extent of lower SMR wetlands by defining SAV as occupying depth contours < 6.0 m. Contour and depth surfaces of the SMR in the areas described in the “Spatial Validity” section above were created using Geographic Information Systems (GIS). Depth data and the SMR boundary were provided by Fisheries and Oceans Canada, Sea Lamprey Control Centre and included over 21,000 sampling points collected during 1993 to 2009 (Figure 1). The SMR boundary was manipulated to fit our study area. The shipping channel was digitized from the National Oceanic and Atmospheric Administration’s (NOAA) coast survey map. The Michigan boundary was downloaded from the Michigan Geographic Data Library. All data were projected to WGS84_1984_UTM_Zone_16N.

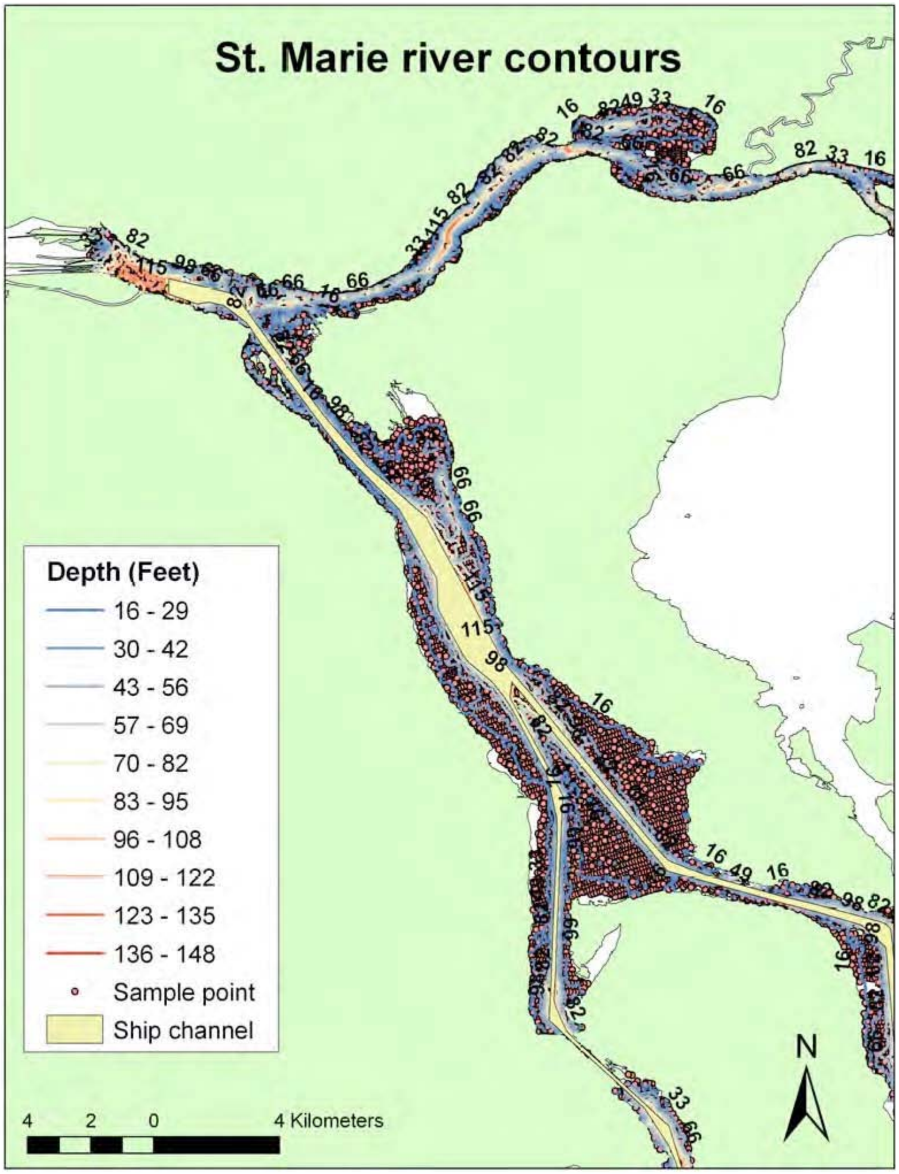

Figure 1. Spatial extent of the St. Marys River analyzed; dots represent depth sampling points, colored lines represent depth intervals (ft), and the shipping channel is indicated in yellow.

Raster analysis and the interpolation scheme available with the spatial analysis extension in ArcGIS were used to interpolate the sampling points and create depth maps corresponding to 0.5 m Lake Huron water elevation intervals ranging from 174.5 to 177.5 m. This elevation range represents an approximate 2.0 m decrease and 1.0 m increase in water elevation compared to the mean water elevation during May through September (i.e., the SAV growing season), 1921-2009 (United States Army Corps of Engineers 2010). The Inverse Distance Weighted method with a power of 2 and a search radius of 12 points was employed with a pixel size equal to 10 m × 10 m. Raster files were then converted to image format for ERDAS IMAGINE (collection of software tools designed specifically to process geospatial satellite imagery) inputs using a pixel depth of 32 bits. The Model Maker tool was used to query 2.0 to 7.0 m depth pixels (except for these depths present in the shipping channel) and overlaid with the study site (Figure 2). The total area of the 2.0 to 7.0 m depth range at each 0.5 m water elevation interval was calculated from the number of 2.0 to 7.0 m depth pixels (Figure 3).

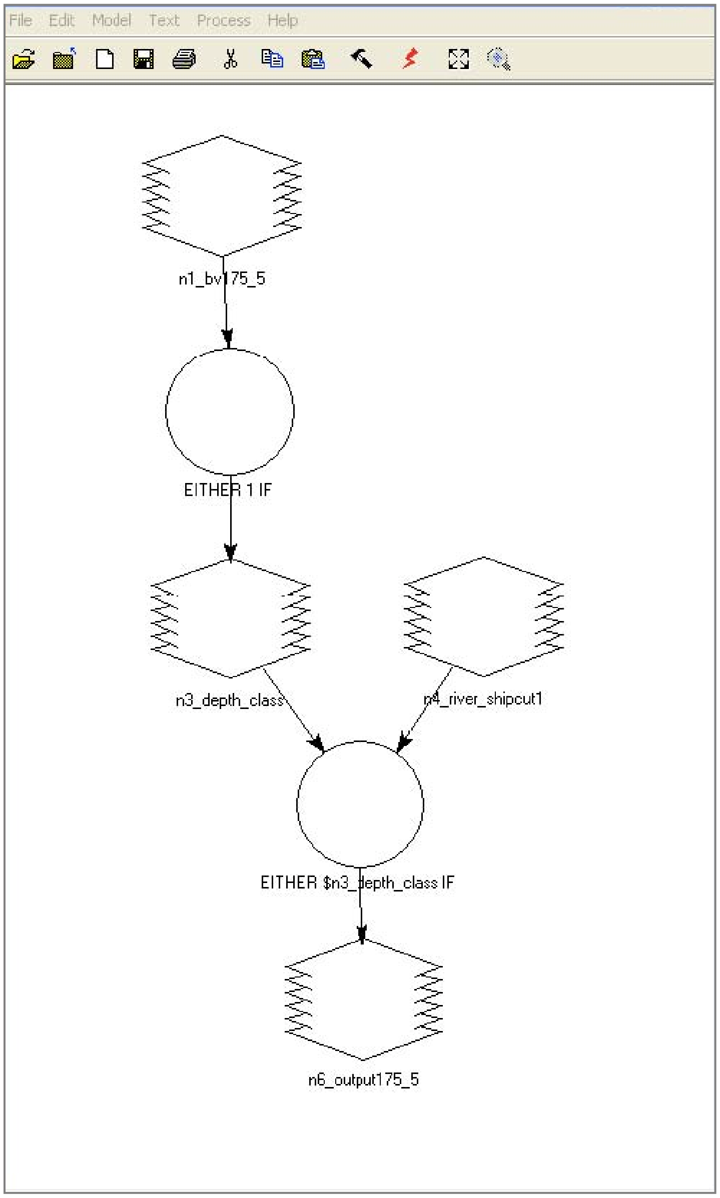

Figure 2. Process structure in the ERDAS Model Maker tool.

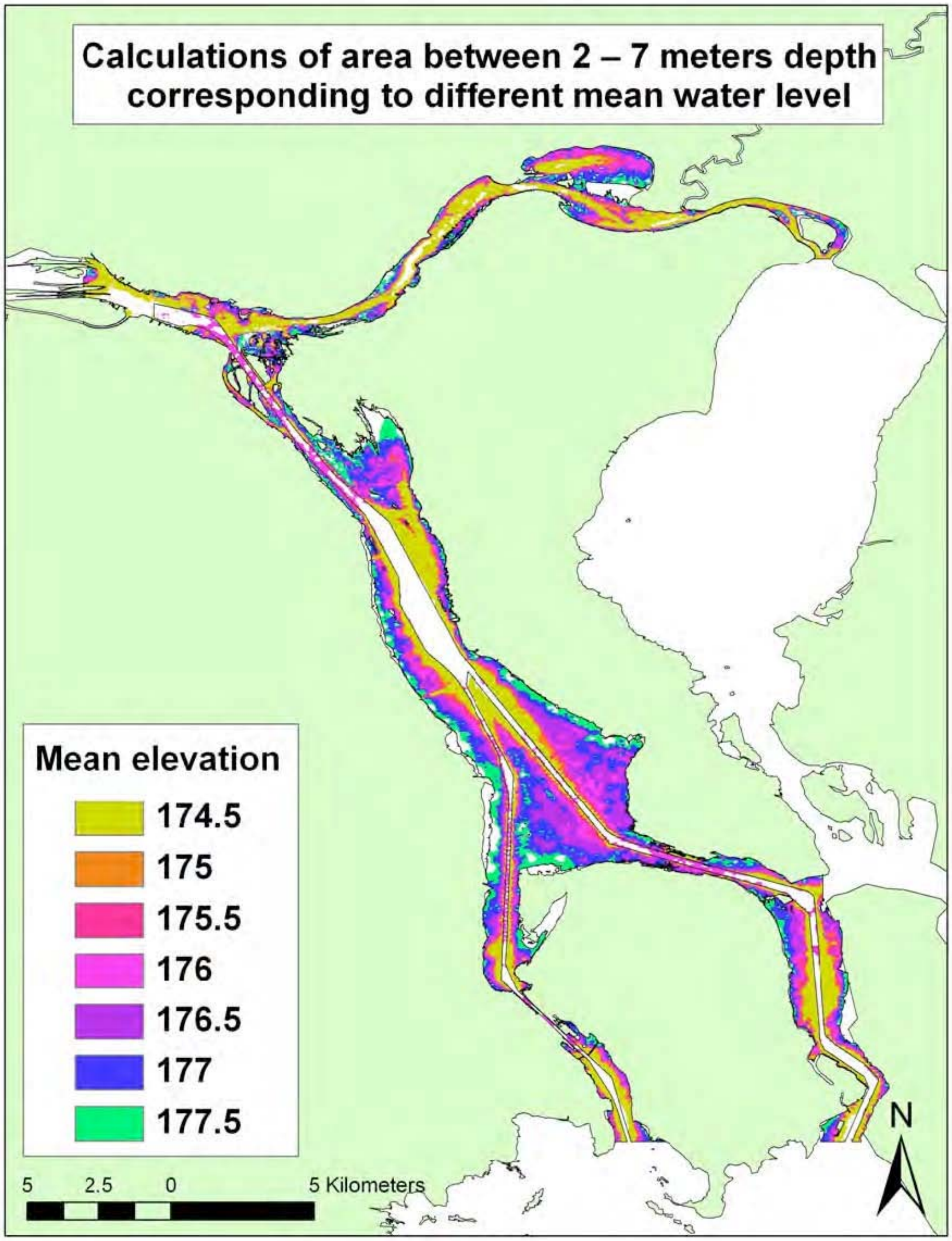

Figure 3. Area of the 2 to 7 meter depth range for each 0.5 m water elevation interval.

Percent change in connected backwater habitat area for each 0.5 m Lake Huron water elevation interval was calculated as follows:

<u>(area at 0.5 m inteval – area at 176.5 m)</u> / <u>(area at 176.5 m)</u>

Suitability scores range from 1 to 0, respectively, for maximum 35% gain in SAV suitable area at 177.5 m and a 55% percent loss in SAV suitable area at 174.5 m.

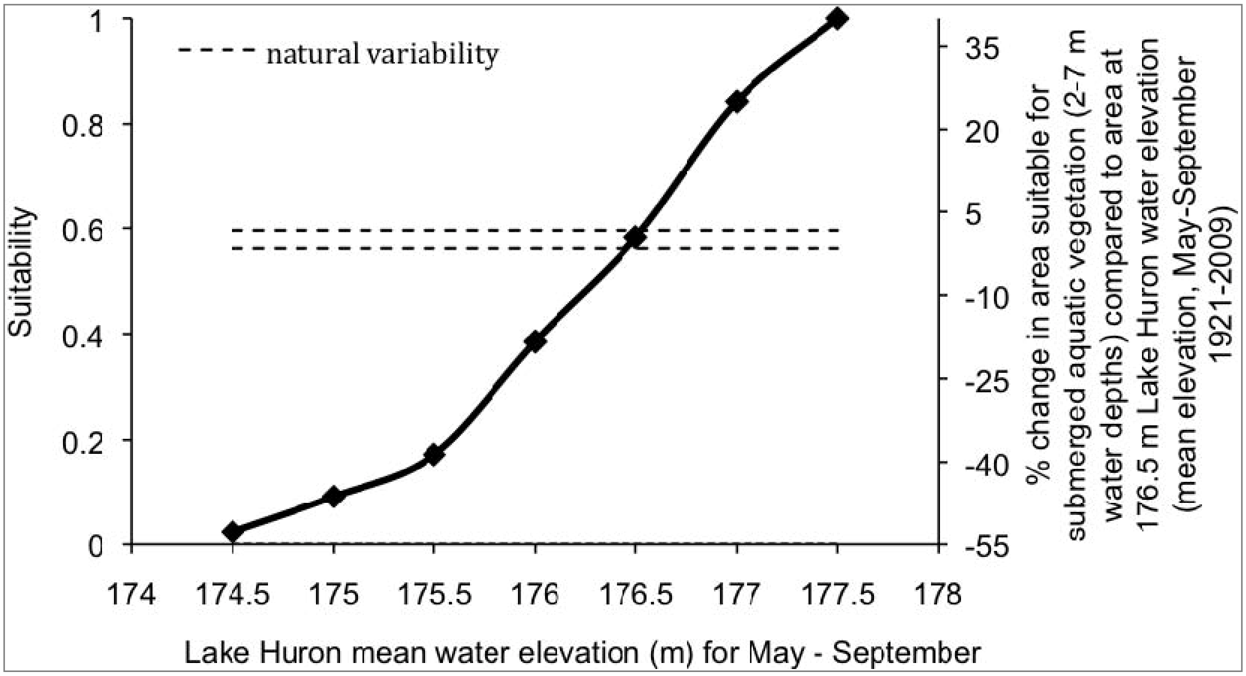

Figure 4. Relationship between Lake Huron water levels and the percent change in area suitable for SAV growth to determine a suitability index for SAV habitat.

Data for SAV "only" wetland areas were not available to our knowledge; however, we assume that SAV respond less strongly to water elevation change than emergent vegetation based on data presented in Williams and Lyon (1991). Natural variability in percent change in SAV suitable area was estimated as $\pm$1.6%, based on the average percent change in wetland (SAV and emergent vegetation) area in Lake Nicolet between 1939 and 1985 (Williams and Lyon 1991).

Coping Zone Criteria: A threshold for maximum percent loss of SAV was identified as 55%, which corresponds to a suitability index of zero and equals the percent difference between the minimum and maximum wetland (SAV and emergent vegetation) area estimated from air photos for the Canadian shoreline from Gros Cap to Hay Bay and including St. Joseph Island in 1935, 1949, 1964, 1973, and 1981 (Bray 1996). The "Zone B" and "Zone C" rules for this criterion were established as follows, based on the relationship shown in Figure 1:

- **SMH-03 Criterion**:
    - Zone B: Mean spring/summer/fall (May-Sep) water level in Lake Huron is less than 174.5 meters for any given year.
    - Zone C: Mean spring/summer/fall (May-Sep) water level in Lake Huron is less than 174.5 meters for 3 or more consecutive years.

Calibration Data: Study results reporting depth ranges and locations for SAV beds in the SMR were used to parameterize the PI. References provided report the depths at which SAV occur extending into the channel from the shoreline and the areal extent of SAV along the river from the late-1930s through the early-1980s.

Validation Data: The model provided is based on published studies; however, a test of the relationship developed has not been conducted with measured SAV area.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. We have modeled response of deep SAV, which occurs, on average, within a depth range of 2.0 to 7.0 m. Effects of water elevation change on shallow SAV habitat present in backwaters are reflected in the Backwater Connectivity PI.
2. Water elevation (i.e., depth) is more of a limiting factor determining SAV distribution than water velocity.
3. Changes in SAV area over time primarily have been in response to changes in water elevation as opposed to human activities (Bray 1996).
4. SAV area declines under lower water elevations and increases under higher water elevations.

We consider this PI to be sound and reliable because it was developed from multiple published studies with similar depth range values.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

Documentation and References:

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Fact Sheet ID: 29

Performance Indicator (PI) Name/Short Description: Emergent Wetlands – total surface area (Lake Nicolet, St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Mark Bain

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric estimates the emergent wetland area (hectares) in Lake Nicolet as a function of Lake Huron water levels.

Along the channels and lakes in the St. Marys River system there are extensive emergent wetlands. These are dominated by three species: hardstem bulrush (*Scirpus acutus*), bur reed (*Sparganium eurycarpum*), and spike rush (*Eleocharis smallii*). These plant taxa and emergent wetlands are sensitive to water level change. Over nearly a half century the area of these wetlands have been photographed and mapped in Lake Nicolet, which is a large water body in the St. Marys River. Changes in Lake Huron water elevation have had a clear effect on the extent of emergent wetlands; a formulae was developed to represent this relationship by Williams and Lyon (1991). This relationship was converted to a suitability index chart showing the effect that Lake Huron water surface elevation has on the area of emergent wetlands in Lake Nicolet. This PI captures a hydrologic determinant of emergent wetland area in the St. Marys River below the point where river flow influences water level. Almost all of the extensive emergent wetlands are under the influence of Lake Huron water level, and these wetlands are especially important to river ecology and biological support.

Ecological Importance/Niche: Emergent wetlands in the Great Lakes are important habitats, supporting birds, mammals, fish, invertebrates, and overall biological productivity. For example, three migratory bird species often listed as conservation priorities nest in emergent wetlands: least bittern (*Ixobrychus exilis*), king rail (*Rallus elegans*), and black tern (*Chlidonias niger*; Evers 1997; Ciborowski et al. 2008). Also, emergent wetlands are important to migratory waterfowl such as the mallard (*Anas platyrhynchos*), the blue-winged teal (*Anas discors*), and the American black duck *(Anas rubripes*). The muskrat (*Ondatra zibethicus*) is a keystone (species that plays a fundamental role in maintaining the plants and animals in an ecosystem) mammal in Great Lakes wetlands because they feed on large plants in wetlands, clear channels, create open water areas and promote the patchiness of wetland habitats (Errington 1961). About a quarter of all Great Lakes fish species are strongly associated with emergent wetlands (Edsall and Charlton 1997) and many of these species use emergent wetlands for spawning and rearing habitats.

In the St. Marys River emergent wetlands serve multiple critical roles. They serve as key spawning, nursery, and feeding areas for 44 fish species of the river. Because the river has a very high water turnover rate, pelagic productivity by phytoplankton and zooplankton is minimal (Duffy 1987). The complex structured habitat formed by emergent wetlands provides more than 90% of the rivers overall dry weight biomass production (Kauss 1991). Also, benthic invertebrate productivity on a per unit area basis exceeds all other habitats including the rapids

(Kauss 1991). Overall, emergent wetlands are key habitats in the Great Lakes and they are especially valuable in the St. Marys River because of the rapid flow of water through this system (Liston and McNabb 1986; Duffy et al. 1987).

Temporal Validity: The PI is based on nearly a half century of carefully assembled data. Therefore, the PI can be considered sound for the range of water levels shown and be considered indicative of predicted effects of water level management.

Spatial Validity: The PI was developed on Lake Nicolet which is a major waterbody in the St. Marys River system. The spatial application of the PI is appropriate for all areas of the river system under the influence of Lake Huron water level. Areas downstream of the Little Rapids and the Lake George Channel below Soo Harbor are not significantly influenced by variations in river volume (ILSBC 2002; Bain 2007). There are very limited wetlands in the Soo Harbor reach because it is largely composed or urban and bulkheaded shoreline (Bain 2007). Thus, the PI covers most of the river system and almost all areas where wetlands are abundant. Because of Lake Nicolet's size and central location in the river system, this waterbody can be considered representative of the St. Marys River wetlands.

Hydrology Link: There is a strong relationship between water level and the area of emergent wetlands for the St. Marys River (Kauss 1991), the Great Lakes (Kelsall and Leopold 2002; Ciborowski et al. 2008; Mortsch et al. 2006, 2008), and waterways in general (Harris and Marshall 1963; Dabbs 1971; Spence 1982). Therefore, representing this relationship in a PI provides a close link between water management and the area of emergent wetlands.

Algorithm: The US Army Corps of Engineers (Williams and Lyon 1991) assembled summer and fall aerial photographs of Lake Nicolet for seven years, 1939 to 1985. Across these years, water levels varied more than 1 m. Lake Nicolet water level is primarily determined by the elevation of Lake Huron because it is downstream of the control point where river volume influences water levels (Little Rapids, ILSBC 2002; Bain 2007). Emergent wetland boundaries were defined and entered into a Geographic Information System (GIS). There was a clear negative relationship between average annual water level and the area of emergent wetlands (linear regression, $P < 0.05$). For Lake Nicolet, there was a 32% change in the area of emergent wetlands through the 46 year study period. This relationship is shown in Figure 1 below with a suitability index axis for inclusion in the overall water management model.

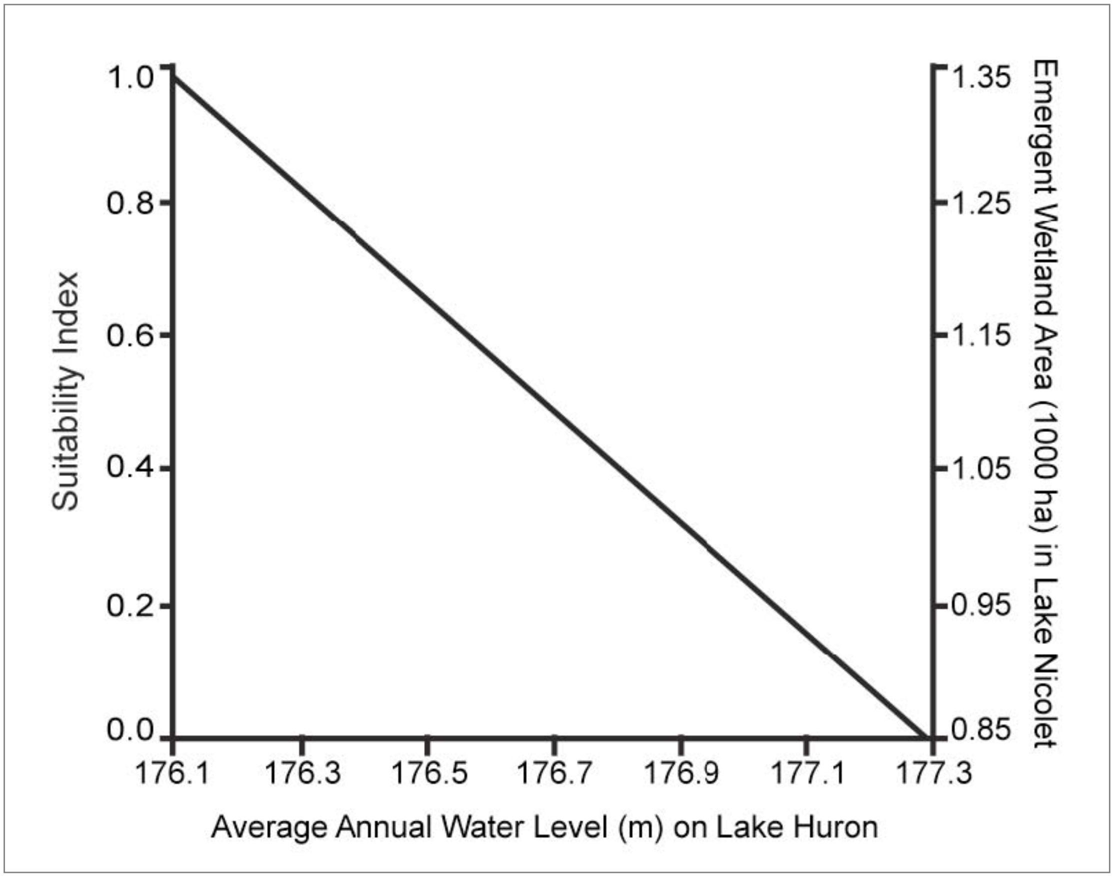

Figure 1. Relationship between Lake Huron water levels and emergent wetland area in Lake Nicolet to determine a suitability index for habitat.

Coping Zone Criteria: No specific coping zone criteria were developed for the Lake Nicolet emergent wetland PI because additional research is needed to confirm the validity of the relationship described in Figure 1 and appropriate thresholds for this PI.

Calibration Data: Data used to form this relationship were assembled, analyzed, and reported by Williams and Lyon (1991). The quality is high and exacting methods were used to define the area of emergent wetlands over years of different average water levels. The years were widely spaced in time yielding independent measure of both water level and emergent vegetation area.

Validation Data: The relationship used here was statistically tested and significant. The years used were independent in time and formed a significant linear regression. Therefore, the data used constitute a very reliable basis for the PI and this indicator was tested and found to be justified by the analyses.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. The years investigated represent future responses to water level change.
2. The study site is typical and reflective of the river system downstream of the water level control points: Little Rapids and the Lake George Channel.

3. Water level is a key factor in shaping the extent of emergent wetlands.

The PI shows a negative relationship between water level and area of emergent wetlands. Other studies have also reported that annual low water levels in the Great Lakes results in increased emergent wetland area (e.g., Ciborowski et al. 2008; Mortsch et al. 2006, 2008). Thus, the PI relationship is consistent with other sites in the Great Lakes and reflects relationships reported from other sites.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

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Fact Sheet ID: 30

Performance Indicator (PI) Name/Short Description: Backwater Habitat Connectivity – suitability index (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Kristin Arend and Pariwate Varnakovida

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is a suitability index for backwater connectivity based on a relationship established between Lake Huron water levels and the area of backwater habitat. Backwater habitats, such as embayments and lagoons, provide slow-moving, warm water habitat that is protected from the higher velocity, colder waters of the main St. Marys River (SMR).

Ecological Importance/Niche: Backwater habitats include barrier protected and connecting channel wetlands and embayments. Along with other nearshore wetlands, backwater habitats are of high quality relative to Great Lakes wetlands overall (Harris et al. 2009). Backwater habitats are accessible from/to the river, enabling exchange of materials (e.g., nutrients) and organisms with the main river. Riverine and Great Lakes fishes depend on these areas as warm water refuges in the spring (Brazner and Beals 1997; Edsall and Charlton 1997) and for important spawning and rearing habitat (Goodyear et al. 1982; Harris et al. 2009). Maintaining connectivity between backwater habitats and the open river is vital for fishes that occupy each habitat type during different life stages (Harris et al. 2009). Backwater habitats also support unique plant and animal communities, increasing species diversity of riverine floral and faunal communities. For example, backwater habitats support submerged and emergent marsh communities composed of species that require slow water movement and reduced wave action (e.g., herbaceous species, species with long-floating propagules (plant part that is capable of independent propagation of a new individual), and shallow submerged aquatic vegetation (SAV) (Nilsson et al. 2002).

SMR coastal wetland habitat loss is listed as a beneficial use impairment in the SMR Area of Concern (Selzer 2007). These marshes are an important conservation priority because they provide essential habitat for waterfowl, migratory bird species, and native fishes that rely on wetlands for at least one life history stage (Harris et al. 2009). Furthermore, SAV beds provide cover and complex habitat for macroinvertebrates and smaller-bodied fishes (Jude and Pappas 1992; Gore and Shields 1995; Randall et al. 1996; Brazner and Beals 1997). Great Lakes macroinvertebrate and fish species diversity are enhanced by the availability of habitat for species with less streamlined morphology (Gore and Shields 1995) and for warm water fish species (e.g., smallmouth bass, *Micropterus dolomieu*; northern pike, *Esox lucius*; and yellow perch, *Perca flavescens*; Edsall and Charlton 1997).

Temporal Validity: Backwater habitats in the lower SMR are available year-round; thus, our PI assesses areal response to mean annual Lake Huron water elevations. Percent change in backwater habitat area was based on mean backwater habitat area at a Lake Huron water elevation of 176.43 m, which is the mean annual water elevation from 1921 to 2009 (United States Army Corps of Engineers 2010).

Spatial Validity: Our backwater connectivity PI is limited to the lower river, where the vast majority of this habitat occurs. Backwater habitat included major embayments or lagoons (e.g., Little Lake George, Echo Bay, Baie de Wasai, and Maskinonge Bay) with direct connections to the SMR and narrow, shallow areas within the SMR located between islands and the Canadian or U.S. shoreline (e.g., east of East Neebish Island, east of the island chain that includes Maskinonge Island, and east of Squirrel Island; Figures 1 and2). These relationships can be applied more broadly to the upper Great Lakes where similar habitat occurs and is connected to the open lake through narrow and/or shallow openings.

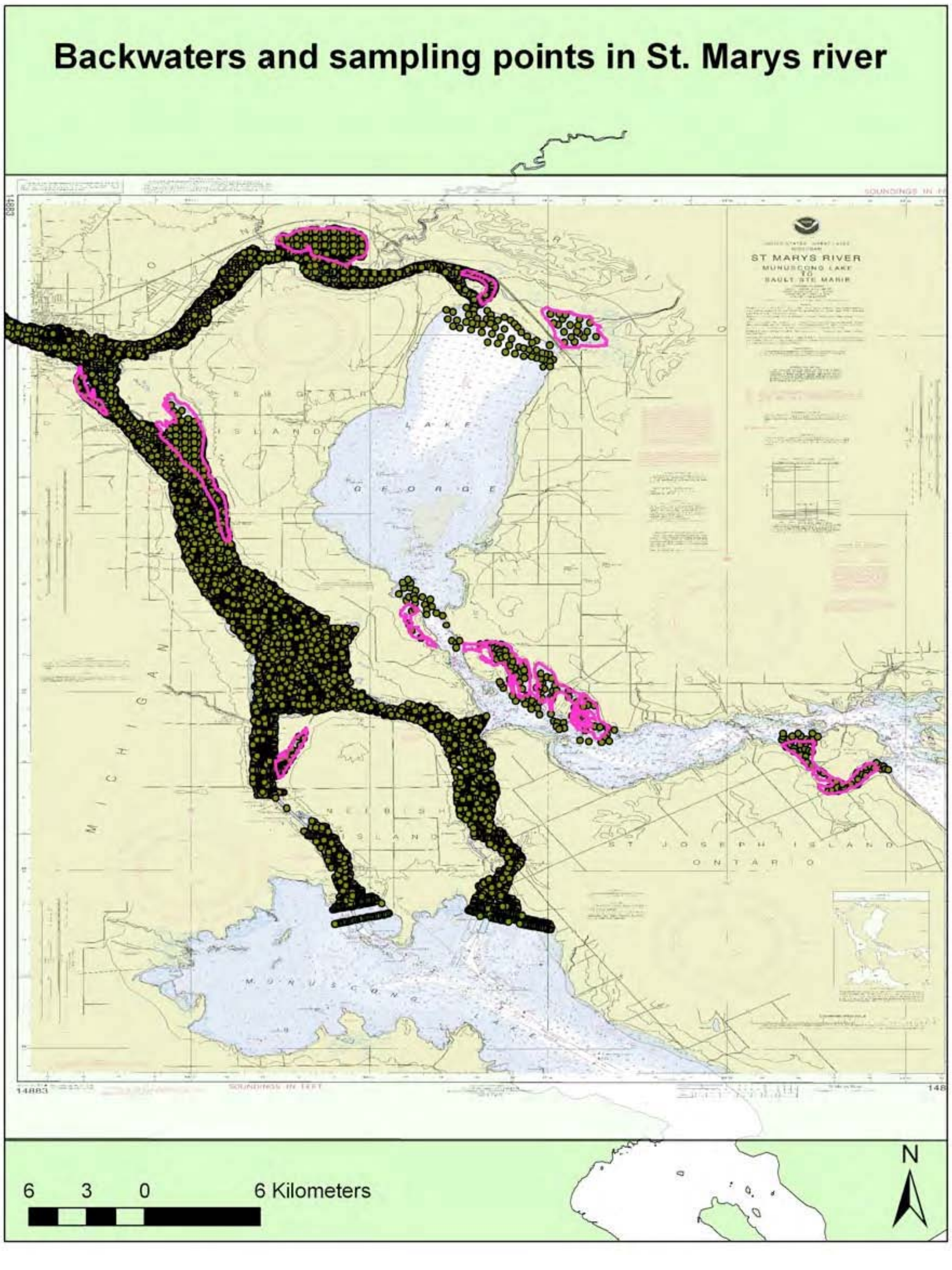

Figure 1. Spatial extent of the St. Marys River analyzed; dots represent depth sampling points; pink lines outline the backwater habitats considered.

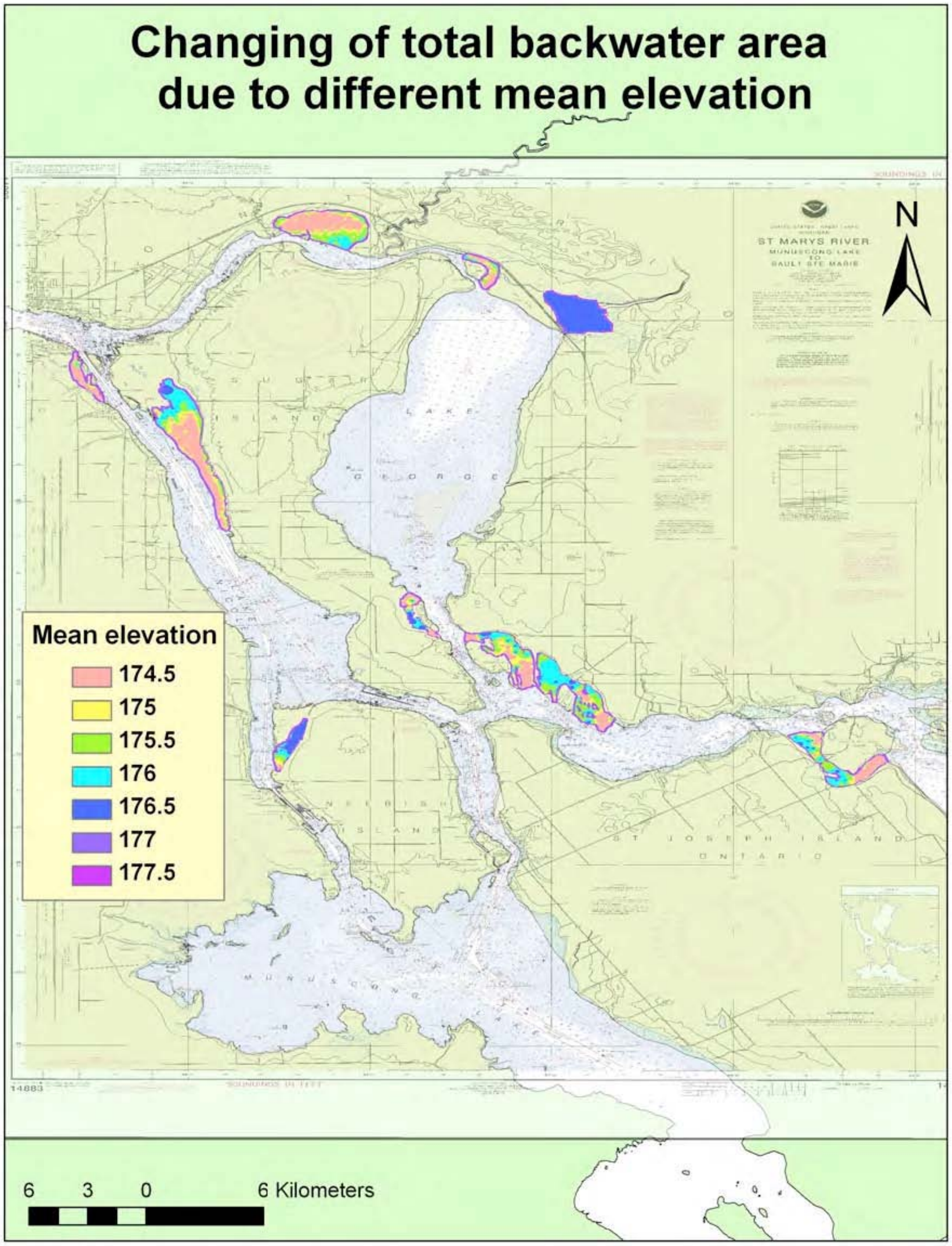

Figure 2. Total backwater habitat area at each 0.5 m water elevation interval ranging from 174.5 m to 177.5 m.

Hydrology Link: Backwater habitat connectivity to SMR nearshore and channel habitat is determined by water elevation. Lower water elevations can result in hydrologic separation of backwaters from the SMR through exposure of sand bars or other bathymetric features above the surface of the water column. Low water elevations also can cause loss of backwater habitat through dewatering of shallow areas. We account for both types of habitat loss in this PI.

Algorithm: Backwater connectivity was defined as the area (m^2) of backwater habitat having a direct surface water connection to the main SMR channel. Geographic Information Systems (GIS) was used to create contour and depth surfaces from depth data available for the SMR and to calculate backwater area for 0.5 m Lake Huron water elevation increments ranging from 174.5 m to 177.5 m. This elevation range represents an approximate 2 m decrease and 1 m increase in water elevation compared to the mean annual water elevation from 1921 to 2009 (United States Army Corps of Engineers 2010). Depth data and the SMR boundary were provided by Fisheries and Oceans Canada, Sea Lamprey Control Centre (SLCC) and included over 21,000 sampling points collected during 1993 to 2009 (Appendix 1). The SMR boundary was manipulated to fit our study area. The shipping channel, 10 backwaters, and depth in areas not sampled by SLCC were digitized from the National Oceanic and Atmospheric Administration's (NOAA) coast survey map that was georeferenced to a base map (Figure 1). The Michigan boundary was downloaded from the Michigan Geographic Data Library. All data were projected to WGS84_1984_UTM_Zone_16N. Raster analysis and the interpolation scheme available with the spatial analysis extension in ArcGIS were used to interpolate the sampling points and create depth maps corresponding to 0.5 m water elevation intervals. The Inverse Distance Weighted method with power of 2 and search radius of 12 points was employed with pixel size set to 10 m × 10 m. Raster files were then converted to image format for ERDAS IMAGINE inputs using a pixel depth of 32 bits.

The Model Maker tool in ERDAS was used to create two models (Figure 3a-b). The first model calculated backwater area for each 0.5 m elevation interval between 174.5 and 176.5 m as follows: (1) identified pixel values greater than 0 and overlaid them with the digitized backwater boundary; and (2) checked if the backwater entrance no longer has a surface water connection to the river. If the backwater entrance was disconnected, then the entire backwater area was deducted from the total backwater habitat area value (i.e., summed area of all backwater habitats considered). Therefore, the final value for backwater habitat area represents area of only those backwaters with a surface water connection to the SMR.

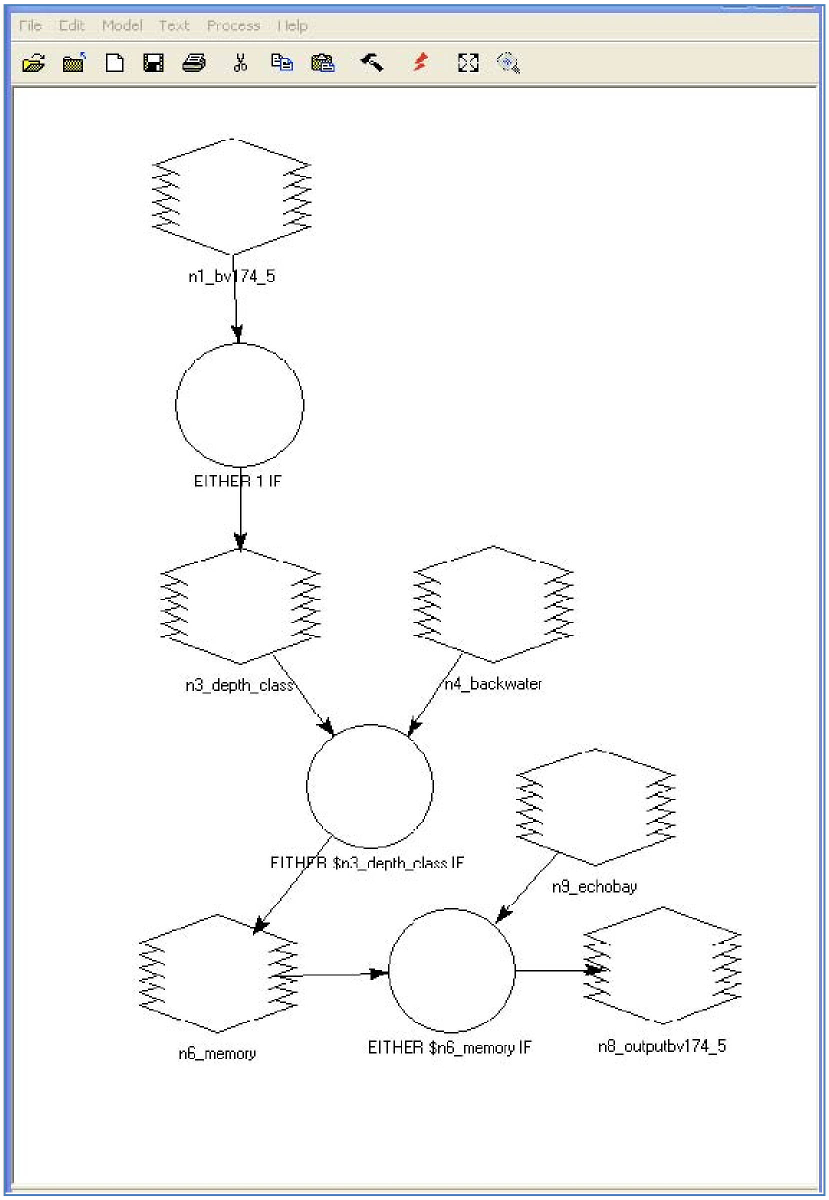

Figure 3a. Model structure used to calculate backwater habitat area at each 0.5 m water elevation interval from 174.5 to 176.5 m.

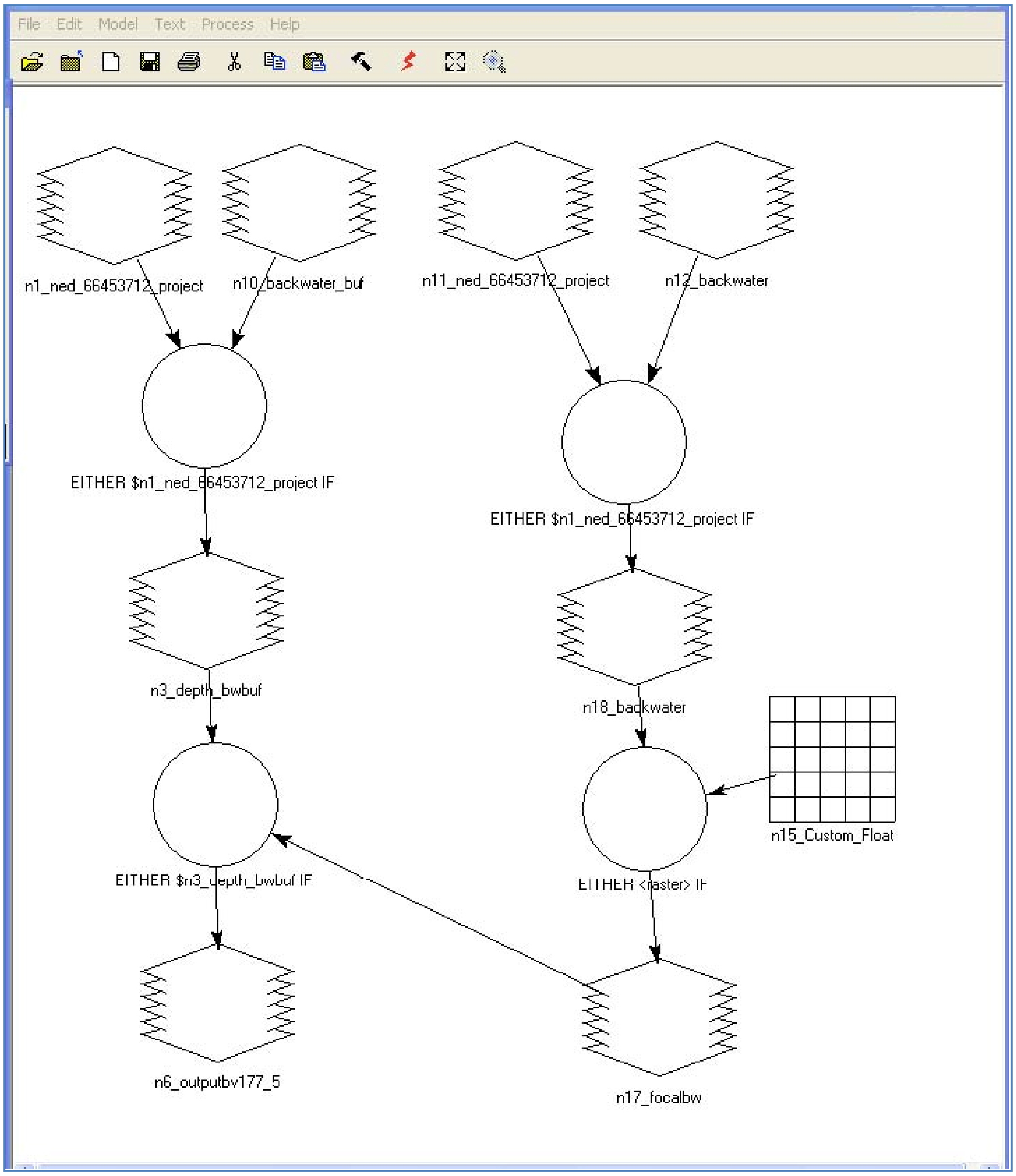

Figure 3b. Model structure used to calculate backwater habitat area for the 177.0 m and 177.5 m water elevation intervals.

The second model was created to calculate backwater area for the 177.0 and 177.5 m elevation intervals. A Digital Elevation Model (DEM) was downloaded from the United States Geological Survey (USGS) National Map Seamless Server (USGS 2010). The model yielded the total conversion of land to backwater habitat at each interval representing water elevation increase beyond the elevation when depth data were collected by SLCC and NOAA. Areal calculations were performed by repeating the following steps for each pixel: (1) clipped backwater boundary and buffered 500 m; (2) used focal operation with 10 × 10 matrices to detect backwater boundary; (3) sequentially simulated water elevation at 177.0 and 177.5 m by adding 0.5 and 1.0 to backwater pixels; (4) identified if the pixel next to the boundary was less than the new boundary added value and, if so, changed that pixel to backwater. Total backwater habitat area was calculated from the total number of pixels identified as backwater (Figure 2).

Percent change in connected backwater habitat area for each 0.5 m Lake Huron water elevation interval (e.g., area at 174.5 m) was calculated as follows:

<u>(area at 0.5 m interval – area at 176.43 m)</u> / <u>(area at 176.43 m)</u>

where backwater habitat area at 176.43 m was estimated by regressing the GIS generated area estimates for each 0.5 m water elevation interval against water elevation:

$$\text{area} = 7.68*10^{6} * \text{water elevation} - 1.33*10^{9};\ R^{2} = 0.995$$

Suitability index scores range from 1 to 0, respectively, for maximum percent gain in backwater area at 177.5 m and maximum percent loss in backwater area at 174.5 m Lake Huron water elevation.

Coping Zone Criteria: Great Lakes backwater habitats are functionally important for supporting a variety of taxonomic groups, yet are frequently exposed to more concentrated human activities (Mackey and Goforth 2005). Backwater habitats have suffered from and continue to be threatened by loss and degradation due to shoreline development (Harris et al. 2009). Therefore, we set the threshold of habitat loss at 30% beyond the approximately 65% of wetland habitat degradation and loss that has already occurred due to human activities (Harris et al. 2009). This area of habitat loss corresponds to a mean annual Lake Huron water level of 175.6 m. The "Zone B" and "Zone C" rules for this criterion are defined as follows:

- <u>**SMH-04 Criterion**</u>:
    - <u>Zone B</u>: Mean annual water level less than 176.0 meters for any given year.
    - <u>Zone C</u>: Mean annual water level less than 175.6 meters for any given year.

Calibration Data: Studies reporting data that relate backwater habitat area to water elevations in the SMR are not available to our knowledge. Therefore, we used the best available bathymetric data to calculate connectivity and backwater habitat area under different Lake Huron water elevations.

Validation Data: The model provided is based on bathymetric data available for the SMR; however, a test of the relationship developed has not been conducted with measured backwater habitat area.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. The functional benefit of backwater habitat to the SMR ecosystem is lost when backwaters become disconnected from the river flow, regardless of whether standing water persists within the backwater habitat.

2. SMR backwater habitats support coastal emergent and submerged wetlands.
3. Additional loss of backwater habitat area could occur as the result of future human development, independent of water elevation change.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

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United State Geological Survey. 2010. The National Map Seamless Server. Retrieved June 28, 2010, from: http://seamless.usgs.gov/.

coordinates an integrated program to reduce lampreys in the St. Marys River using spot treatment with lampricide, trapping adults, and release of sterile male adults (Great Lakes Fishery Commission 2000). This combination of control measures has reduced lamprey productivity by 90% in the river (Schleen et al. 2003). Increasing the productive capacity of the St. Marys River to produce other fish and aquatic biota will likely serve to assist with lamprey reduction efforts. Changes in rapids flow, habitat area, and the Fishery Remedial Works have not been evaluated for effects on lamprey spawning production (Young et al. 1996). Without specific data, we developed an approximate relation between rapids aquatic habitat area, water flow, gate openings, and lamprey production to consider this important water management effect for the St. Marys River.

Temporal Validity: The PI applies to spawning habitat in the rapids for the spawning period: June and July. This is the general spawning period for sea lamprey in the Upper Great Lakes (Manion and Hanson 1980).

Spatial Validity: The PI was designed to represent flow changes, gate openings on the Compensating Works, and wetted habitat in the main rapids. The main rapids constitute the best and large majority of suitable spawning habitat in the St. Marys River (Eshenroder et al. 1987; Krauss 1991; Schleen 1992; Young et al. 1996). Also, consideration of changing rapids aquatic habitat area by modifying gate opening rules for fish and aquatic biota will have an effect on lamprey spawning area in the rapids.

Hydrology Link: The area of aquatic habitat in the St. Marys River rapids is based on the volume of flow released by the Compensation Works. Studies of rapids flow and watered habitat have been reported in terms of the number of gates open. The specific volume of flow varies by open gates because of the elevation of Lake Superior. Therefore, it is easier and more direct to measure volume in terms of gate openings. For this PI, both the number of open gates and rapids flow volume are reported. Flow volume is based on gate discharges reported in Hough et al. (1981) for a lake elevation of 183.0 m.

Algorithm: The PI plot below (Figure 1) was based on a similar wetted habitat and flow relationship plot in Koshinsky and Edwards (1983). This study and all data on flow and habitat area were developed prior to the Fishery Remedial Works in 1985 and 1986. A berm starts at the Compensating Works and roughly follows the Canadian shore down the rapids. Its purpose is to maintain water released from Gate #1 (normally 1/2 open) along the Canadian shore and fill side channels in the area. The berm effectively isolates the Canadian shore from the main rapids that extend to the US shore; it elevates the water surface north of the berm. Prior to the construction of the Fishery Remedial Works, studies of flow and wetted habitat along the Canadian shore calculated that four to six gates need to be open to have sufficient flow to inundate the Canadian shore and side channels (ILSBC 1974; Hough et al. 1981; Koshinsky and Edwards 1983). The plot in Koshinsky and Edwards (1983) shows the increase in wetted habitat from one-half gate to four gates and does not include habitat in the area maintained by the Fishery Remedial Works. This information shows the increase in wetted area primarily in the main rapids. Figure 1 also shows there is aquatic habitat when no gates are open. This aquatic habitat is expected because as much as 14 m^3/s of water leaks through the Compensating Works (ILSBC 1974) and standing water pools exist at this minimum flow.

The suitability index for lamprey spawning reduction in the rapids would be optimal at zero flow because this would be the minimum support for lamprey spawning - no habitat. However, we assigned the optimal condition to be a one-half open gate to maintain the current habitat for other fishes. A suitability index score of one would be the highest flow that would inundate the main rapids from the highest US shore to the Fishery Remedial Works berm along the Canadian shore. Four gates open would cause inundation and is the worst case for lamprey control.

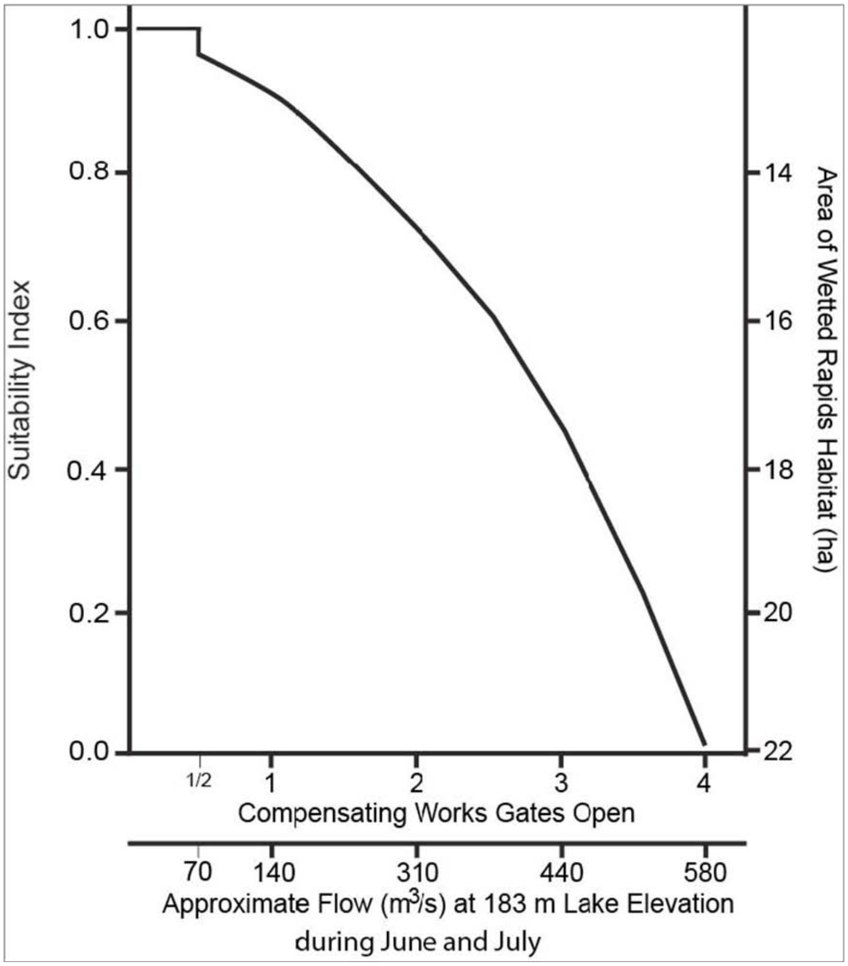

Figure 1. Relationship between flow and habitat area to determine a suitability index value for sea lamprey spawning habitat.

Coping Zone Criteria: The relationship between open gates, flow, and wetted habitat is gradual so there is no clear threshold level to be identified. However, four gates open would provide essentially all possible habitat area in the main rapids for lamprey spawning, and this condition would maximize the potential for upstream escapement of sea lamprey through the Compensating Works and colonization of tributaries in the upper St. Marys River. Therefore, maintaining four open gates should be considered a threshold for “Zone B”:

- **SMG-01**:
    - Zone B: Compensating Works operated with 4 or more gates open for the May-July period for any given year.

It is not necessary to expressly design the selected Lake Superior regulation plan to avoid "Zone B" conditions for sea lamprey in the St. Marys Rapids. However, it is important that the Great Lakes Fishery Commission (GLFC) be notified when "Zone B" conditions occur, so that they can design and implement any necessary control measures in streams that are tributary to the upper St. Marys River above the Compensating Works.

Calibration Data: Data used to develop this relationship and serves as the basis for the PI was reported in Koshinsky and Edwards (1983); they used data, study results, and air imagery at different flows to compile their plot. These are the best data and information available at this time. Repeated assessments of habitat, flows, and gate openings were conducted prior to the final decision and design of the Fishery Remedial Works. After this structure was built, there have been no similar analyses of the rapids area.

Validation Data: The model or relationship provided is based on multiple studies and assessment by fishery experts. However, testing of the relationship developed has not been conducted nor has a quantitative study of lamprey spawning habitat been conducted in the rapids. The rapids are difficult to survey and measure because of variable topographic structure, high velocities in watered area, and the width of the channel.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. The relationship between flow and wetted rapids habitat represents the main rapids area at flows under four open gates.
2. The area of aquatic habitat in the rapids is an indicator of lamprey spawning habitat support.
3. Flowing water over gravel and rubble substrates provides lamprey nesting habitat.

These basic assumptions are used to project lamprey spawning habitat area in the St. Marys River rapids and to target control measures. Thus, confidence can be considered high for the general relationship developed here.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

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Fact Sheet ID: 22

Performance Indicator (PI) Name/Short Description: Native Fish – available habitat area in St. Marys River rapids (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)
Researched by: Ashley Moerke

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: This PI metric describes the total surface area of native fish habitat available in the St. Marys River rapids.

The St. Marys River (SMR) rapids drop over 6 m in a 1.2 km reach, resulting in fast-flowing water dominated by cobble, boulder, and bedrock substrate. Large and diverse substrates and fast flows are lacking throughout the remainder of the 112 km river, which makes the rapids an important area for biotic production. The rapids provides habitat for native fishes. Although this habitat was historically, construction of the Compensating Works (16-gated control structure used to control Lake Superior water level) and hydropower facilities diverted over 90% of the Lake Superior outflow and dewatered over 25 hectares of the rapids (Duffy et al. 1987). In 1981, a berm (Fishery Remedial Works, flow diverting berm - raised barrier separating two areas) was constructed to reduce dewatering of the main rapids at lower flows; however, available habitat still varies with Compensating Works gate operations.

The remaining rapids provides critical habitat for fish and benthic macroinvertebrates, but the habitat is limited to the area inundated by flows through the Compensating Works. Therefore, this PI was developed to relate the wetted area of the main rapids to changes in water elevations associated with the Compensating Works gates. Current water elevation regulations may lead to decimation of biota by reducing water flows over the rapids habitat which may strand fish and invertebrates, freeze fish eggs deposited in the substrate, and eliminate spawning and nursery habitat. Future water elevation regulations via Compensating Works gate operations could be altered to enhance habitat available for macroinvertebrate production and fish spawning, rearing, and foraging.

This indicator is limited to the main rapids because the area north of the berm (Fishery Remedial Works) is isolated from the main rapids and remains wetted with gate operation consistently open at 20 cm. Operational changes to the Compensating Works gates would largely influence the main rapids.

Ecological Importance/Niche: The fish community in the rapids is unique and dissimilar to communities in other habitats of the river. Historically, the rapids provided high quality spawning habitat for native species, including white sucker (*Catostomus commersonii),* slimy sculpin (*Cottus cognatus),* lake whitefish (*Coregonus clupeaformis),* brook trout (*Salvelinus fontinalis),* and lake trout (*Salvelinus namaycush).* The rapids continue to provide spawning and feeding habitat for numerous game species, including steelhead (*Oncorhynchus mykiss)*, brown trout (*Salmo trutta),* and chinook salmon (*Oncorhynchus tshawytscha),* and important Great Lakes forage fishes such as longnose dace (R*hinichthys cataractae*), alewife *(Alosa* *psuedoharengus)* and rainbow smelt *(Osmerus mordax)* (Gleason et al. 1981; Goodyear et al. 1982; Steimel 2010). The rapids may also provide critical spawning habitat for lake sturgeon (*Acipenser fulvescens*), a threatened species in Michigan. Macroinvertebrate composition and productivity in the rapids also differs substantially from other habitats in the river, and are dominated by net-spinning caddisfly larvae (Trichoptera: Hydropsychidae) (Duffy et al. 1987; Kauss 1991) due to the faster flowing waters and larger substrate. These hydropsychids likely serve as a valuable food source for benthic fishes such as sculpin, pelagic forage fishes such as longnose dace, and juvenile fishes. Reduction of the rapids habitat has occurred due to the locks, the Compensating Works, and hydropower generation. Currently, less than 10% of Lake Superior outflows flow through the rapids; flows are now regulated by Compensating Works gates at the head of the rapids. Previous studies (e.g., Hough et al. 1983; Koshinsky and Edwards 1983) have indicated that the flows experienced at three open gates or less result in considerable drying of rapids habitat, which limits habitat available for biotic use and production. Regulation of flow through the Compensating Works is a feasible strategy to enhance fish and benthic macroinvertebrate production in the rapids.

Temporal Validity: Annual - the rapids are used throughout the year for fish spawning, egg incubation, and larval rearing. For example, many salmonids spawn in the rapids in the late spring (May-June) or fall (August-November), but their eggs incubate over the winter months. The rapids also provide nursery habitat for species throughout the entire year.

Spatial Validity: This indicator applies to the main rapids of the SMR (south of the berm) where changes in the Compensating Works gate operations will alter wetted area and available habitat for biota. The area north of the berm (Canadian side) is isolated from the main rapids and remains wetted with gate operation consistently open at 20 cm.

Hydrology Link: The wetted area of the rapids was related to flow volume released through the Compensating Works gates. Koshinsky and Edwards (1983) reported river discharge based on the number of gates open and then related this to wetted area in the rapids.

Algorithm: Data used in development of this PI are summarized as a plot in Koshinsky and Edwards (1983). Flow volume is based on gate discharges for a lake elevation of 183.0 m. This and other existing studies relating flow and habitat area in the rapids were conducted prior to the Fishery Remedial Works in 1985 and 1986. This structure is a berm that starts at the Compensating Works and roughly follows the Canadian shore down the rapids. Its purpose is to maintain water released from Gate #1 (normally open 20 cm) along the Canadian shore and fill side channels in the area. The berm effectively isolates the Canadian shore from the main rapids that extend to the US shore; it elevates the water surface north of the berm. Prior to the construction of the Fishery Remedial Works, studies of flow and wetted habitat along the Canadian shore calculated that four to six gates needed to be open to have sufficient flow to inundate the Canadian shore and side channels (ILSBC 1974; Hough et al. 1981; Koshinsky and Edwards 1983, and others). The plot in Koshinsky and Edwards (1983) shows the increase in wetted habitat from one-half gate open to four gates open. The plot does not include habitat in the area maintained by the Fishery Remedial Works. This information shows the increase in wetted area primarily in the main rapids. Figure 1 also shows aquatic habitat exists when no gates are open. This is expected because as much as 15 m^3/s leaks through the Compensating

Works (ILSBC 1974) and standing water pools would exist at this minimum flow.

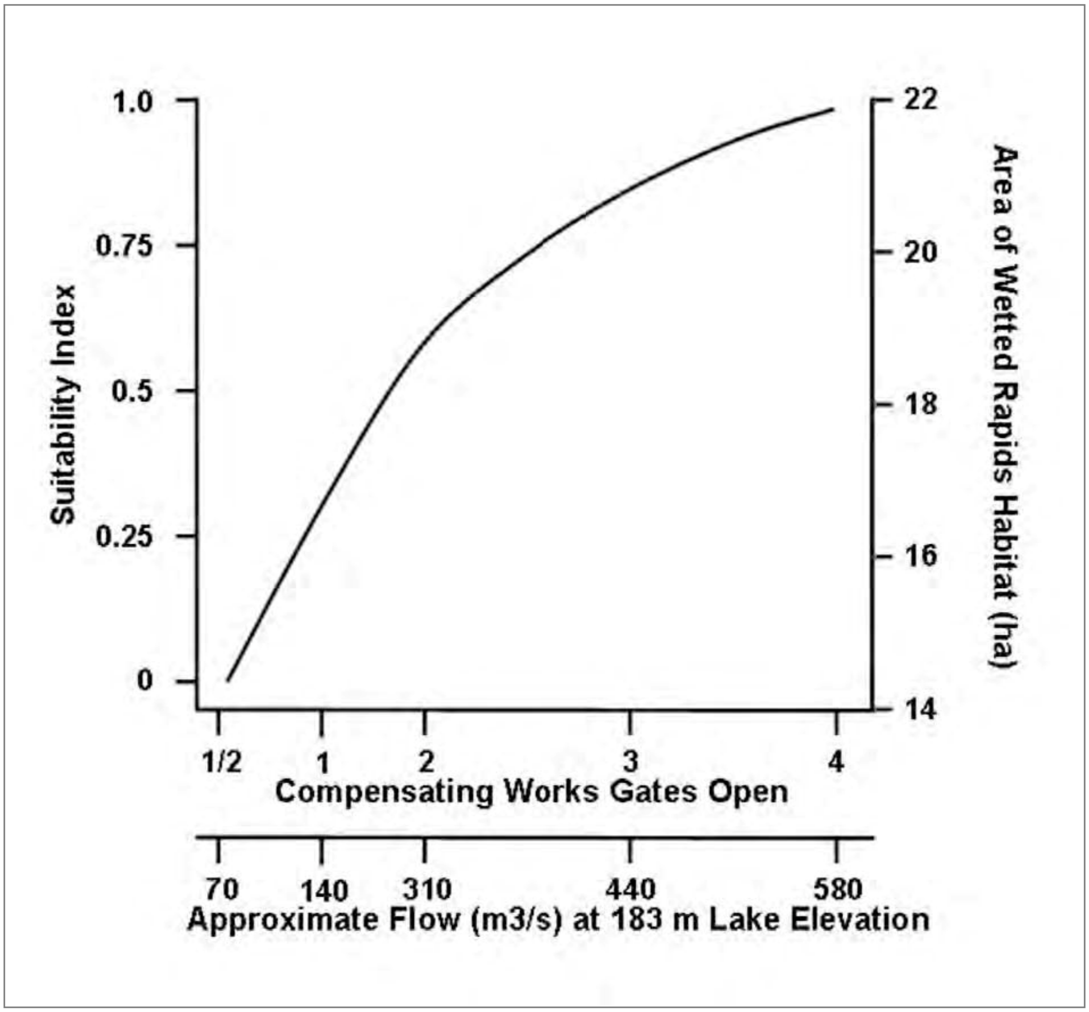

Figure 1: Relationship between flow and area of wetted rapids to determine a suitability index for native fish habitat area.

The suitability index for wetted area in the rapids would be optimal at 1.0 when four gates are open because this would provide maximum inundation of the rapids and increase availability of habitat for macroinvertebrates and fishes. A suitability index score of zero would be when only one-half gate is open in the rapids. A reduction in gates open from four to one-half would result in a loss of over one-third of the existing rapids wetted habitat.

Coping Zone Criteria: The coping zone criterion developed for this PI reflects expert opinion that the St. Marys Rapids should never experience flows below the ½ gate opening. This is a the minimum flow set between the US and Canada in current plan. Any duration of lower flow would dry the rapids more than now and strand fish, desiccate invertebrates, and set a new lower flow condition. Therefore, the critical condition applies to any length of time, as reflected in the description provided below:

- **SMG-02**:
  - Zone C: Compensating Works operated with less than 0.5 gate open for any given month in any given year.

Calibration Data: Data used to develop this PI are from Koshinsky and Edwards (1983). This is the best information currently available, but the relationship was developed prior to the final decision and design of the Fishery Remedial Works. After this structure was built, there has been no similar analysis of the rapids area.

Validation Data: The model provided is based on multiple studies; however, no test of the relationship developed has been conducted since the construction of the Fishery Remedial Works.

Risk and Uncertainty Assessment: The following are the main assumptions of PI model:

1. The relationship between flow and wetted rapids habitat represents the main rapids area at flows under four gates open.
2. The relationship between flow and wetted rapids habitat, based on data prior to the construction of the Remedial Fishery Works, is similar to the relationship between flow and wetted rapids habitat after construction of the berm.
3. The area of wetted habitat in the rapids is an indicator of benthic macroinvertebrate and fish production.

These basic assumptions are used to project wetted areas in the SMR based on flow volume released from the Compensating Works. Confidence can be considered relatively high for the general relationship developed here.

Confidence, Significance, and Sensitivity: See discussion in preceding sections.

Documentation and References:

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Fact Sheet ID: 23

Performance Indicator (PI) Name/Short Description: Fish Stranding in Rapids - ramping rate suitability index (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Mark Bain

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: A PI is presented that relates potential fish losses, via fish stranding, to the speed of change in gate openings and flow volume to address this concern in reconsidering the operation of the Compensating Works.

The speed of water level change due to gate changes on the Compensating Works (16-gated control structure used to control Lake Superior water level) above the rapids of the St. Marys River has been a concern of fisheries management (Godby 2006) and river conservations organizations (Harris et al. 2009). The speed of gate adjustments and changes in water releases are often called 'ramping rates' and usually apply to hydroelectric plant discharges. For the St. Marys River, this issue is limited to the rapids and does not involve the hydropower plants; the rapids were maintained to support the river's famous salmonid fishery. Rapid ramping rates can impact fish resulting in the loss of a substantial portion of small, young fish. This loss adds to natural mortality and can greatly diminish populations. The rate of rapid flow volume changes associated with changes in the Compensating Works gate openings have been judged too erratic and damaging on fish in the rapids (Harris 2009).

Ecological Importance/Niche: Observations of fish stranding under rapidly declining river water levels have been reported below many hydroelectric facilities. The rate of fish losses due to abrupt declines in water level have been primarily studied in Norway, which relies entirely on hydropower for its electric supply and has very important salmon and trout fisheries in its broad, boulder dominated, cold rivers. These studies are applicable to the St. Marys River: same kinds of fish, boulder strewn habitats, and cold climate. Studies have been done in the US and in other countries, but the Norwegian research has been the most thorough. A series of conclusions from experiments on fish losses from rapid and gradual water level changes are reported in Salveit et al. (2001) and Halleraker et al. (2003, 2007). Salmonid fish losses primarily occur because of stranding during rapidly falling water levels. Salmonid fishes less than 100 mm in length are most vulnerable to stranding. Higher rates of standing occur in coarse substrates with high current speeds. Finally, criteria were developed for the speed of change that does not pose a threat to river fishes.

Temporal Validity: The fish stranding and ramping rate PI applies to gate and flow changes in any season for the rapids. Salmonid fishes are present year round so quick changes in water levels are a potential threat at any time.

Spatial Validity: The PI applies only to the St. Marys River rapids below the Compensating Works south of the Fishery Remedial Works - the main rapids. All of the St. Marys River hydroelectric plants discharge directly into deep channel waters where the ramping fish standing/ramping rate issue does not exist.

Hydrology Link: The rate of water level change is central to this PI. The Norwegian research on ramping rate impacts was summarized to develop protection criteria in Halleraker et al. (2003), which gives specific guidance for minimizing losses of salmonid fishes by stranding.

> *Dewatering slower than 10 cm an hour drastically decreased stranding of young trout, the most vulnerable group of fishes. For rivers dominated by coarse substrate, these slow ramping rates (<10 cm/hr) must be achieved. Gentle drops in discharge after long stable flow periods are recommended.*

I present a PI (Figure 1) that was developed with the < 10 cm/hr change rate defining optimum conditions (Suitability index = 1). In Halleraker et al. (2003) a fast rate of change was a measure for fish losses: 60 cm/hr with 22% mortality of small salmonid fishes. This rate of change was considered unacceptable and labeled with a suitability index of zero. The rate of fish loss was considered linear between these points; an intermediate change rate of 13 cm/hr was computed and fell directly on the straight line in the plot.

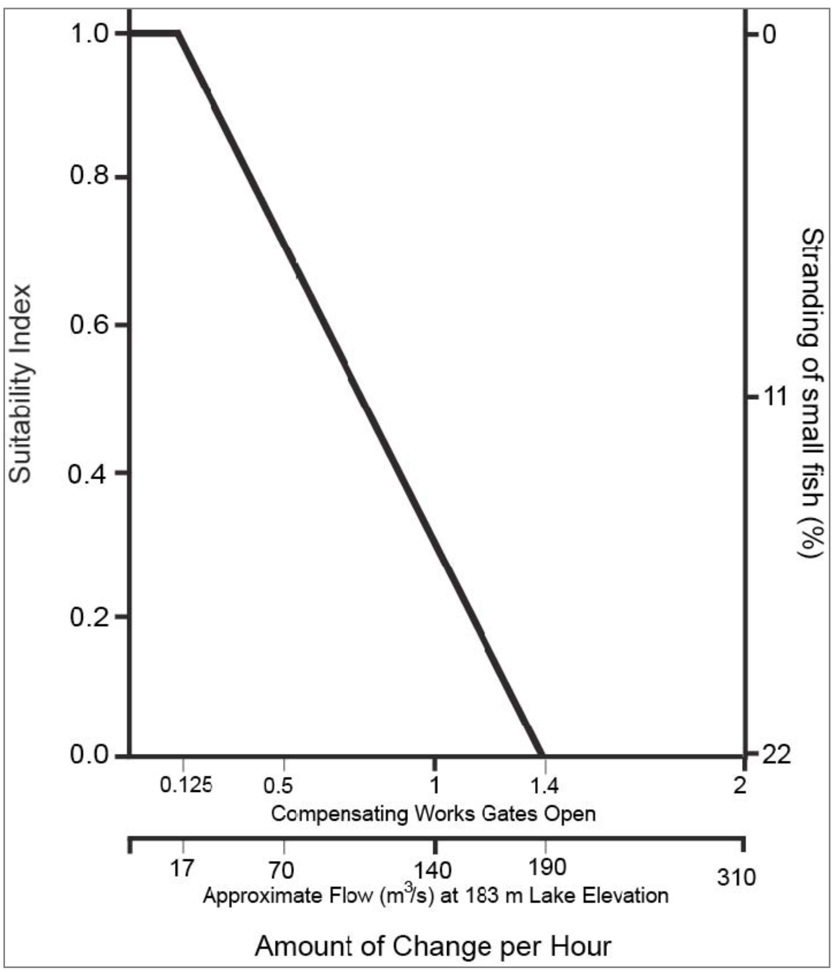

Figure 1. Relationship between flow and stranding of small fish to determine a suitability index for ramping rates.

Algorithm: The key rates of change (10 and 60 cm/hr) were converted to main rapids flow and gate opening (at a common lake level 183 m, Houke et al. 1981) using a set of calculations based on standard hydraulic properties of river channels. Hydraulic rules in Leopold and Maddock (1953) and Dunne and Leopold (1978) provide the computations for this conversion. The conversion to a rate of change in Compensating Works operations started with the basic formula:

$$\mathbf{d = cQ}^{f}$$

Where **d** is the average channel depth (ft), **Q** is the flow in ft^3/s, ***f*** is an exponent, and **c** is a numerical constant. Leopold and Maddock (1953) and Dunne and Leopold (1978) have parameterized this formula in English units for many river channels around the World. The exponent ***f*** was set to 0.40, which is an average value for many rivers. The numerical constant **c** was calculated using data extracted from International Lake Superior Board of Control (ILSBC 1974, see p. 86) and St. Marys Rapids Working Group (1983, see Table 2). The formula above was rearranged to compute an estimate of **c** using rapids flow and average depths:

$$\mathbf{c = d/Q}^{f}$$

Six flows with average rapid water depths were used to compute **c,** ranging from 2,500 to 46,000 ft^3/s. The estimates of c ranged from 0.06 to 0.16 and an average of these values was used (0.10). Any flow can then be inserted in the first formulae using ***f*** = 0.40 and **c** = 0.10 to calculate average water depth. Estimations were done to define the amount that rapids flow can be changed to match the 10 and 60 cm/hr rate of change. The results were then converted to metric units and plotted on the PI plot (Figure 1). The x-axis flow is in units of m^3/s for gate openings and is based on a common gate flow reported in Houke et al. (1981) with Lake Superior elevation at 183 m. The final PI plot shows a suitability rating of gate and volume change per hour with an estimate of potential fish losses.

A one half open gate is the common opening equivalent on the Compensating Works for the current flow rate for the rapids. There are 16 gates on the Compensating Works and a change of one half open gate should be done in no less than four hours to meet the suitability index of 1. A rate of change in rapids flow should be ≤ 17 m^3/s per hour to maintain a rate of water surface change of no more than 10 cm/hr. Because one half open gate releases approximately 70 m^3/s water, this amount of gate change needs to be spread over four hours to approximate a flow rate of change of 17 m^3/s.

Coping Zone Criteria: Based on the above discussion the rate of change in St. Marys Rapids water depth should always be maintained at less than 60 cm/hr, keeping in mind that the ideal rate of change is less than 10 cm/hr. Therefore, "Zone C" conditions are encountered when the rate of change in water depth is greater than or equal to 60 cm/hr. This criterion is operational in nature, and therefore it is not represented directly in the IERM2 model or the accompanying

Coping Zone calculator, which operate on monthly mean water level time series.

Calibration Data: Calibration data were scarce because of the need for both rapids volume and an estimate of average depth. Data were found for six widely varied rapids flows in ILSBC (1974, see p. 86) and St. Marys Rapids Working Group (1983, see Table 2). The resulting computations provided a narrow range of values used in the formula to relate volume and depth in the rapids. The exponent of this formula was a central value reported in standard river hydraulics references (Leopold and Maddock 1953; Dunne and Leopold 1978).

Validation Data: There are no validation studies available for fish losses under varying water levels in the St. Marys River rapids. However, thorough research in Norway was done to identify rates of change associated with near zero fish losses and high losses. These were combined with standard hydraulic formulas to predict rates of change in the St. Marys River.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. The standards for fish loss, under varying water levels, apply to the St. Marys River.
2. Parameterization of St. Marys River rapids hydraulic properties is realistic.
3. The resulting standards will improve conditions for fish with modified Compensating Works operations.

Although many theoretical and approximate calculations were done to estimate operating standards, there are no alternatives at this time to address the issue of rapid flow changes and fish losses in the rapids.

Confidence, Significance, and Sensitivity: See discussion in preceding sections.

Documentation and References:

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Fact Sheet ID: 24

Performance Indicator (PI) Name/Short Description: Lake Sturgeon – spawning habitat area (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Geoffrey Steinhart

Modeled by: LimnoTech (Redder, DePinto)

PI Metric/Niche: The PI metric is the percent increase in lake sturgeon spawning habitat area. It is based on the relationship between SMR discharge and the percent increase in suitable velocities for lake sturgeon spawning habitat.

Lake sturgeon (*Acipenser fulvescens*) are an ancient fish species that were once abundant in the Great Lakes and the St. Marys River (SMR), but the population is suspected to be 1% of its original size (Harkness and Dymond 1961). The SMR has an estimated population size of around 500 individuals that appear genetically distinct from other lake sturgeon populations in the Great Lakes (Gerig et al. in press). Lake sturgeon spawn in areas with a moderate flow (Seyler 1997; Manny and Kennedy 2002; Friday 2006) and hard substrate (Auer 1996; Seyler 1997; Bruch and Binkowski 2002). The SMR has several sites that meet these requirements (Goodyear et al. 1982), but maintenance of these spawning habitats is linked to flow regime to maintain adequate water velocities.

Ecological Importance/Niche: While once an abundant resource for the Ojibwe living near the SMR (Cleland 1982) and abundant throughout the Great Lakes (Harkness and Dymond 1961), lake sturgeon are now listed as threatened in Michigan and Ontario, including the area of the SMR. In addition, lake sturgeon are listed as endangered in Illinois, Indiana and Ohio, as a species of concern in Wisconsin and Minnesota, and as a globally rare species by The Nature Conservancy (Goforth 2000). The precipitous decline in lake sturgeon populations has made them a priority in the Great Lakes Basin (Holey et al. 2000; Great Lakes Fishery Commission 2008). In the SMR, lake sturgeon restoration is a conservation target for the SMR Conservation Action Plan (Harris et al. 2009). The lake sturgeon population in the St. Marys River is estimated to be 505 individuals (A. Moerke, Lake Superior State University (LSSU), personal communication), and preliminary data indicate that this population is genetically distinct (N. Kirkpatrick, LSSU, personal communication).

Two potential barriers to lake sturgeon recovery are the lack of suitable spawning sites (Daugherty et al. 2008) and intermittent spawning (Becker 1983). The biology of lake sturgeon makes them particularly susceptible to changes in recruitment. Males do not reach sexual maturity until the age of 12-21 years, and females reach maturity at 14-33 years. Once mature, male lake sturgeon may spawn as frequently as every other year, but females typically spawn every 4-8 years (Becker 1983; Threader et al. 1998). In addition, egg morality is high, as much as 99% or more. Therefore, to ensure adequate spawning success and recruitment, sufficient habitat and flows must be maintained for lake sturgeon spawning.

Although specific spawning sites in the St. Marys River are unknown, we do know that access to suitable spawning habitat is a limiting factor to lake sturgeon recovery in much of Lake Huron. Risks to the lake sturgeon population include reduced age-zero recruitment during years of low June flows. The problems with successive years of low recruitment or year class failure are exacerbated in the future (12-3 years post low flow) as that cohort recruits to the adult spawning population, which is then diminished (Neal Godby, personal communication).

Temporal Validity: Lake sturgeon begin to stage, in preparation for spawning, around water temperatures of 9°C (Friday 2006). Spawning occurs at water temperatures ranging from 12-18 °C (Becker 1983; Threader et al. 1998). In the SMR, these temperatures typically occur in June (unpublished data from 1982-2007; Roger Greil, Lake Superior State University Aquatic Research Laboratory). We defined the period from June 1 through June 30 as the period of concern for lake sturgeon spawning in the SMR.

Spatial Validity: Our lake sturgeon PI is tuned for the SMR with an emphasis placed on putative (or assumed) spawning areas. Lake sturgeon typically spawn in water depths less than 5 m (Becker 1983; Threader et al. 1998). They prefer hard substrates and a moderate current for spawning (Auer 1996; Seyler 1997; Bruch and Binkowski 2002; Manny and Kennedy 2002; Friday 2006). The area between Sugar Island and East Neebish Island is a historic spawning area for lake sturgeon (Goodyear et al. 1982). Recent work by Gerig et al. (in press) has shown lake sturgeon moving from Lake George to this area. It is unknown whether lake sturgeon spawn in the Lake George Channel; however, telemetry studies have found that they commonly frequent these areas (Gerhig et al. in press) and that suitable substrate and depths exist, so spawning may occur if velocities were appropriate. The SMR rapids are a historic breeding area for lake sturgeon (Goodyear et al. 1982), but the flow in the rapids was not considered since they are under separate hydrologic control (via the Compensating Works – a 16-gated control structure used to control Lake Superior water level) than the rest of the potential spawning areas (e.g., flow through the three hydroelectric plants).

Hydrology Link: Lake sturgeon spawn in areas with a distinct current (Threader et al. 1998). Typical velocities in lake sturgeon spawning areas range from 0.46-1.1 m/s (Seyler 1997; Manny and Kennedy 2002; Friday 2006), but can be as low as 0.2 m/s and as high as 1.4 m/s (LaHaye et al. 1992). Maintaining proper flows during the staging and spawning period has clear consequences for lake sturgeon reproductive and recruitment success (Brousseau 1987).

Algorithm: We estimated current velocity using transects to estimate cross-sectional area along putative lake sturgeon spawning areas. Sites included in the analysis were the area between Sugar Island and East Neebish Island (5 transects, 0.2km apart), the eastern end of the Lake George Channel, from the Garden River to Lake George (10 transects, 0.5km apart), and mid-way along the Lake George Channel (7 transects, 0.25km apart). The first three sites, all in or below the Lake George Channel, were assumed to receive 30% of the total SMR flow (ILSBC 2002). Average water velocity for each transect was estimated by dividing the total flow (m^3/s) by the cross-sectional area of the transect (m^2). All transects with a flow between 0.46-1.1 m/s were summed after weighting. Weighting was done by calculating the amount of suitable habitat in each site (i.e., the area with water depths less than 5 m), and dividing by the sum of all suitable habitat in all sites. The PI was created for total SMR flows ranging from 1600-2400 m^3/s

(Figure 1).

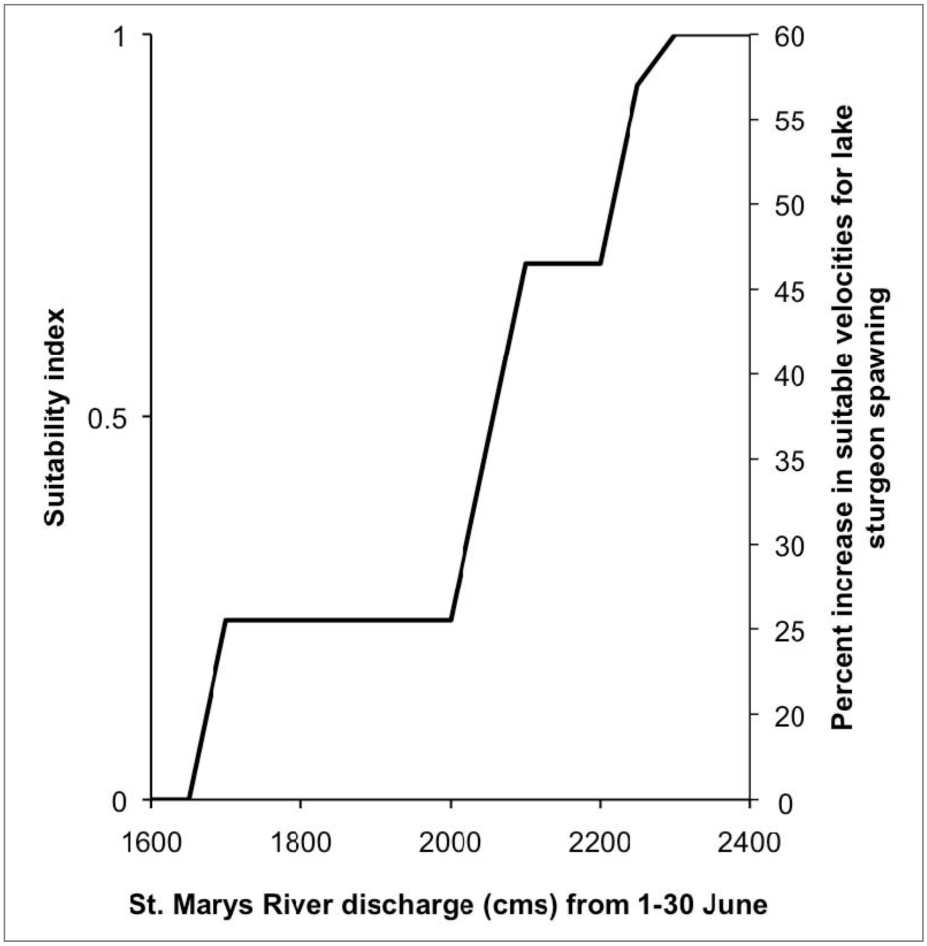

Figure 1. Relationship between St. Marys River discharge flow and suitable velocities for lake sturgeon spawning to determine a suitability index value.

Coping Zone Criteria: A threshold for this PI is at a flow of 1700 m^3/s, which increases the number of transects with suitable spawning velocities by 25% of the transects examined. The specific coping zone criterion developed for lake sturgeon spawning is as follows:

- **SMQ-01:**
    - Zone B: Mean flow rate during June maintained below 1,700 m^3/s for any 3 years in a 5-year window.
    - Zone C: Mean flow rate during June maintained below 1,700 m^3/s for 5 or more consecutive years.

This threshold was chosen because of the need to restore lake sturgeon populations and, thus, a need to increase reproductive and recruitment success. Peak suitability occurs at 2300 m^3/s. It should be noted that extreme velocities may interfere with lake sturgeon spawning, so discharge in excess of 2800 m^3/s may be detrimental for lake sturgeon spawning (data not shown). Sturgeon can experience years that are poor for reproduction, and this long-lived fish has the ability to withstand poor years of recruitment. However, this species is not known to be spawning in the river at favorable levels currently, and it is considered a priority conservation species in many Great Lakes states and Canada. Thus, violation of the threshold should be minimized and occur only sporadically through time.

Calibration Data: Study results reporting lake sturgeon spawning locations, habitat requirements, and temperature were used to create the spatial and temporal validity of this PI.

Validation Data: Model validation data do not exist for this PI as many lake sturgeon spawning sites are known only from historical records or estimated from seasonal movements. Current velocity has not been recorded in the SMR while lake sturgeon were actively spawning. Future work should confirm these putative spawning sites and determine the flow in which specific aggregations of lake sturgeon spawn.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. Lake sturgeon may move to other spawning areas, or find different velocities within a site, if velocities are not appropriate.

2. Egg survival is related to juvenile and adult abundance.

3. The simplification of velocity estimates (i.e., average velocity across transects) adequately reflects the true velocities across heterogeneous transects, at least within the accepted range of velocities.

Although where lake sturgeon spawn in the SMR today or how many spawn in tributaries to the SMR is still unknown, this PI uses one known spawning area and other putative spawning locations. Furthermore, because these sites contain suitable depth and substrate, they should be representative of other spawning locations. Therefore, the approach described above is the best approach currently available for calculating this PI. The specific thresholds and durations for minimum flow can be adjusted as necessary as additional information becomes available concerning the lake sturgeon population (e.g., via monitoring associated with an adaptive management process).

Confidence, Significance, and Sensitivity: See discussion in preceding sections.

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Fact Sheet ID: 25

Performance Indicator (PI) Name/Short Description: Sediment Flushing Flows – suitability index (St. Marys River, Lake George)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Geoffrey Steinhart

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is based on the velocities needed to erode or transport 1 mm diameter sand particles. A suitability index is calculated from the relationship between St. Marys River (SMR) discharge and the percent of transects in the Lake George Channel with sand transport.

Stream flow regime influences sediment transport, which in turn affects channel morphology, habitat, and biota (Reiser et al. 1990; Poff et al. 1997; Kondolf and Williams 1999). When structures or diversions reduce flow, the amount of sediment transport may be reduced, leading to sediment aggradation (to fill and raise the level of the bed of a stream by deposition of sediment) (Reiser et al. 1989). To simulate a more natural environment, controlled releases may be used to flush sediment in a manner approaching conditions prior to implementation of control structures or diversions (Poff et al. 1997). These controlled releases are often called flushing flows. Proper implementation of flushing flows is necessary to maintain ecological integrity (see Table 2 in Poff et al. 1997) while allowing for control of flow for other purposes during the remainder of the year.

Ecological Importance/Niche: The accumulation of sediment in areas previously swept clear of fine sediment can make channels narrower and/or shallower, reduce formation of bars, and cover valuable spawning habitat (Reiser et al. 1989; Poff et al. 1997). These changes have obvious negative consequences for boating, vegetation, and fishes (respectively). Without flushing flows, eggs and larvae of many amphibians, fish, and invertebrates may suffer high mortality rates (see references in Wiley et al. 1995). A lack of flushing flows can be especially important in areas where sediment input is high, as is the case in many of the low-gradient, clay and sand-dominated tributaries that flow from the Eastern Upper Peninsula into the St. Marys River (SMR).

Temporal Validity: Natural flushing flows typically coincide with spring runoff. Furthermore, unnaturally changing flows during periods of ice cover may lead to early ice-out, which may influence the hatch timing of fishes (e.g., cisco - *Coregonus artedi*; Colby and Brooke 1970; Næsje et al. 1995). Therefore, flushing flows are recommended to occur around the time of spring runoff, the typical date of ice-out, and before most spring-spawning fishes reproduce. Because high flows may attract lake sturgeon (*Acipenser fulvescens*) to suitable spawning areas (Seyler 1997; see lake sturgeon PI), high flow before lake sturgeon spawn may serve two beneficial roles. We defined the time for flushing flows as between May 15 and June 15, which corresponds to the staging and start of the lake sturgeon spawning season (based on spawning temperature preferences and unpublished temperature data from 1982-2007; Roger Greil, Lake Superior State University Aquatic Research Laboratory).

Three continuous days of flushing flow velocities per year are recommended, based on recommendations for other ecosystems, like the Colorado River (U.S. Department of the Interior 2002)

Spatial Validity: With the modifications to the SMR to facilitate shipping, some flow has been diverted away from the Lake George Channel to the shipping canal and through Lake Nicolet (ILSBC 2002). For this reason, we defined the spatial extent of this PI to include the Lake George Channel because it is an area that historically experienced natural flushing flows, but due to channel and flow modifications, flow has been reduced. In addition, the Lake George Channel is likely spawning habitat for key fishes.

Hydrology Link: Sediment resuspension and transport is a function of current velocity (Hjulström 1935; Leopold 1994). With the creation of the shipping channel and various upstream engineering projects, discharge through the Lake George Channel is now reduced and more seasonally stable than in the past (ILSBC 2002).

Algorithm: For the Lake George Channel, our goal was the mobilization and transport of 1 mm diameter sand particles. We constructed depth profiles using 17 transects across the Lake George Channel (approximately 1km apart). We assumed the Lake George Channel received 30% of the total SMR flow (ILSBC 2002). Average water velocity for each transect was estimated by dividing the total flow (m^3/s) by the cross-sectional area of the transect (m^2). The velocities needed to erode or transport particles were determined from Hjulström's curve (Hjulström 1935). Each transect was then given a score based on the mean velocity: 1 if the velocity met or exceeded the minimum velocity needed to mobilize the target particle size (0.35 m/s) and 2 if the velocity was able to mobilize a particle 85% larger than the target size (0.5 m/s). The latter computation was performed because the velocity needed for erosion of sediment may be impeded at depth or over rough substrate (Reiser et al. 1990).

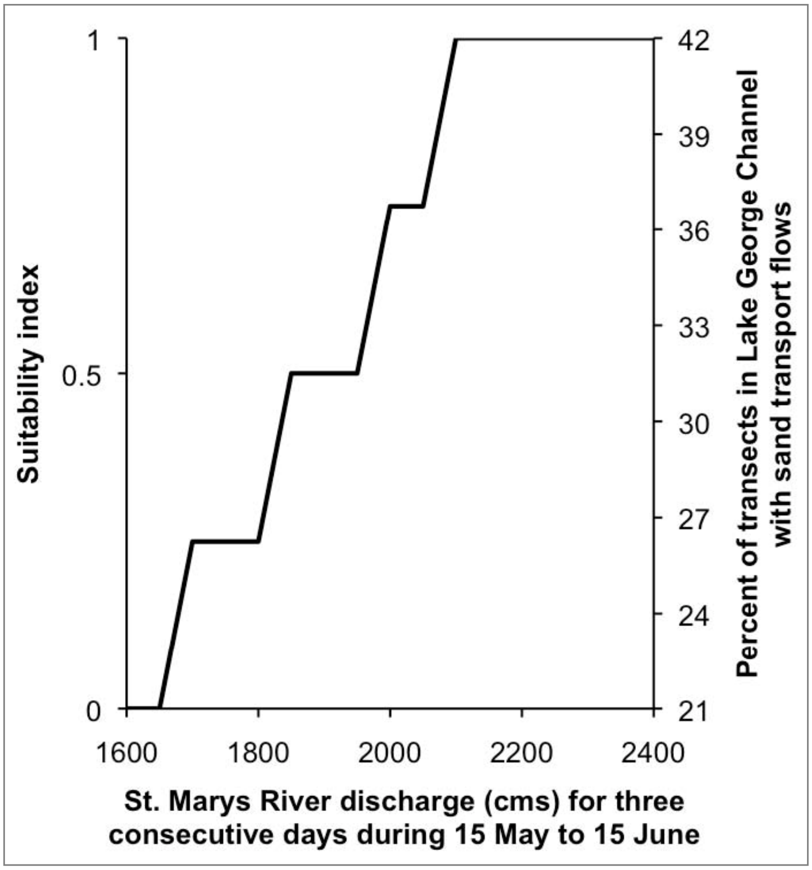

Figure 1. Relationship between St. Marys River discharge and the percent of transects in the Lake George Channel with sand transport flow to determine a suitability index.

Coping Zone Criteria: A threshold for this PI occurs at a flow of 2000 m^3/s, which results in roughly 40% of the transects in the Lake George Channel having suitable mean velocities to mobilize and transport sand. It should be noted that these flow rates also should produce adequate flows to transport smaller, clay particles within Lake George (data not shown). The final criteria is identified as “SMQ-02” in the IERM2 Coping Zone Calculator:

- **SMQ-02:**
  - Zone B: Mean flow rate during May-June maintained below 2,000 m^3/s for any 5 years in a 7-year window.
  - Zone C: Mean flow rate during May-June maintained below 2,000 m^3/s for 7 or more consecutive years.

Calibration Data: Well documented physical hydrology studies were used to determine the critical velocities needed for this PI. However, the depth and composition of the substrate were assumed to be homogenous and to represent the typical values used to generate Hjulström’s curve.

Validation Data: The flushing flow PI should be field verified as the magnitude, timing, and frequency of flushing flows are unique for every system. In addition, data on substrate composition and depth would add additional detail.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. Local current velocities are influenced by depth, rugosity (measure of small-scale variations or amplitude in the height of a surface), and channel morphology data, which were not available for developing this PI.

2. The model focuses on the magnitude of flow required. Duration and frequency of flushing is based on ecosystem objectives for the Colorado River and may be different for the SMR.

3. Increased flows could mobilize potentially contaminated sediments from some locations in Lake George and the Lake George Channel.

Confidence, Significance, and Sensitivity: See discussion in preceding sections.

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Fact Sheet ID: 26

Performance Indicator (PI) Name/Short Description: Cisco (lake herring) **–** spawning habitat suitability index (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Geoffrey Steinhart

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: Cisco *(Coregonus artedi*; formerly called lake herring) have been a traditional component of the native fish community in the Great Lakes. Cisco are broadcast spawners that deposit their eggs in relatively shallow water. Because cisco, and other coregonids (e.g., lake whitefish), spawn in late fall and do not hatch until spring, they are sensitive to water elevation changes that occur during winter (Greeley and Bishop 1932). Furthermore, cisco eggs may hatch prematurely when exposed to light or physical disturbance, both of which may be associated with water elevation changes that disturb surface ice (Colby and Brooke 1970).

The PI metric is based on the relationship between Lake Huron water elevation and the percent change in cisco habitat area to determine a suitability index value for cisco spawning habitat in the St. Marys River (SMR).

Ecological Importance/Niche: Cisco have been a commercially important fish and are still a popular sport fish, but their abundance has declined across the Great Lakes (Fielder et al. 2002; Mohr and Evener 2005). They are listed as threatened in Michigan, and are a priority for restoration in Lake Huron (Lake Huron Technical Committee 2007) and across the Great Lakes Basin (Great Lakes Fishery Commission 2008). Cisco restoration is being pursued because the current prey fish community lacks diversity and is dominated by species that are rich in thiaminase (enzyme that breaks down thiamine) (Fitzsimons et al. 1998), the cause of thiamine deficiency complex (TDC; Ketola et al. 2000). TDC may be impeding efforts to restore lake trout in the Great Lakes. In addition, cisco grow to larger sizes than many current prey fishes, which makes them a more energetically advantageous prey for lake trout (Lake Huron Technical Committee 2007). Therefore, maintaining or increasing the current cisco population not only may help this threatened species, but also may help restore lake trout. The SMR is one of the few areas where cisco have persisted (Fielder 1998, 2002), making it a critical area to preserve and for the collection of gametes (a reproductive cell - male (sperm) or female (egg)) for reintroduction elsewhere in the Great Lakes. Furthermore, other fall spawning fishes (e.g., lake whitefish, *Coregonus clupeaformis*) may be similarly affected by declines in water elevation.

Temporal Validity: Cisco typically spawn in November in the SMR and peak larval abundance usually occurs in May, coinciding with typical ice-out (Colby and Brooke 1970; Liston and McNabb 1986; Fielder 1998, 2000). We defined November 1 through May 15 as the period of concern for water elevation change in the SMR.

Spatial Validity: Our cisco PI is tuned for the SMR with an emphasis placed on known spawning areas. Fielder (1998, 2000) documented the locations of gravid (advanced stage of pregnancy), ripe (ready to spawn), partially spent (partially spawned), and spent (spawned out) cisco in the SMR. With this information, Fielder hypothesized that cisco spawned in areas of the Lake George Channel, Lake George, Baie de Wasai, and downstream from the Rock Cut. However, using transport models, eggs deposited in the Rock Cut were suspected to be carried downstream by currents (Fielder 1998) and Lake George may only be a staging ground for cisco. Therefore, we limited our analyses to the Lake George Channel and Baie de Wasai, the latter being the focal site of recent efforts to collect spawning cisco (Chuck Madenjian, USGS, Ann Arbor, personal communication) and repeatedly cited as an important spawning area (Behmer et al. 1979; Gleason et al. 1979; Jude et al. 1988).

Hydrology Link: Cisco eggs may be vulnerable to desiccation if water elevations drop. Furthermore, eggs may be vulnerable to dislodgement, destruction, or early hatching if ice-out is accelerated by dropping water elevations (Colby and Brooke 1970; Fielder 1998, 2000). Because these areas are driven more by Lake Huron water elevations than discharge through the Compensation Works (16-gated control structure used to control Lake Superior water level) and hydroelectric facilities (ILSBC 2002; Bain 2007), changes in Lake Huron water elevation could lead to undesirable effects on cisco egg survival.

Algorithm: Cisco have been documented to spawn in water as shallow as 1 m (Cahn 1927), but more frequently between 3-6 m in depth (Smith 1956; Smith 1985; Savino et al. 1994). We assumed that eggs may be deposited in water depths ranging from 1-6 m. We constructed depth profiles using transects at 10m intervals across the known spawning area in Baie de Wasai (six transects approximately 0.5km apart) and a putative (or assumed) spawning area in the Lake George Channel (seven transects approximately 0.25km apart). Our base water elevation was 176.4 m in Lake Huron. We then used change in Lake Huron water elevation to predict new depth profiles across these transects. Any locations between 1-6 m that were later found to be less than 1m deep (following a drop in water elevation) were assumed to be no longer suitable for incubation because there are no records of cisco spawning shallower than 1 m. We did not model an increase in water elevation because it was assumed that any temporary increase in depth would not affect incubation (cisco eggs have been found in 18 m deep water in Lake Superior; Dryer and Beil 1964). Under each water elevation change examined (-0.25, -0.5, -0.75, -1, and 1.25 m), the number of suitable 10-meter sections were summed for each transect and, subsequently, scaled to create a suitability index.

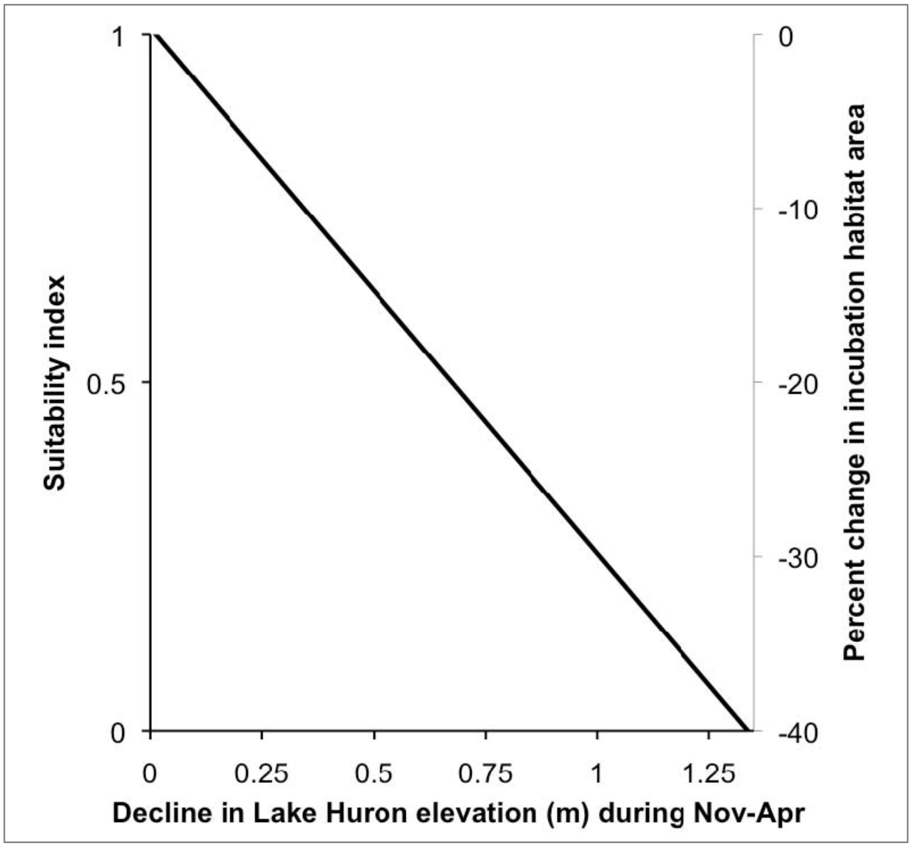

Figure 1. Relationship between Lake Huron water elevation and the percent change in cisco habitat area to determine a suitability index value.

Coping Zone Criteria: A threshold for this PI is zero on the suitability index: a drop of 1.25 m in Lake Huron would result in approximately 40% of the cisco spawning habitat decreasing in depth to less than 1 meter. Because cisco are listed as threatened, and their annual recruitment is notoriously variable (S. Greenwood, Ontario Ministry of Natural Resources, personal communication), any loss of cisco incubation habitat could be seen as detrimental. The "Zone B" and "Zone C" rules for this criterion are as follows:

- **SMH-01 Criterion**:
    - Zone B: The water level decrease between November and the following April exceeds 1.00 meters for any given year.
    - Zone C: The water level decrease between November and the following April exceeds 1.25 meters for any given year.

Calibration Data: Study results reporting cisco spawning locations and timing were used to create the spatial and temporal validity of this PI.

Validation Data: Model validation data do not exist for this PI. In fact, people are still investigating the reproductive behavior and success of cisco in the SMR. Better validation data could be obtained with a more focused and intensive effort towards determining the exact depths at which cisco spawn in the SMR, the percent of eggs deposited at different depths and the amount of egg movement after deposition.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. Eggs, once deposited, are not carried away from the spawning site by currents.
2. Egg survival is related to juvenile and adult abundance.
3. Baie de Wasai and the Lake George Channel are suitable representative areas for other putative spawning areas in the SMR.

Modeling results suggest eggs are not flushed from Baie de Wasai (Fielder 1998, 2000), but no such modeling has been completed for the Lake George Channel. Furthermore, the link between egg survival and adult abundance has rarely been demonstrated conclusively, possibly due to density-dependent effects. Much speculation exists about the extent of cisco spawning areas in the SMR. Baie de Wasai is a known spawning area, but other areas may receive some eggs. Finally, cisco are not the only fall spawning fishes, and we believe this algorithm is the best approach to predicting the potential loss of incubation habitat for fall spawning fishes in the SMR.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

Documentation and References:

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Fact Sheet ID: 27

Performance Indicator (PI) Name/Short Description: Black Tern – nesting success suitability index (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Mark Bain

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is based on Lake Huron water levels, which is used to determine a suitability index for black tern nesting success.

Black terns (*Chlidonias niger*) are one of most prominent of the migratory birds that nest in marshes and emergent wetlands along the coast of the Great Lakes (Currier 2000). They build nests from dried reeds, stalks, and grasses on mounds of vegetation often dominated cattails (*Typha* sp.) or bulrushes (*Scirpus* sp.; Cuthbert 1954, Dunn 1979). Nesting sites are usually at the interface of emergent wetlands and open water where both vegetation and open habitats is about equally common (Hickey and Malecki 1997). Nesting sites are selected by black terns within a very limited range of water depths (Mazzocchi et al. 1997; Alsop 2001; Maxson et al. 2007). Nests are vulnerable to flooding and destruction by wave action, conditions that are often associated with increases in water level, or water level variability during the breeding and nesting seasons (Shuford 1999; Naugle 2004; Mortsch et al. 2006). When evaluating the implications of water levels on the black tern, the bird's nesting success and survival needs require direct consideration.

Ecological Importance/Niche: Many species of migratory birds nest in emergent vegetation of marshes along the Great Lakes shorelines: Pied-billed Grebe (*Podilymbus podiceps*), American Bittern (*Botaurus lentiginosus*), Least Bittern (*Ixobrychus exilis*), Yellow Rail (*Coturnicops noveboracensis*), King Rail (*Rallus elegans*), Virginia Rail (*Rallus limicola*), Sora (*Porzana carolina*), Common Moorhen (*Gallinula chloropus*), American Coot (*Fulica americana*), Forster's Tern (*Sterna forsteri*), Black Tern (*Chlidonias niger*), Marsh Wren (*Cistothorus palustris*), Mallard (*Anas platrhynchos*), and Swamp Sparrow (*Melospiza georgiana*; Peck and James 1983, Timmermans 2001, Poole and Gill 2002). We will use the black tern as our representative species for evaluating the impact of water level changes on this important ecological guild (groups of species that exploit the same resources in the same way) of birds.

The black tern is designated as a Vulnerable Species by the Ontario Ministry of Natural Resources and endangered or a species special concern in many Great Lakes states, including Wisconsin, Michigan, and Ohio. It has been a candidate for federal listing under the US Endangered Species Act. In the upper Great Lakes region, black terns occur mainly along the shorelines of Lakes Michigan, Huron, and eastern Lake Superior (Brewer et al. 1991; Chu 1994; Currier 2000). Black tern populations have been decreasing since the 1960s (Peterjohn and Sauer 1997). Specific hydrologic conditions are needed for black tern habitats, especially stable water levels during the breeding season (Mortsch et al. 2006).

Temporal Validity: Black terns nest in the upper Great Lakes region from mid-May through early to mid-August (Chu 1994; Currier 2000). However, in northern Michigan, nesting has been observed to begin in late May and early June and extend to late July (Cuthbert 1954; Bergman et al. 1970). Eggs are incubated for 17 to 22 days, and young fledge (bird is old enough to fly away from the nest) 19 to 25 days after hatching. We define from June 1 through August 15 as the period of concern for water level change for the St. Marys River.

Spatial Validity: Our black tern PI is timed for the St. Marys River area but can be applied more broadly to lakes Michigan and Huron with an expansion of the temporal validity period.

Hydrology Link: Nests are vulnerable to flooding and destruction by wave action, conditions that could be exacerbated by increases in water level or its variability during the breeding and nesting seasons (Shuford 1999; Naugle 2004; Mortsch et al. 2006).

Algorithm: Black terns have been documented to build nests in water ranging in depth from 0.2 to 1.2 m (Dunn 1979; Currier 2000; Alsop 2001; Maxson et al. 2007). Average water depth at nest sites is about 0.5 to 0.6 m deep (Mazzocchi et al. 1997; Zimmerman 2002). Stable water levels during nesting are critical for nesting success. Using an average nest water depth of 0.6 m and the maximum range of 1.2 m, we estimate that a rise in water level of 0.6 m would impact nesting success because of flooding resulting in water depths higher than normally used. Thus, an increase in water level during the nesting period (June 1 -August 15) of 0.6 m would be unsuitable for nesting and no change in water level would be optimal. The PI plot below shows this relationship and links Lake Huron water levels and black tern nesting success.

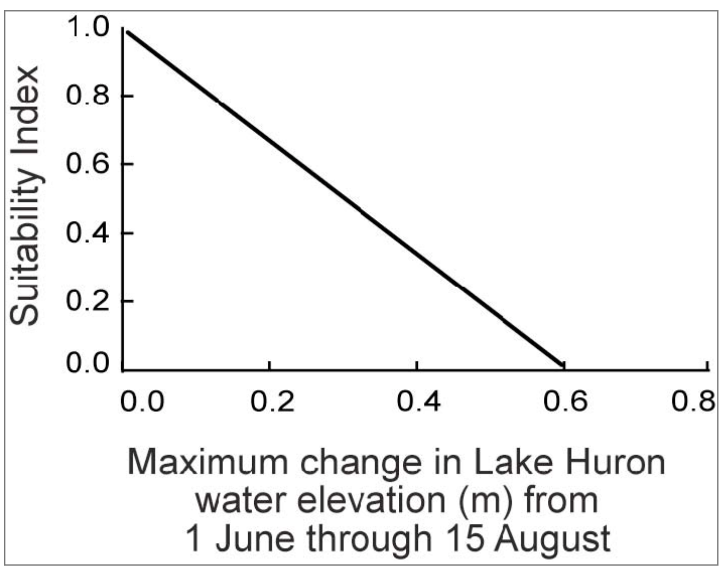

Figure 1. Suitability index for black tern nesting success based on Lake Huron water level.

Coping Zone Criteria: A threshold for this PI is 0.5 on the suitability scale, which corresponds to a maximum change in Lake Huron water level of 0.3 m. This threshold was selected to minimize any loss of nesting habitat. The black tern is a conservation priority in the multiple states and in Ontario, and its represents other marsh nesting bird that are also conservation priorities. The “Zone B” and “Zone C” rules for this criterion are defined as follows:

- **<u>SMH-02 Criterion</u>**:
  - <u>Zone B</u>: Maximum change in Lake Huron water level during the June-August period is greater than 0.2 meters for any given year.
  - <u>Zone C</u>: Maximum change in Lake Huron water level during the June-August period is greater than 0.3 meters for any given year.

Calibration Data: Study results reporting microhabitat conditions of black tern nesting sites were used to parameterize the PI. References cited provide the source of water depths used for nest site selection.

Validation Data: The model provided is based on multiple published studies; however, a test of the relationship developed has not been tested with measured nesting success.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. Nesting success has a major influence on species abundances.
2. Nesting success declines with water level changes beyond the average conditions and maximum range used by the species.
3. Black terns select nesting sites based on the water depth ranges and emergent wetland conditions early in the nesting period.

We consider this PI very sound and reliable because it was developed from multiple publishes studies with similar water level values. Also, the threat of nest flooding and wave impacts brought on by water level changes has been repeated in multiple accounts of causes for the species decline.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

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Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, North Dakota.

Fact Sheet ID: 28

Performance Indicator (PI) Name/Short Description: Submerged Aquatic Vegetation (SAV) – habitat suitability index (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Kristin Arend and Pariwate Varnakovida

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is based on the relationship between Lake Huron water levels and the percent change in area suitable for SAV growth to determine a suitability index for SAV habitat.

SAV beds primarily occur on clay substrate throughout the St. Marys River (SMR) system at water depths of 2.0 to 7.0 m (Duffy et al. 1987). Clay substrate dominates within these depth ranges throughout the SMR (Liston et al. 1980; Liston et al. 1986), providing a substantial amount of suitable habitat for SAV communities (Liston et al. 1986). The spatial distribution, species composition, and biomass of SAV beds in the SMR have been relatively stable since 1935 (Liston et al. 1986; Williams and Lyons 1991). Total wetland area in the SMR has changed only 1.6% (Williams and Lyons 1991), with interannual fluctuations driven by variation in water elevation across a range of 1.04 m (Williams and Lyon 1991; Bray 1996). Intra- and interannual fluctuations in water elevation are thought to help maintain these nearshore, wetland habitats in an early successional state (Williams and Lyons 1991; Bray 1996).

Ecological Importance/Niche: The structural complexity and reduced wave action provided by SAV beds are important functions of nearshore ecosystems (Strayer and Findlay 2010). SAV beds reduce erosion and turbidity by stabilizing clay sediment (Liston et al. 1986). SAV beds are highly productive areas that support diverse assemblages of macroinvertebrates and fishes. SAV contributes to the majority of primary productivity in the SMR (Liston et al. 1980; Williams and Lyons 1991). They are an important source of food for decomposers (Liston et al. 1980) and of food and cover for a diverse and abundant macroinvertebrate community (Liston et al. 1980 [and references therein]; Duffy et al. 1987; Edsall and Charlton 1997). Macroinvertebrates are more than five times as abundant outside of the navigation channel compared to within the navigation channel (Liston et al. 1980). SAV beds in the SMR also provide spawning and nursery habitat to a high proportion of Great Lakes fish species (Liston et al. 1980; Lane et al. 1996a,c) and resident habitat to warmwater fishes (e.g., Centrarchids; Lane et al. 1996b). SAV support the larger SMR fish community by serving as an important link in lower food web material exchange (Liston et al. 1980).

Temporal Validity: SAV beds begin to develop in early spring (at 5°to 6° C), with peak biomass in late August or early September (Liston et al. 1986). We define from May 1 through September 31 as the period of concern regarding water elevation change effects on SAV in the SMR.

Spatial Validity: Our SAV PI is specific to the cooler thermal regime and higher water clarity of the SMR and Upper Great Lakes. The PI includes the lower SMR starting below the main rapids at Sault Ste. Marie, Ontario, and extending through the north channel ending at the head of Lake George,the main channel through Lake Nicolet and its east and west branches ending at the head of Lake Munuscong. This area includes much of the area included in Liston et al (1986) and Williams and Lyon (1991) and some of the area included in Bray (1996). Lake George was not included in our PI due to data limitations (see below) and because the primary sediment in Lake George is sand, which does not support SAV (S. Greenwood, Ontario Ministry of Natural Resources, personal communication; K. Arend, personal observation). This PI directly applies to lower reaches of the SMR included in our analysis. The indicator also can be applied more broadly to the upper SMR, Lakes Superior and Huron, and northern Lake Michigan by modifying the temporal period (to account for effect of different thermal regimes on length of growing season) and depth range (to account for SAV occurrence at greater or shallower depths under conditions of greater or lower light penetration).

Hydrology Link: SAV bed area is determined primarily by water depth (Williams and Lyon 1991), but also substrate, slope, water clarity, and water velocity (Liston et al. 1980; Liston et al. 1986; Duffy et al. 1987). Changes to water elevation will impact the availability of suitable habitat along and extending into the SMR channel from the shoreline through direct or indirect effects on these additional factors.

Algorithm: Deep SAV beds have been documented to extend away from the river shoreline from a 2.0 m minimum depth to a 7.0 m maximum depth in the lower SMR (Liston et al. 1986). SAV primarily occupies clay substrate, which is the dominant substrate type in the SMR. Bray (1996) similarly determined areal of extent of lower SMR wetlands by defining SAV as occupying depth contours < 6.0 m. Contour and depth surfaces of the SMR in the areas described in the “Spatial Validity” section above were created using Geographic Information Systems (GIS). Depth data and the SMR boundary were provided by Fisheries and Oceans Canada, Sea Lamprey Control Centre and included over 21,000 sampling points collected during 1993 to 2009 (Figure 1). The SMR boundary was manipulated to fit our study area. The shipping channel was digitized from the National Oceanic and Atmospheric Administration’s (NOAA) coast survey map. The Michigan boundary was downloaded from the Michigan Geographic Data Library. All data were projected to WGS84_1984_UTM_Zone_16N.

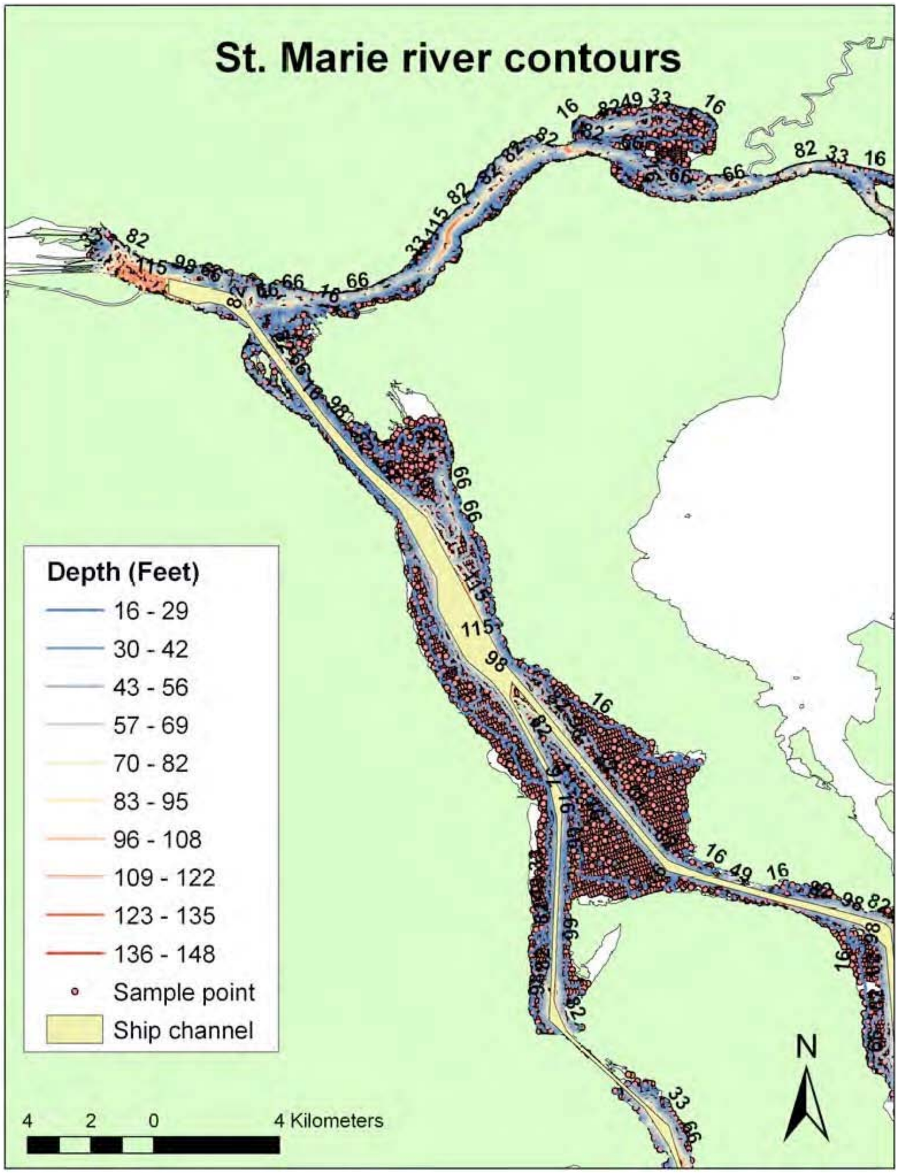

Figure 1. Spatial extent of the St. Marys River analyzed; dots represent depth sampling points, colored lines represent depth intervals (ft), and the shipping channel is indicated in yellow.

Raster analysis and the interpolation scheme available with the spatial analysis extension in ArcGIS were used to interpolate the sampling points and create depth maps corresponding to 0.5 m Lake Huron water elevation intervals ranging from 174.5 to 177.5 m. This elevation range represents an approximate 2.0 m decrease and 1.0 m increase in water elevation compared to the mean water elevation during May through September (i.e., the SAV growing season), 1921-2009 (United States Army Corps of Engineers 2010). The Inverse Distance Weighted method with a power of 2 and a search radius of 12 points was employed with a pixel size equal to 10 m × 10 m. Raster files were then converted to image format for ERDAS IMAGINE (collection of software tools designed specifically to process geospatial satellite imagery) inputs using a pixel depth of 32 bits. The Model Maker tool was used to query 2.0 to 7.0 m depth pixels (except for these depths present in the shipping channel) and overlaid with the study site (Figure 2). The total area of the 2.0 to 7.0 m depth range at each 0.5 m water elevation interval was calculated from the number of 2.0 to 7.0 m depth pixels (Figure 3).

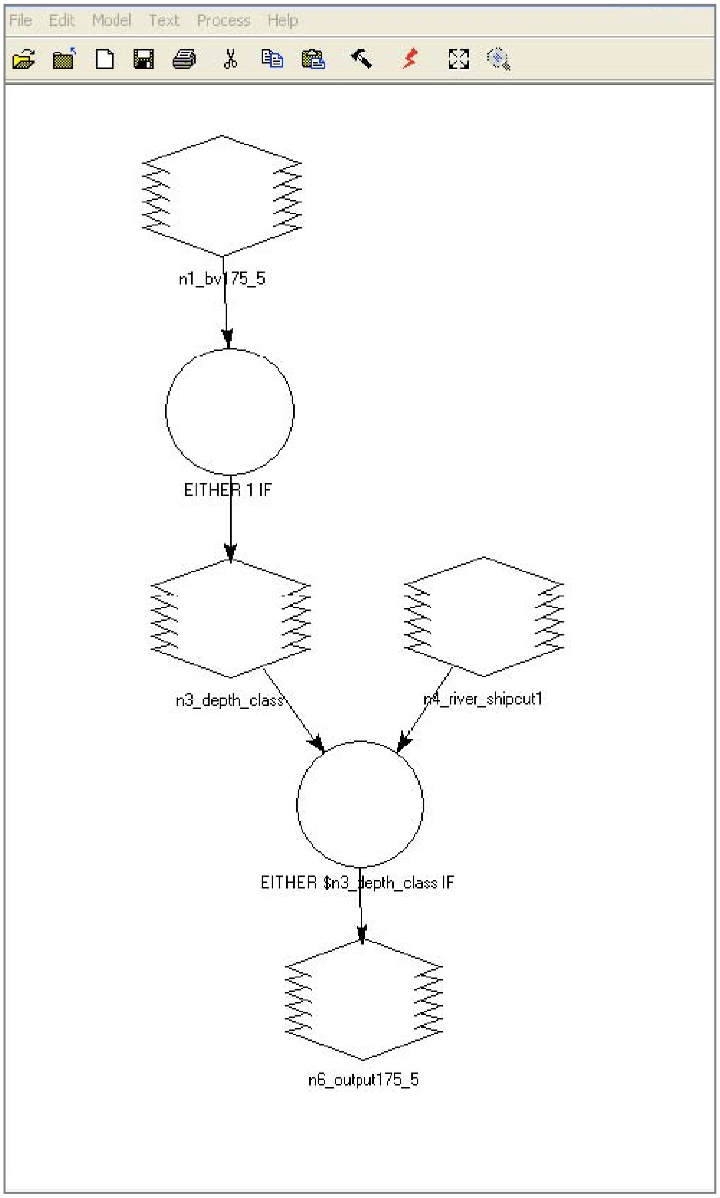

Figure 2. Process structure in the ERDAS Model Maker tool.

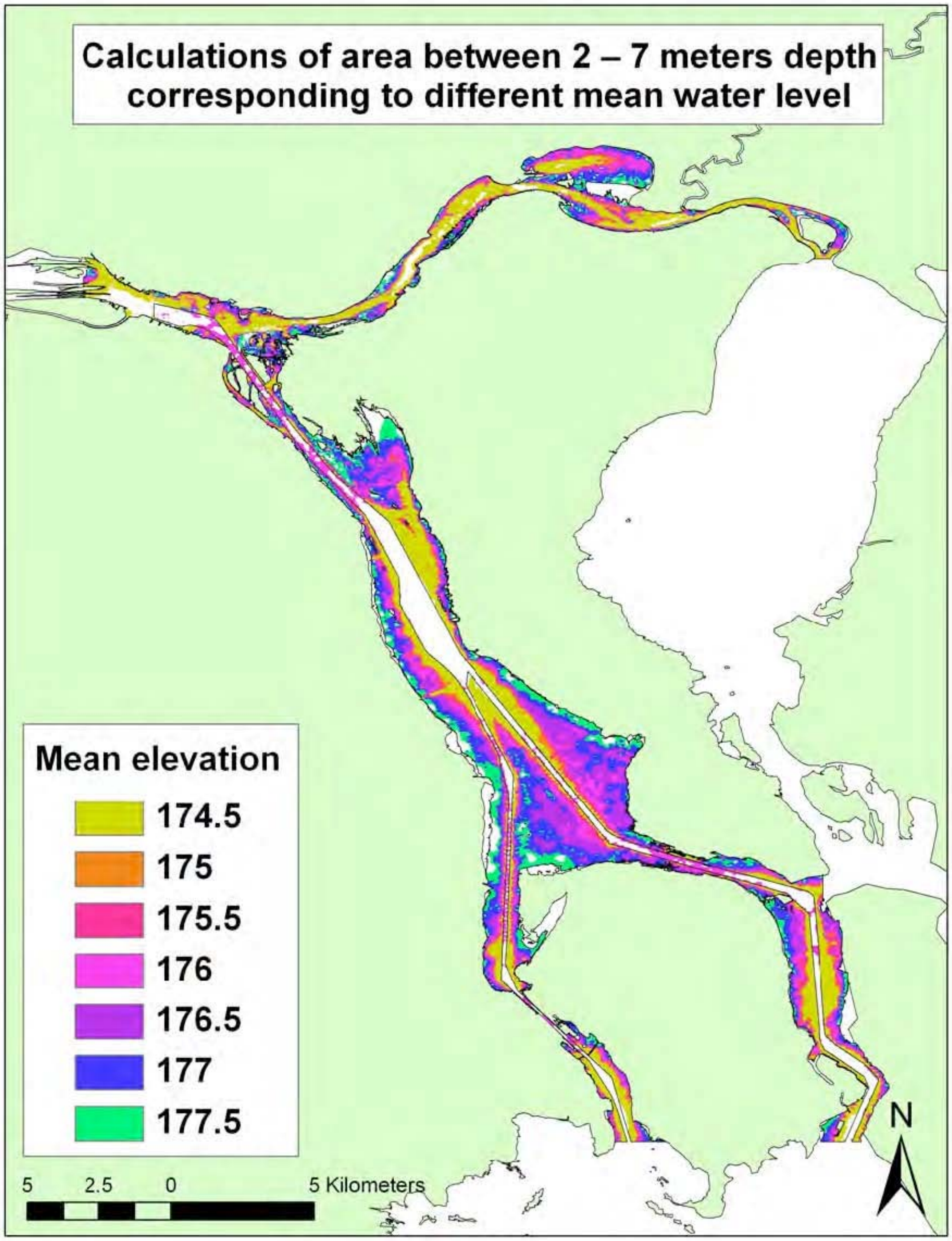

Figure 3. Area of the 2 to 7 meter depth range for each 0.5 m water elevation interval.

Percent change in connected backwater habitat area for each 0.5 m Lake Huron water elevation interval was calculated as follows:

<u>(area at 0.5 m inteval – area at 176.5 m)</u> / <u>(area at 176.5 m)</u>

Suitability scores range from 1 to 0, respectively, for maximum 35% gain in SAV suitable area at 177.5 m and a 55% percent loss in SAV suitable area at 174.5 m.

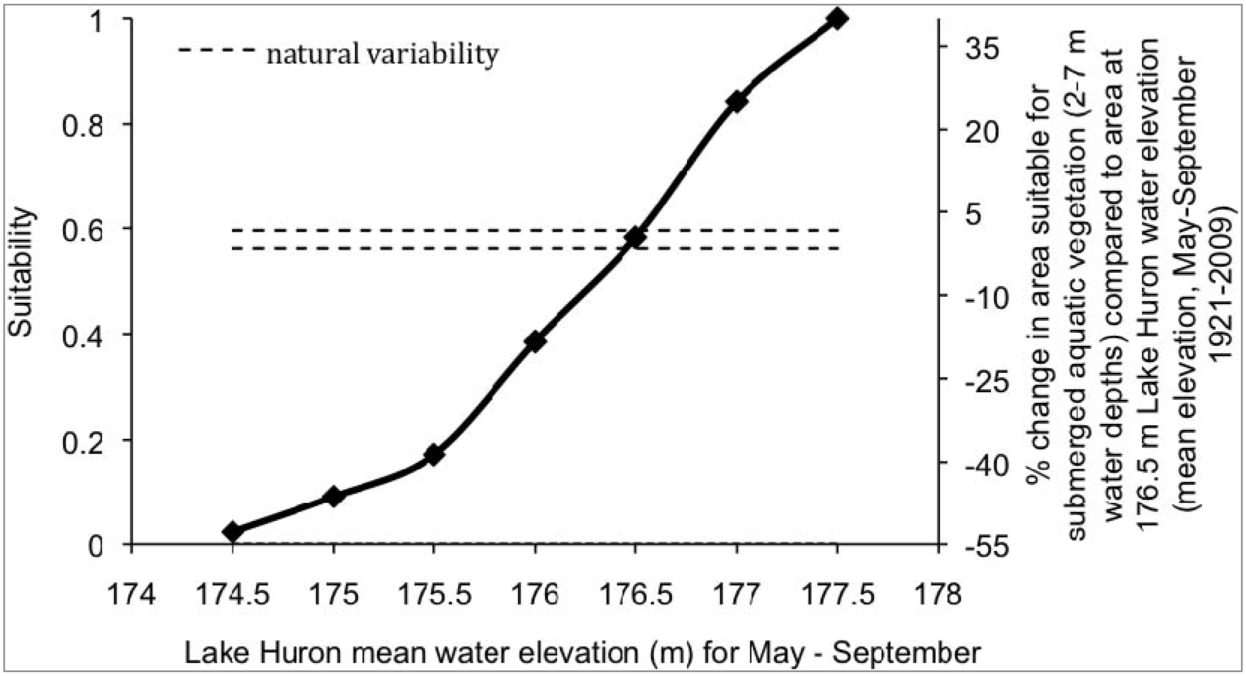

Figure 4. Relationship between Lake Huron water levels and the percent change in area suitable for SAV growth to determine a suitability index for SAV habitat.

Data for SAV "only" wetland areas were not available to our knowledge; however, we assume that SAV respond less strongly to water elevation change than emergent vegetation based on data presented in Williams and Lyon (1991). Natural variability in percent change in SAV suitable area was estimated as $\pm$1.6%, based on the average percent change in wetland (SAV and emergent vegetation) area in Lake Nicolet between 1939 and 1985 (Williams and Lyon 1991).

Coping Zone Criteria: A threshold for maximum percent loss of SAV was identified as 55%, which corresponds to a suitability index of zero and equals the percent difference between the minimum and maximum wetland (SAV and emergent vegetation) area estimated from air photos for the Canadian shoreline from Gros Cap to Hay Bay and including St. Joseph Island in 1935, 1949, 1964, 1973, and 1981 (Bray 1996). The "Zone B" and "Zone C" rules for this criterion were established as follows, based on the relationship shown in Figure 1:

- **SMH-03 Criterion**:
    - Zone B: Mean spring/summer/fall (May-Sep) water level in Lake Huron is less than 174.5 meters for any given year.
    - Zone C: Mean spring/summer/fall (May-Sep) water level in Lake Huron is less than 174.5 meters for 3 or more consecutive years.

Calibration Data: Study results reporting depth ranges and locations for SAV beds in the SMR were used to parameterize the PI. References provided report the depths at which SAV occur extending into the channel from the shoreline and the areal extent of SAV along the river from the late-1930s through the early-1980s.

Validation Data: The model provided is based on published studies; however, a test of the relationship developed has not been conducted with measured SAV area.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. We have modeled response of deep SAV, which occurs, on average, within a depth range of 2.0 to 7.0 m. Effects of water elevation change on shallow SAV habitat present in backwaters are reflected in the Backwater Connectivity PI.
2. Water elevation (i.e., depth) is more of a limiting factor determining SAV distribution than water velocity.
3. Changes in SAV area over time primarily have been in response to changes in water elevation as opposed to human activities (Bray 1996).
4. SAV area declines under lower water elevations and increases under higher water elevations.

We consider this PI to be sound and reliable because it was developed from multiple published studies with similar depth range values.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

Documentation and References:

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Knoecklein, F. Koehler, R. Ligman, R. O'Neal, M. Siami and P. Roettger. 1986. Limnological and fisheries studies of the St. Marys River, Michigan, in relation to proposed extension of the navigation season, 1982 and 1983. Final Report, U.S. Fish and Wildlife Service, Washington DC. 828 pp.

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Fact Sheet ID: 29

Performance Indicator (PI) Name/Short Description: Emergent Wetlands – total surface area (Lake Nicolet, St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Mark Bain

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric estimates the emergent wetland area (hectares) in Lake Nicolet as a function of Lake Huron water levels.

Along the channels and lakes in the St. Marys River system there are extensive emergent wetlands. These are dominated by three species: hardstem bulrush (*Scirpus acutus*), bur reed (*Sparganium eurycarpum*), and spike rush (*Eleocharis smallii*). These plant taxa and emergent wetlands are sensitive to water level change. Over nearly a half century the area of these wetlands have been photographed and mapped in Lake Nicolet, which is a large water body in the St. Marys River. Changes in Lake Huron water elevation have had a clear effect on the extent of emergent wetlands; a formulae was developed to represent this relationship by Williams and Lyon (1991). This relationship was converted to a suitability index chart showing the effect that Lake Huron water surface elevation has on the area of emergent wetlands in Lake Nicolet. This PI captures a hydrologic determinant of emergent wetland area in the St. Marys River below the point where river flow influences water level. Almost all of the extensive emergent wetlands are under the influence of Lake Huron water level, and these wetlands are especially important to river ecology and biological support.

Ecological Importance/Niche: Emergent wetlands in the Great Lakes are important habitats, supporting birds, mammals, fish, invertebrates, and overall biological productivity. For example, three migratory bird species often listed as conservation priorities nest in emergent wetlands: least bittern (*Ixobrychus exilis*), king rail (*Rallus elegans*), and black tern (*Chlidonias niger*; Evers 1997; Ciborowski et al. 2008). Also, emergent wetlands are important to migratory waterfowl such as the mallard (*Anas platyrhynchos*), the blue-winged teal (*Anas discors*), and the American black duck *(Anas rubripes*). The muskrat (*Ondatra zibethicus*) is a keystone (species that plays a fundamental role in maintaining the plants and animals in an ecosystem) mammal in Great Lakes wetlands because they feed on large plants in wetlands, clear channels, create open water areas and promote the patchiness of wetland habitats (Errington 1961). About a quarter of all Great Lakes fish species are strongly associated with emergent wetlands (Edsall and Charlton 1997) and many of these species use emergent wetlands for spawning and rearing habitats.

In the St. Marys River emergent wetlands serve multiple critical roles. They serve as key spawning, nursery, and feeding areas for 44 fish species of the river. Because the river has a very high water turnover rate, pelagic productivity by phytoplankton and zooplankton is minimal (Duffy 1987). The complex structured habitat formed by emergent wetlands provides more than 90% of the rivers overall dry weight biomass production (Kauss 1991). Also, benthic invertebrate productivity on a per unit area basis exceeds all other habitats including the rapids

(Kauss 1991). Overall, emergent wetlands are key habitats in the Great Lakes and they are especially valuable in the St. Marys River because of the rapid flow of water through this system (Liston and McNabb 1986; Duffy et al. 1987).

Temporal Validity: The PI is based on nearly a half century of carefully assembled data. Therefore, the PI can be considered sound for the range of water levels shown and be considered indicative of predicted effects of water level management.

Spatial Validity: The PI was developed on Lake Nicolet which is a major waterbody in the St. Marys River system. The spatial application of the PI is appropriate for all areas of the river system under the influence of Lake Huron water level. Areas downstream of the Little Rapids and the Lake George Channel below Soo Harbor are not significantly influenced by variations in river volume (ILSBC 2002; Bain 2007). There are very limited wetlands in the Soo Harbor reach because it is largely composed or urban and bulkheaded shoreline (Bain 2007). Thus, the PI covers most of the river system and almost all areas where wetlands are abundant. Because of Lake Nicolet's size and central location in the river system, this waterbody can be considered representative of the St. Marys River wetlands.

Hydrology Link: There is a strong relationship between water level and the area of emergent wetlands for the St. Marys River (Kauss 1991), the Great Lakes (Kelsall and Leopold 2002; Ciborowski et al. 2008; Mortsch et al. 2006, 2008), and waterways in general (Harris and Marshall 1963; Dabbs 1971; Spence 1982). Therefore, representing this relationship in a PI provides a close link between water management and the area of emergent wetlands.

Algorithm: The US Army Corps of Engineers (Williams and Lyon 1991) assembled summer and fall aerial photographs of Lake Nicolet for seven years, 1939 to 1985. Across these years, water levels varied more than 1 m. Lake Nicolet water level is primarily determined by the elevation of Lake Huron because it is downstream of the control point where river volume influences water levels (Little Rapids, ILSBC 2002; Bain 2007). Emergent wetland boundaries were defined and entered into a Geographic Information System (GIS). There was a clear negative relationship between average annual water level and the area of emergent wetlands (linear regression, $P < 0.05$). For Lake Nicolet, there was a 32% change in the area of emergent wetlands through the 46 year study period. This relationship is shown in Figure 1 below with a suitability index axis for inclusion in the overall water management model.

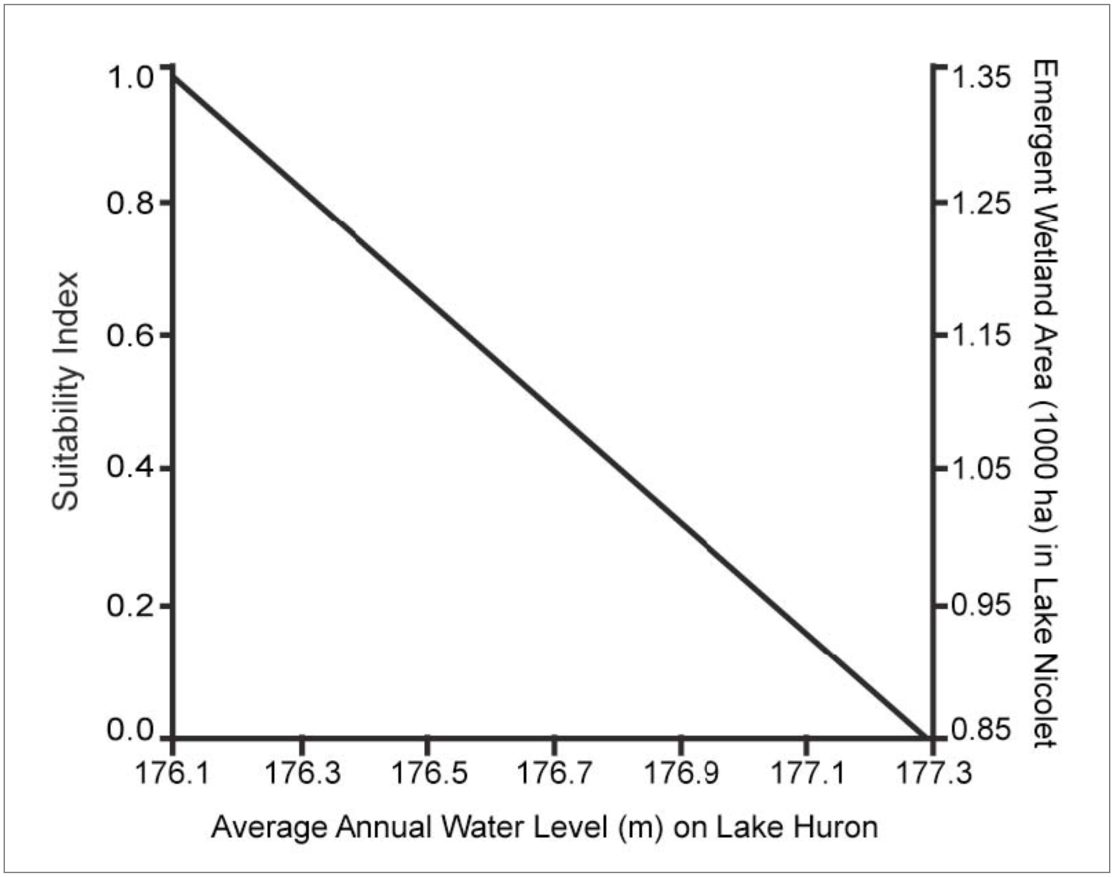

Figure 1. Relationship between Lake Huron water levels and emergent wetland area in Lake Nicolet to determine a suitability index for habitat.

Coping Zone Criteria: No specific coping zone criteria were developed for the Lake Nicolet emergent wetland PI because additional research is needed to confirm the validity of the relationship described in Figure 1 and appropriate thresholds for this PI.

Calibration Data: Data used to form this relationship were assembled, analyzed, and reported by Williams and Lyon (1991). The quality is high and exacting methods were used to define the area of emergent wetlands over years of different average water levels. The years were widely spaced in time yielding independent measure of both water level and emergent vegetation area.

Validation Data: The relationship used here was statistically tested and significant. The years used were independent in time and formed a significant linear regression. Therefore, the data used constitute a very reliable basis for the PI and this indicator was tested and found to be justified by the analyses.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. The years investigated represent future responses to water level change.
2. The study site is typical and reflective of the river system downstream of the water level control points: Little Rapids and the Lake George Channel.

3. Water level is a key factor in shaping the extent of emergent wetlands.

The PI shows a negative relationship between water level and area of emergent wetlands. Other studies have also reported that annual low water levels in the Great Lakes results in increased emergent wetland area (e.g., Ciborowski et al. 2008; Mortsch et al. 2006, 2008). Thus, the PI relationship is consistent with other sites in the Great Lakes and reflects relationships reported from other sites.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

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Fact Sheet ID: 30

Performance Indicator (PI) Name/Short Description: Backwater Habitat Connectivity – suitability index (St. Marys River)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Kristin Arend and Pariwate Varnakovida

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is a suitability index for backwater connectivity based on a relationship established between Lake Huron water levels and the area of backwater habitat. Backwater habitats, such as embayments and lagoons, provide slow-moving, warm water habitat that is protected from the higher velocity, colder waters of the main St. Marys River (SMR).

Ecological Importance/Niche: Backwater habitats include barrier protected and connecting channel wetlands and embayments. Along with other nearshore wetlands, backwater habitats are of high quality relative to Great Lakes wetlands overall (Harris et al. 2009). Backwater habitats are accessible from/to the river, enabling exchange of materials (e.g., nutrients) and organisms with the main river. Riverine and Great Lakes fishes depend on these areas as warm water refuges in the spring (Brazner and Beals 1997; Edsall and Charlton 1997) and for important spawning and rearing habitat (Goodyear et al. 1982; Harris et al. 2009). Maintaining connectivity between backwater habitats and the open river is vital for fishes that occupy each habitat type during different life stages (Harris et al. 2009). Backwater habitats also support unique plant and animal communities, increasing species diversity of riverine floral and faunal communities. For example, backwater habitats support submerged and emergent marsh communities composed of species that require slow water movement and reduced wave action (e.g., herbaceous species, species with long-floating propagules (plant part that is capable of independent propagation of a new individual), and shallow submerged aquatic vegetation (SAV) (Nilsson et al. 2002).

SMR coastal wetland habitat loss is listed as a beneficial use impairment in the SMR Area of Concern (Selzer 2007). These marshes are an important conservation priority because they provide essential habitat for waterfowl, migratory bird species, and native fishes that rely on wetlands for at least one life history stage (Harris et al. 2009). Furthermore, SAV beds provide cover and complex habitat for macroinvertebrates and smaller-bodied fishes (Jude and Pappas 1992; Gore and Shields 1995; Randall et al. 1996; Brazner and Beals 1997). Great Lakes macroinvertebrate and fish species diversity are enhanced by the availability of habitat for species with less streamlined morphology (Gore and Shields 1995) and for warm water fish species (e.g., smallmouth bass, *Micropterus dolomieu*; northern pike, *Esox lucius*; and yellow perch, *Perca flavescens*; Edsall and Charlton 1997).

Temporal Validity: Backwater habitats in the lower SMR are available year-round; thus, our PI assesses areal response to mean annual Lake Huron water elevations. Percent change in backwater habitat area was based on mean backwater habitat area at a Lake Huron water elevation of 176.43 m, which is the mean annual water elevation from 1921 to 2009 (United States Army Corps of Engineers 2010).

Spatial Validity: Our backwater connectivity PI is limited to the lower river, where the vast majority of this habitat occurs. Backwater habitat included major embayments or lagoons (e.g., Little Lake George, Echo Bay, Baie de Wasai, and Maskinonge Bay) with direct connections to the SMR and narrow, shallow areas within the SMR located between islands and the Canadian or U.S. shoreline (e.g., east of East Neebish Island, east of the island chain that includes Maskinonge Island, and east of Squirrel Island; Figures 1 and2). These relationships can be applied more broadly to the upper Great Lakes where similar habitat occurs and is connected to the open lake through narrow and/or shallow openings.

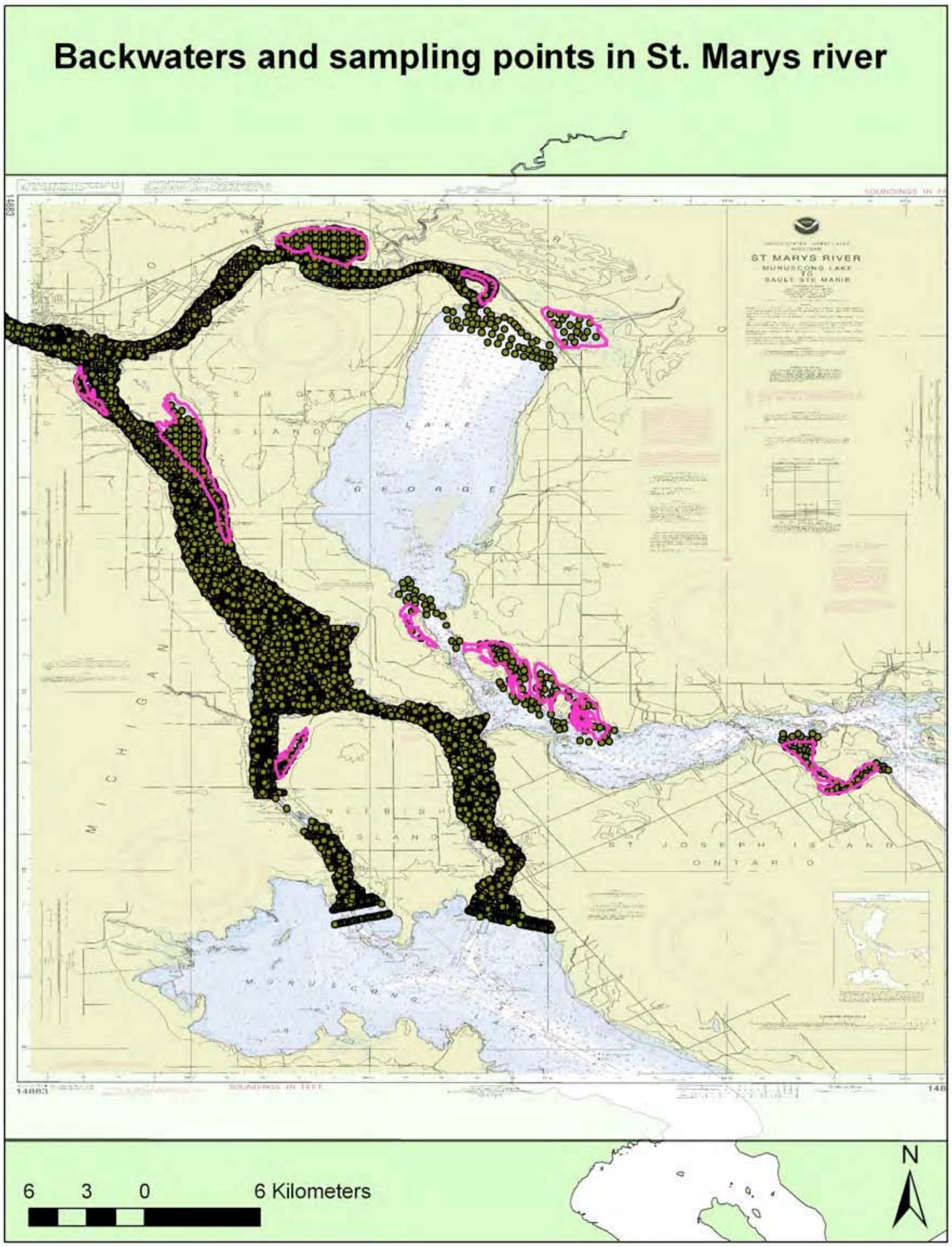

Figure 1. Spatial extent of the St. Marys River analyzed; dots represent depth sampling points; pink lines outline the backwater habitats considered.

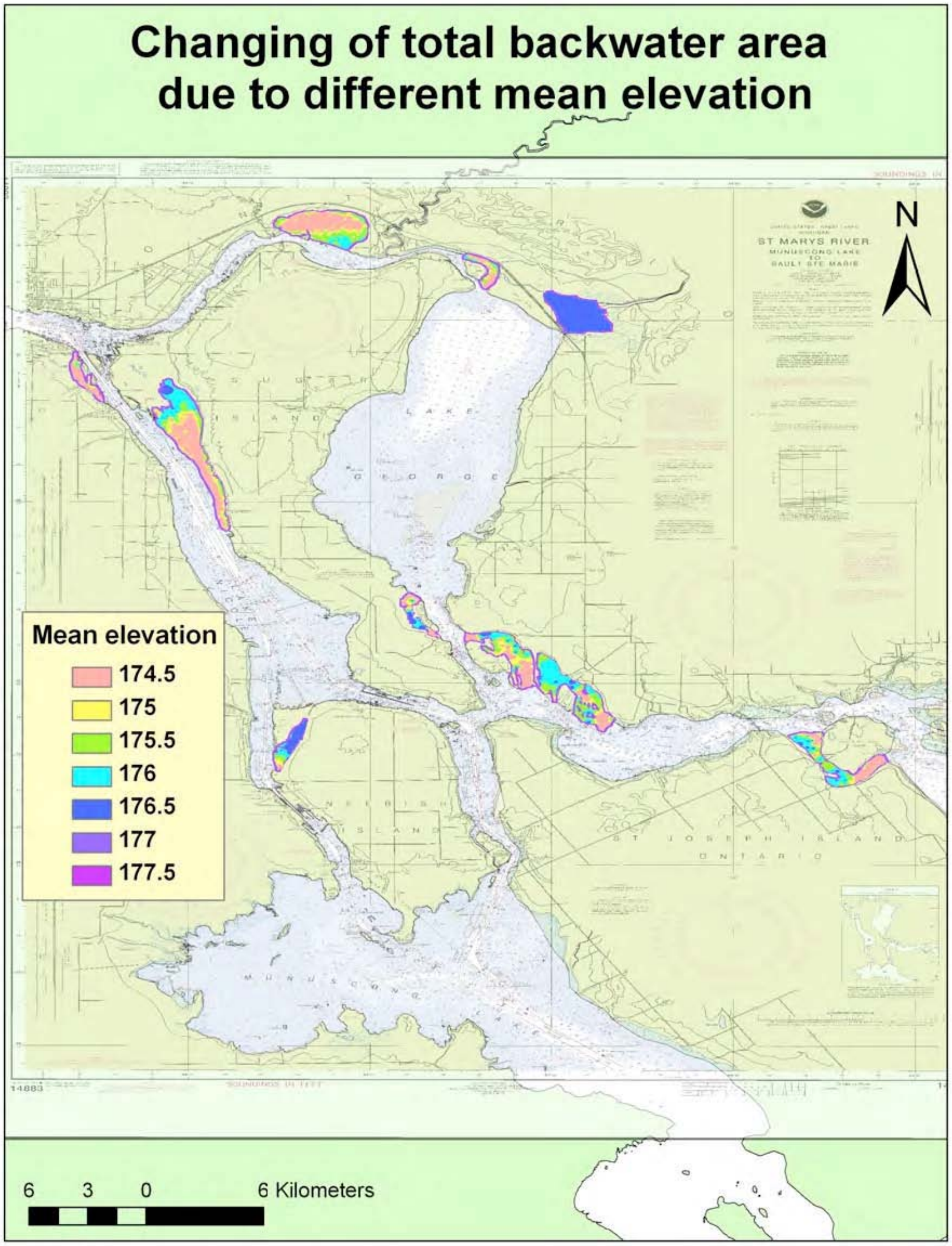

Figure 2. Total backwater habitat area at each 0.5 m water elevation interval ranging from 174.5 m to 177.5 m.

Hydrology Link: Backwater habitat connectivity to SMR nearshore and channel habitat is determined by water elevation. Lower water elevations can result in hydrologic separation of backwaters from the SMR through exposure of sand bars or other bathymetric features above the surface of the water column. Low water elevations also can cause loss of backwater habitat through dewatering of shallow areas. We account for both types of habitat loss in this PI.

Algorithm: Backwater connectivity was defined as the area (m^2) of backwater habitat having a direct surface water connection to the main SMR channel. Geographic Information Systems (GIS) was used to create contour and depth surfaces from depth data available for the SMR and to calculate backwater area for 0.5 m Lake Huron water elevation increments ranging from 174.5 m to 177.5 m. This elevation range represents an approximate 2 m decrease and 1 m increase in water elevation compared to the mean annual water elevation from 1921 to 2009 (United States Army Corps of Engineers 2010). Depth data and the SMR boundary were provided by Fisheries and Oceans Canada, Sea Lamprey Control Centre (SLCC) and included over 21,000 sampling points collected during 1993 to 2009 (Appendix 1). The SMR boundary was manipulated to fit our study area. The shipping channel, 10 backwaters, and depth in areas not sampled by SLCC were digitized from the National Oceanic and Atmospheric Administration's (NOAA) coast survey map that was georeferenced to a base map (Figure 1). The Michigan boundary was downloaded from the Michigan Geographic Data Library. All data were projected to WGS84_1984_UTM_Zone_16N. Raster analysis and the interpolation scheme available with the spatial analysis extension in ArcGIS were used to interpolate the sampling points and create depth maps corresponding to 0.5 m water elevation intervals. The Inverse Distance Weighted method with power of 2 and search radius of 12 points was employed with pixel size set to 10 m × 10 m. Raster files were then converted to image format for ERDAS IMAGINE inputs using a pixel depth of 32 bits.

The Model Maker tool in ERDAS was used to create two models (Figure 3a-b). The first model calculated backwater area for each 0.5 m elevation interval between 174.5 and 176.5 m as follows: (1) identified pixel values greater than 0 and overlaid them with the digitized backwater boundary; and (2) checked if the backwater entrance no longer has a surface water connection to the river. If the backwater entrance was disconnected, then the entire backwater area was deducted from the total backwater habitat area value (i.e., summed area of all backwater habitats considered). Therefore, the final value for backwater habitat area represents area of only those backwaters with a surface water connection to the SMR.

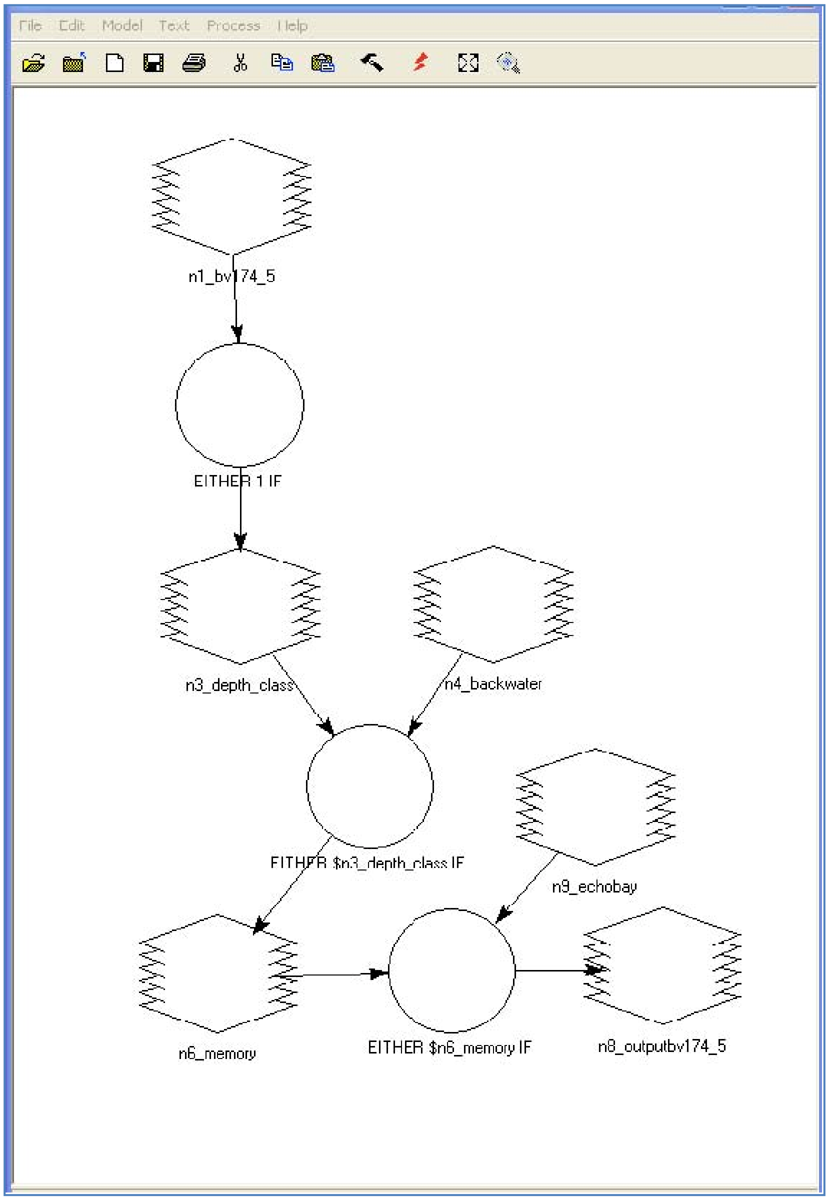

Figure 3a. Model structure used to calculate backwater habitat area at each 0.5 m water elevation interval from 174.5 to 176.5 m.

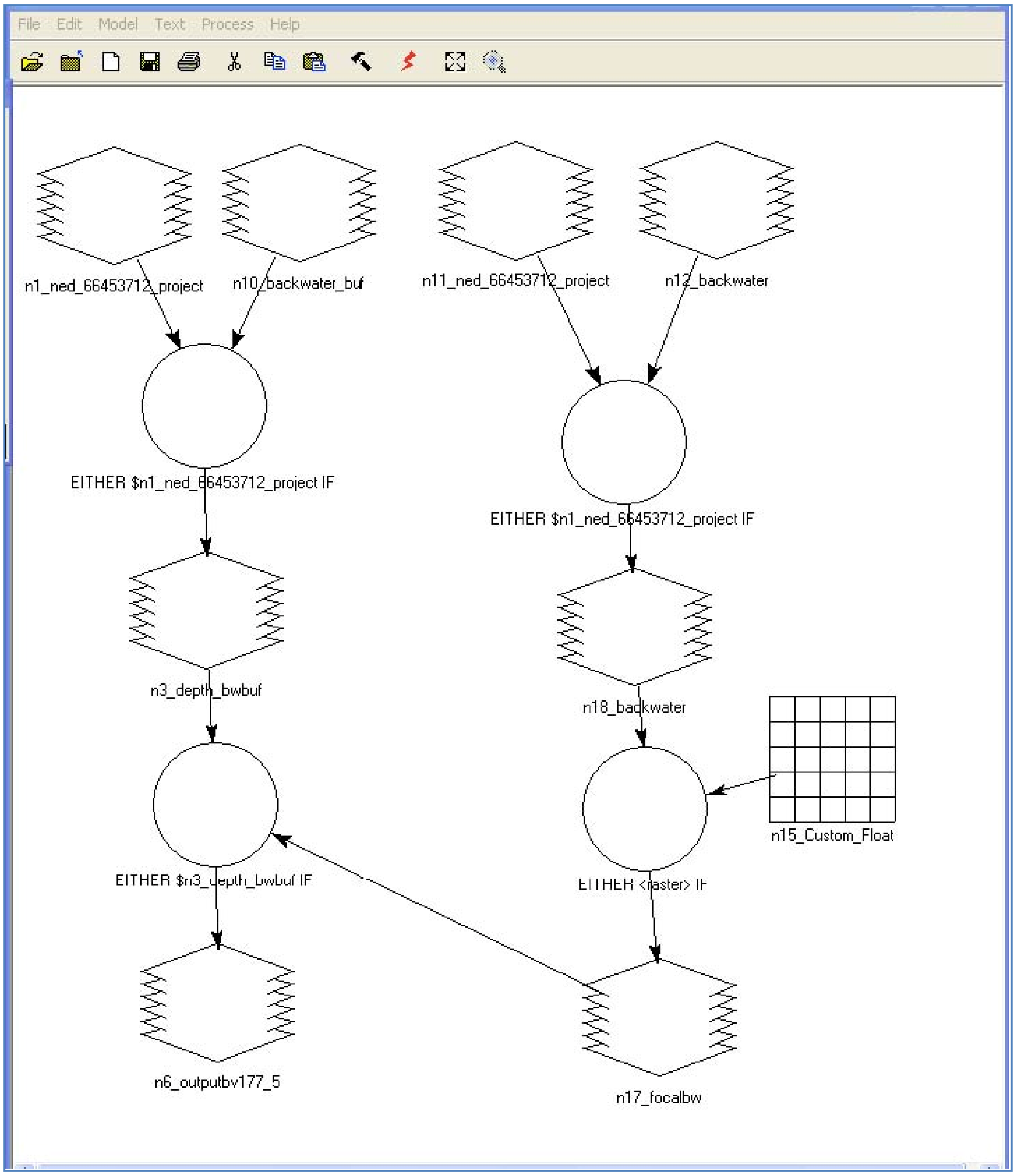

Figure 3b. Model structure used to calculate backwater habitat area for the 177.0 m and 177.5 m water elevation intervals.

The second model was created to calculate backwater area for the 177.0 and 177.5 m elevation intervals. A Digital Elevation Model (DEM) was downloaded from the United States Geological Survey (USGS) National Map Seamless Server (USGS 2010). The model yielded the total conversion of land to backwater habitat at each interval representing water elevation increase beyond the elevation when depth data were collected by SLCC and NOAA. Areal calculations were performed by repeating the following steps for each pixel: (1) clipped backwater boundary and buffered 500 m; (2) used focal operation with 10 × 10 matrices to detect backwater boundary; (3) sequentially simulated water elevation at 177.0 and 177.5 m by adding 0.5 and 1.0 to backwater pixels; (4) identified if the pixel next to the boundary was less than the new boundary added value and, if so, changed that pixel to backwater. Total backwater habitat area was calculated from the total number of pixels identified as backwater (Figure 2).

Percent change in connected backwater habitat area for each 0.5 m Lake Huron water elevation interval (e.g., area at 174.5 m) was calculated as follows:

(area at 0.5 m interval – area at 176.43 m) / (area at 176.43 m)

where backwater habitat area at 176.43 m was estimated by regressing the GIS generated area estimates for each 0.5 m water elevation interval against water elevation:

$$\text{area} = 7.68 \times 10^{6} \times \text{water elevation} - 1.33 \times 10^{9};\ R^{2} = 0.995$$

Suitability index scores range from 1 to 0, respectively, for maximum percent gain in backwater area at 177.5 m and maximum percent loss in backwater area at 174.5 m Lake Huron water elevation.

Coping Zone Criteria: Great Lakes backwater habitats are functionally important for supporting a variety of taxonomic groups, yet are frequently exposed to more concentrated human activities (Mackey and Goforth 2005). Backwater habitats have suffered from and continue to be threatened by loss and degradation due to shoreline development (Harris et al. 2009). Therefore, we set the threshold of habitat loss at 30% beyond the approximately 65% of wetland habitat degradation and loss that has already occurred due to human activities (Harris et al. 2009). This area of habitat loss corresponds to a mean annual Lake Huron water level of 175.6 m. The "Zone B" and "Zone C" rules for this criterion are defined as follows:

- **SMH-04 Criterion**:
    - Zone B: Mean annual water level less than 176.0 meters for any given year.
    - Zone C: Mean annual water level less than 175.6 meters for any given year.

Calibration Data: Studies reporting data that relate backwater habitat area to water elevations in the SMR are not available to our knowledge. Therefore, we used the best available bathymetric data to calculate connectivity and backwater habitat area under different Lake Huron water elevations.

Validation Data: The model provided is based on bathymetric data available for the SMR; however, a test of the relationship developed has not been conducted with measured backwater habitat area.

Risk and Uncertainty Assessment: The following are the main assumptions of the PI model:

1. The functional benefit of backwater habitat to the SMR ecosystem is lost when backwaters become disconnected from the river flow, regardless of whether standing water persists within the backwater habitat.

2. SMR backwater habitats support coastal emergent and submerged wetlands.
3. Additional loss of backwater habitat area could occur as the result of future human development, independent of water elevation change.

Confidence, Significance, and Sensitivity: See related discussion in preceding sections.

Documentation and References:

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APPENDIX C

Enhanced St. Marys River Sea Lamprey Control
Project Description and Work Plan

St. Marys River GLRI Research Coordination
Draft Document for Discussion (Ongoing)

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Project Title: Enhanced St. Marys River Sea Lamprey Control

Total Project Funding: $228,000

Benefit to Organization: The Great Lakes Fishery Commission (commission) was established in 1955 by the Canadian/U.S. Convention on Great Lakes Fisheries. The commission is a multinational organization supported by the Great Lakes States, Province, and the Federal Governments of Canada and the United States. The commission coordinates fisheries research, controls the invasive sea lamprey, and facilitates cooperative fishery management among the state, provincial, tribal, and federal management agencies. The sea lamprey control program (Program) is administered by the commission and its two control agents, the U.S. Fish and Wildlife Service (Service) and Fisheries and Oceans Canada (DFO). The Program is a critical component of fisheries management in the Great Lakes because it significantly reduces fish mortality caused by feeding parasitic sea lampreys, thereby facilitating the rehabilitation of important fish stocks and supporting the economy in the Great Lakes region. The overall objective of this project is to enhance the Program through increased sea lamprey control in the St. Marys River.

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Programmatic Capability: The commission, working with its control agents through annual MOAs, has a long history of successful agreements with federal and non-federal partners both basin-wide and specifically within the St. Marys River. Within the last 3 years, the commission has worked through the following assistance agreements specifically in the St. Marys River:

1. The U.S. Army Corps of Engineers to operate sea lamprey traps at their generating stations.
2. Cloverland Electric Cooperative to operate a sea lamprey trap at their generating station.
3. The U.S. Army Corps of Engineers and Cloverland Electric Cooperative to construct a new trap at the Cloverland generating station.
4. Brookfield Renewable Power to operate sea lamprey traps at their generating station.
5. Research contracts with the University of Guelph and the USGS to study sea lamprey migratory behavior.

In all cases, successful completion and management of the commission's agreements was/is assured by clearly defining the agreement, identifying specific objectives and deliverables, maintaining thorough oversight, and facilitating accurate reporting. The history of the commission meeting reporting requirements for these agreements lies in the submissions of annual progress and completion reports (both the commission and its control agents), and financial compliance statements. Documentation of meeting the expected results was/is also achieved through submissions of annual progress and completion reports, and financial compliance statements.

Brief Project Description: Trapping sea lampreys is an important component in controlling the invasive sea lamprey in the St. Marys River. Trapping occurs at hydropower plants and typically only 40% of the annual spawning population is captured. Sea lamprey behavior in the vicinity of traps remains largely unknown, especially under varying flow conditions, and could be the key to developing trapping innovations that would further suppress sea lampreys. Results will be used to develop plans to move towards achieving a target level of acceptable sea lamprey abundance.

Problem Statement: The sea lamprey is a destructive invasive species in the Great Lakes that contributed to the collapse of lake trout and other native species in the mid-20th century and continues to threaten efforts to restore and rehabilitate the fish community. In support of the GLRI Action Plan's Invasive Species Prevention and Control Focus Area, we plan to implement an on-the-ground project to enhance existing control strategies and to develop new technologies to control the populations of invasive sea lampreys in the Great Lakes region, particularly the St. Marys River, Lake Huron.

Project Location: Upper St. Marys River, Sault Ste. Marie, Michigan 49783. Latitude 46.505, Longitude 84.355.

Proposed Work: This project is directly related to the Great Lakes Restoration Initiative in that it targets increased control of sea lampreys, an established invasive species capable of decimating the Great Lakes ecosystem due to its parasitic nature. Additionally, the St. Marys River has been identified as an Area of Concern (AOC) by the EPA where degradation of fish and wildlife populations is listed as an impaired beneficial use. Increased sea lamprey control efforts will help restore impaired fisheries in the St. Marys River as well as northern Lake Huron and Lake Michigan and may result in a decrease in lampricide treatments in the St. Marys River.

The commission's sea lamprey control program is also linked to the following initiatives:

1. The Great Lakes Regional Collaboration (http://www.glrc.us/initiatives/invasives/index.html), under the Invasive Species chapter, calls for full funding for the commission's sea lamprey management program. Sea lampreys are the one invader that can be controlled, and the control effort is the backbone of fishery restoration and economic benefits of the fishery. Thus, this request is critical to both invasive species control and native species restoration.
2. The commission's Vision (http://www.glfc.org/pubs/SpecialPubs/StrategicVision2001.pdf) calls for healthy Great Lakes ecosystems, integrated management of sea lamprey, and institutional/stakeholder partnerships. All three of those components are supported by this project. Additionally, the Strategic Vision calls for the use of alternative control technologies to accomplish at least 50% of sea lamprey suppression, while reducing pesticide use by 20%, through increased use of current alternative control methods such as sterile-male-release, trapping, and barrier deployment, and at least one new alternative-control method. This project supports an increase in sterile male-release, trapping, and uses at least one new alternative control method.
3. The eight Great Lakes states, federal fishery agencies (e.g. the Service, U.S. Geological Survey, and DFO), the Province of Ontario, and the tribes together developed Fish Community Objectives (http://www.glfc.org/lakecom/) for each of the Great Lakes. Fish community objectives specify the desired fish communities, indicate how those objectives should be met, and outline how the success of the rehabilitation efforts will be measured. The foundation of fish community objectives, including the restoration of native species, is sea lamprey control. Without sea lamprey control, the fishery management agencies would be unable to achieve their objectives.

Stocking of hatchery-reared lake trout was initiated in Lake Huron in 1973 following the implementation of sea lamprey control, but was met with limited success due to the impacts of overfishing and sea lamprey parasitism. In March 1983, the Lake Huron Committee (LHC) established the Lake Huron Technical Committee (LHTC) to plan a coordinated, lake-wide lake trout rehabilitation strategy. The goal of lake trout rehabilitation in Lake Huron is to restore self-sustaining populations that are capable of yielding 1.4 to 1.8 million kg by the year 2020, accomplished by employing stocking strategies, implementing fishery regulations, and continued sea lamprey control (Ebener 1998).

The Drummond Island (northern Lake Huron) refuge has a spawning population of lake trout that could support natural recruitment, but recruitment remains poor (Madenjian et al. 2008). The refuge is located in close proximity to the mouth of the St. Marys River; therefore any additional sea lamprey control applied to the river would benefit recovering lake trout populations. In fact, lampricide applications in the St. Marys River in 1999, 2000, and 2002 were attributed with reducing sea lamprey wounding rates on lake trout in the Drummond Island area (Madenjian et al. 2008). Riley et al. (20007) indicated that there is localized natural lake trout reproduction in Thunder Bay, credited to St. Marys River sea lamprey control efforts. Any increase in sea lamprey-induced mortality would negatively affect this localized population.

The Lake Huron Fish Community Objectives (DesJardine et al. 1995) call for a high level of sea lamprey control on the St. Marys River, which is considered to be the major single source of sea lampreys into Lake Huron. Sea lamprey abundance is considered to be a major impediment to the achievement of fish-community objectives in Lake Huron and demands timely and aggressive management action.

Imperative to controlling Lake Huron sea lamprey populations are the integrated pest management tactics used on the St. Marys River:

1. Trapping of migratory sea lampreys removes spawning-phase sea lampreys from the population before they reproduce;
2. The sterile-male-release technique releases chemically sterilized males captured in trapping operations on Great Lakes tributaries, including the St. Marys River, to spawn with fertile females to form offspring that do not develop beyond the egg stage, and;
3. Lampricide spot treatments are conducted annually to reduce the abundance of sea lamprey larvae and reduce recruitment of sea lampreys.

This project will focus on sea lamprey trapping operations conducted at hydropower plants during the spawning migration and on sea lamprey nest surveys conducted in the international rapids, typically June to July. Historically, trapping efficiency on the St. Marys River averages about 40% of the overall river population. New understanding of the environment and sea lamprey behavior near the sea lamprey traps, however, could lead to increases in trapping efficiency thereby reducing reproduction and recruitment of larvae to the St. Marys River, and providing more males to the sterile-male-release technique. This, in turn, would lead to reductions in the parasitic population in northern lakes Huron and Michigan.

Sea lamprey trapping currently occurs in conjunction with assessment traps deployed at three hydropower facilities (Cloverland Electric Cooperative, U.S. Army Corps of Engineers, Brookfield Renewable Power) to exploit the sea lamprey's natural tendency to seek out attractant flow during their migration. Peaking and ponding operations of the hydropower facilities have the potential to affect sea lamprey behavior near traps. For example, changes in discharge at the hydropower facilities may change the water levels near the trap entrances, increasing turbulence and air entrainment that may affect how sea lampreys approach the traps. In much the same manner changes in discharge may change the flow patterns near trap sites, either discouraging or prohibiting sea lampreys from entering the tailrace or traps. Sea lamprey behavior over a range of discharges will be evaluated using DIDSON high-resolution sonar imaging. This technology has been used to observe and quantify the behavior of eels and Pacific lampreys at hydropower facilities (Mueller et al. 2008).

Reduced flows through the power generation facilities for short durations during peak spawning will allow divers to observe and remove spawning sea lampreys in the power canal. Information on the distribution of sea lampreys that have been fin-clipped for assessment purposes will allow the control agents to observe the distribution of sea lampreys near the trap sites, and to evaluate the assumption that all sea lampreys are equally available to be trapped. For example, if sea lampreys that have previously been trapped, fin-clipped, and released downstream are found in greater proportions closer to the trap sites, this indicates that some sea lampreys have a greater likelihood of being trapped and/or recaptured, thereby introducing bias into the river-wide estimate of sea lamprey abundance. Evaluation of this assumption is important in developing estimates of sea lamprey abundance in the St. Marys River. Flow manipulations through the power plants will be planned and coordinated with plant operators and the Lake Superior Board of Control to minimize economic impacts to power production.

Other areas within the St. Marys River also have attractant flow attributes, in particular the areas associated with the compensating gates at the head of the St. Marys River rapids. Previous efforts to trap in this area have met with some success, but this site was deferred while new traps were placed at the outflow of Cloverland Electric Cooperative and along the south bank in the Brookfield Renewable Power tailrace. Proposed flow manipulations at the compensating gates will allow for the movement of a portable trap around in this area to find the most efficient trapping site. These activities will be coordinated with the Lake Superior Board of Control.

The opportunity to manipulate discharge in the St. Marys River rapids area will enable the control agents to better evaluate the success of the sterile-male-release technique through the monitoring of sea lamprey nests in the rapids area. This monitoring requires observers to physically locate and sample nests by wading in the rapids (Bergstedt et al. 2003, Kaye et al. 2003). Presently the discharge allocated to the rapids area limits the amount of area that can be safely searched for sea lamprey nests. Lower water levels as a result of reduced discharge through the rapids should enable more nests to be found and sampled from areas that are not currently available.

Due to the timing of the spawning-phase sea lamprey migration and the approval of this proposal, the timeline of the experiment needs to be modified to late 2010 and 2011 (Table 1). Additionally, the plan that determines water allocation across the St. Marys River is being reviewed for modification by the International Upper Great Lakes Study (IUGLS) Team during 2010. The information sought in this proposal was to provide guidance to the Plan Formulation and Evaluation Group in developing alternative water allocation plans. However, field results will not be available until 2011 which will be too late to have an impact on plan development. Therefore, historical data analyses and a proof of concept study will be applied during 2010, allowing the investigators to gather information for the IUGLS and to strengthen the actual experiment during 2011. Field experiments will occur during early June through early August, 2011.

OBJECTIVES:

1. To evaluate how flow, water level, and hydropower peaking and ponding activities affect trapping efficiency.
2. To observe the behavior of sea lamprey in the vicinity of traps, and determine behaviors that may be exploited for trapping, including whether sea lampreys remain attached to the face of the hydropower plants or turbines.
3. To evaluate the feasibility and efficiency of a trapping device placed at the Compensating Gates.
4. To observe the spatial distribution of fin-clipped sea lampreys to evaluate the assumption that all sea lampreys migrate to trap sites and have the potential to be trapped.
5. To determine the feasibility of manually removing sea lampreys from the river bottom with divers.
6. To measure how a reduction in water flow through the rapids area affects the number of nest observations completed by the control agents.

METHODS:

1. During winter 2010-2011, we will collect and analyze historical data to analyze how flow, water

level, and hydropower peaking and ponding activities affect trapping efficiency. During fall 2010 and/or spring-summer 2011, we will measure river height near traps using level loggers while coordinating with hydropower plants to adjust flow at a range of discharges, for example:
   a. minimum hydropower flow;
   b. 10% higher than minimum;
   c. 20% higher than minimum;
2. During fall 2010, we will acquire DIDSON equipment and experiment in the power plant tailraces to identify optimal settings and locations. During May – July 2011, we will document sea lamprey behavior in the vicinity of sea lamprey traps and at the face of hydropower plants using DIDSON high definition sonar-imaging to determine sea lamprey behaviors that affect trap efficiency. We will document:
   a. whether sea lampreys approach traps from above, below, side, or avoid trap entrances;
   b. how sea lampreys enter the traps, either immediately, with hesitation, if they make multiple approaches without entering, or if they enter and leave;
   c. if sea lampreys attach to the dam face and cease searching movements that are necessary for capture.
3. During May – July 2011, we will place a portable trapping device in the Compensating Gates and coordinate with the Lake Superior Board of Control, U.S. Army Corps of Engineers (USACE), and Brookfield Renewable Power to adjust gate settings to accommodate trapping, thereby assessing the:
   a. feasibility and logistics of placing and servicing a trap and likelihood of constructing a permanent trapping structure;
   b. trapping efficiency to determine cost-effectiveness.
4. During May – July 2011, we will coordinate a brief reduction in flow volume at the hydropower plants at peak spawning migration during which divers will canvas the river bottom in the channel downstream of the Brookfield Renewable Power and USACE powerhouses. We will work with the hydropower plants to explore ways to do this and minimize economic impacts to power production. We will document:
   a. presence of fin-clipped and unmarked sea lampreys;
   b. location of sea lampreys.
5. During May – July 2011, divers will manually collect sea lampreys for removal, thereby assessing the:
   a. feasibility of manual removal under normal and reduced flow conditions;
   b. scope for manual removal as a control technique.
6. During July – August 2011, we will coordinate with the Lake Superior Board of Control , USACE, and Brookfield Renewable Power to adjust gate settings to achieve a short-term (hours) diversion of water flow in the rapids area to accommodate expanded sea lamprey nest evaluations during late July and early August (2 times/week for three weeks). We will document:
   a. Number of sea lamprey nests sampled within the fish channel north of the concrete fish berm;
   b. Number of sea lamprey nests sampled on the south side of the concrete fish berm as compared to previous years.

Project Milestones: Table 1. Methods, associated timelines, and proposed outcomes.

Method	Proposed Timeline	Proposed Outcome
1. Analyze historic river data to	October 2010 - March 2011;	Results used by IUGLS Team to

explore how flow, water level, and hydropower peaking and ponding activities affect trapping efficiency; Install level loggers near trap sites to collect additional water level data	May – July 2011	suggest alternatives to current water allocation plan in St. Marys River; Potential to manipulate discharge to increase trap efficiency
2. Monitor behavior using DIDSON		
Proof of concept	September 2010	Identify optimal settings
Field study	May - July 2011	Identify sea lamprey swimming or resting behaviors that can be exploited to increase efficiency of alternative control strategies
3. Compensating Gate trap	May- July 2011	Assess feasibility and cost-effectiveness of placing a permanent trap at Compensating Gates
4. Monitor location and marked sea lampreys using professional divers	May- July 2011	Validate assumption that unmarked and marked sea lampreys mix in river and are equally vulnerable to assessment traps
5. Manually remove sea lampreys using professional divers	May- July 2011	Potential additional alternative control strategy
6. Expand nest surveys	July – August 2011	Additional alternative control and larger sample size to assess effects of sterile male release

Environmental Results: The commission and its partners believe that understanding how sea lampreys behave near trapping sites will allow the Program to manipulate current trapping devices and develop innovative new methods to exploit such behaviors. Additionally, understanding how water level and flow affects trapping efficiency and spawning activity may enable us to manipulate flows to achieve higher efficiency, thereby removing more sea lampreys from the system. Results of this project will employ innovative technologies (DIDSON) and/or new methods (flow manipulation, manual removal) to reduce the spread of sea lamprey in an effective, efficient, and environmentally sound manner. This will allow the commission to add tools to the integrated pest management strategy in the St. Marys River and move towards sea lamprey abundance levels that will allow achievement of Fish Community Objectives in Lake Huron (lake trout rehabilitation).

Results from the historic data analysis proposed in this project will be used by the IUGLS to evaluate the effects of river operations on hydropower, commercial navigation, and ecosystems under Plan 1977-A, which determines water allocations across the St. Marys River. Results will be used to guide development of alternative regulation plans.

Results of this project can also be applied outside of the St. Marys River. There are 65 tributaries in the Program trapping network throughout the Great Lakes with varying trapping efficiencies. Behaviors noted in the project results can be exploited in tributaries with historically low trapping efficiencies. This project will also provide a capital equipment investment in innovative technologies to support research in other Great Lakes tributaries where sea lamprey trapping is conducted, both with and without a barrier-integrated trapping system, and in tributaries known to receive a spawning run, but not yet exploited via traditional means. Results of this project will be presented to commission task forces that plan and evaluate sea lamprey control, lake and lake technical committees, hydropower groups, and other interest groups during fall/winter 2011-2012 meetings and also via written reports. Recommendations will be made to incorporate study results into field operation planning for 2012.

Measuring Progress: We will measure progress toward achieving workplan outputs and outcomes by evaluating the success of the control program in achieving a local increase in trap efficiency on the St. Marys River and regionally by meeting the specified target levels of sea lampreys in the Great Lakes. Under the Measures of Progress in the GLRI Action Plan, this can be applied to Measure 2, "Acres managed for populations of invasive species controlled to a target level." Additionally, progress will be measured by fulfilling the following objectives from the GLRI Action Plan: "…four technologies that either contain or control invasive species will be developed or refined and piloted by 2011"; and "By 2014, invasive species populations within the Great Lakes Ecosystem will have been controlled and reduced, as measured…by removing 5,000 pounds of invasive species from the Great Lakes ecosystem".

Description of Coordination: This work will be conducted in conjunction with the IUGLS and the International Joint Commission to evaluate the effects of river operations on hydropower, commercial navigation, and ecosystems under Plan 1977-A, which determines water allocations across the St. Marys River. Results from both projects will be used to guide development of alternative regulation plans.

Collaboration with the hydropower plants, namely Cloverland Electric Cooperative, the U.S. Army Corps of Engineers, and Brookfield Renewable Power will occur to conduct experiments in the vicinity of the tailraces (see attached letters of support). Several meetings or conference calls will be scheduled to ensure that project objectives will be met in a timely fashion. Coordination will occur with the hydropower plants on-site during scheduled experimentation.

Further coordination with the Michigan Department of Natural Resources will occur in the form of requesting concurrence to place spawning-phase assessment traps in the St. Marys River, accompanied by the appropriate collection permits. Weekly spawning-phase assessment trap reports will be available at http://www.glfc.org/sealamp/catchdb/index.html.

This work will occur concurrently with an acoustic telemetry project, led by the U.S. Geological Survey (USGS) in the St. Marys River detailing movements of sea lamprey as they migrate upstream. The combination of these two projects will provide knowledge of the complete migration cycle up the St. Marys River, behavior near assessment traps at the terminal ends, and subsequent spawning activity in the rapids area of the St. Marys River. Daily coordination with USGS will occur on the river.

Study plans and results will be coordinated with the St. Marys River Task Group (SMRTG) made up of state, federal, provincial, tribal, and university representation. The SMRTG coordinates fisheries management on the St. Marys River. Meetings are held twice per year and conference calls scheduled when necessary.

This study also offers an additional learning opportunity to Lake Superior State University (LSSU) students. The Service has a cooperative agreement with the Aquatics Laboratory at LSSU to conduct spawning-phase assessment on the St. Marys River. Further coordination would allow students to become more familiar with invasive species issues on the Great Lakes, to see first-hand what is being done about it, and to establish relationships with natural resource professionals. LSSU students work with Service personnel on a daily basis on the river.

St. Marys River GLRI Research Coordination

1. **Project description**

Trapping sea lampreys is an important component in controlling the invasive sea lamprey in the St. Marys River. Trapping occurs at hydropower plants and typically only 40% of the annual spawning population is captured. Sea lamprey behavior in the vicinity of traps remains largely unknown, especially under varying flow conditions, and could be the key to developing trapping innovations that would further suppress sea lampreys through increased trap catch. Results of this study will determine the relationship between water flow and trap catch and will be used to modify trapping operations to capture more sea lampreys. With increased trap catch, sea lamprey abundance and the damage inflicted on fish will be reduced.

2. **GLRI study objectives**

   a. Analysis of *existing* flow and elevation data to determine effect on trapping efficiency. Previous analysis indicated a positive correlation between elevation and trap catch.
      i. Timing: In process.
      ii. Flow requirement: None.

   b. Analysis of *future* flow and elevation data to determine effect on trapping efficiency
      i. Timing: Late May to late July.
      ii. Flow requirement: During 2011, request that Brookfield and Cloverland alternate high and low flows each day from approximately 6 p.m. to 6 a.m. during May 15 - July 31. Rate of change is at discretion of power plant. For example, during July 2010, the Brookfield power plant operated between approximately 300cms (low flow) and 1,100cms (high flow). The table below illustrates the flow request.

Date	Time	Flow (cms)
May 15, 2011	6 p.m. to 6 a.m.	300
May 16, 2011	6 p.m. to 6 a.m.	1,100
May 17, 2011	6 p.m. to 6 a.m.	300
May 18, 2011	6 p.m. to 6 a.m.	1,100
Alternate through July 31		

iii. Comments: Other flow manipulations of interest to the group are included in the list below. We would like to know how amenable the IJC is to accommodating the variations.
    1. Year-to-year variations (one year of low flow for the entire river followed by a year of high flows).
    2. North vs. South variations (alternate high flows and low flows coming out of Canadian and U.S. plants).
    3. Whole day variations (alternate days of high flows and low flows).
    4. Turbine variations (allow for manipulation of turbine flows at specific sites, such as Brookfield and Cloverland).

c. River height near traps under varying conditions
   i. Timing: Anytime.
   ii. Flow requirement: We will set level loggers at all trap sites and monitor the elevation response to changes in plant output. What range of flows can be accommodated by Brookfield, Cloverland, and the Corps and when is the best time to complete? Also, when varying flow, how long does it take the tailrace elevation to stabilize? For example, when going from 50% output to 75% output, how long will plant need to run at 75% output to get an accurate elevation reading? Rate of change is at discretion of power plant.

d. Use of DIDSONs/acoustic telemetry to monitor behavior near trap and trap entrances
   i. Timing: late May, late July.
   ii. Flow requirement: We are requesting two weekends of low flow from Brookfield to allow divers to install and remove hydrophones in the tailrace. Rate of change is at discretion of Brookfield. This will need to be coordinated with flows requested in 2.b. and could be combined with the low flow requested in 2.g.

e. Compensating Gates trap(s)
   i. Timing: Late May to late July.
   ii. Flow requirement: We are requesting the diversion of flow from Gates 9/10 to Gate 18 to supply attractant flow. Rate of change is at discretion of IJC.

f. Evaluate assumption that all sea lampreys migrate to trap sites and have the potential to be trapped
    i. Timing: Late June.
    ii. Flow requirement: We are requesting one weekend of low flow from Brookfield to allow divers to observe sea lamprey behavior in the tailrace. Rate of change is at discretion of Brookfield. This will need to be coordinated with flows requested in 2.b.

g. Feasibility of manual removal of spawning sea lampreys
    i. Timing: Mid to late July.
    ii. Flow requirement: We are requesting one weekend of low flow from Brookfield to allow divers to test sea lamprey removal techniques. Rate of change is at discretion of Brookfield. This will need to be coordinated with flows requested in 2.b. and could be combined with the low flow weekend requested in 2.d.

h. Nest surveys (expanded)
    i. Timing: Late July to early August.
    ii. Flow requirement: We are requesting the diversion of flow from Gate 1 down to Gate 16-20 two times per week for three weeks. This could be accomplished by decreasing the setting at Gate 1 from ½ open to ¼ open (unsure of current gate opening). Rate of change is at discretion of IJC.