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

Integrated Ecological Response Model Contextual Overview

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Integrated Ecological Response Model

Contextual Overview

1. Introduction

This cover document briefly summarizes the overall strategy and methods that will be used by the International Upper Great Lakes Study (IUGLS) for the International Joint Commission (IJC) 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 Strategy Approach is available in a document that was peer-reviewed in 2009 (ETWG 2009). The Integrated Ecological Response Model (IERM2) summary report is meant to help peer reviewers assess whether or not the Study Board will have appropriate metrics and tools to evaluate the ecological response to alternative plans for the regulation of Lake Superior outflows.

1.1 Geographic Study Area

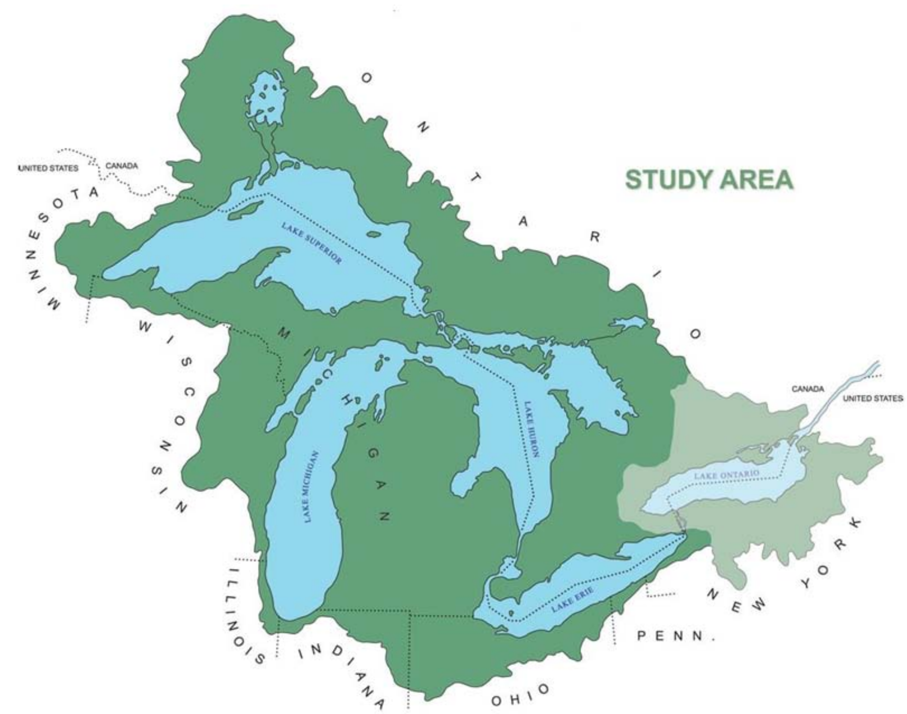

Figure 1. Geographic Study Area.

The study area is the Great Lakes drainage basin including lakes Superior, Michigan, Huron and Erie and the connecting channels up to Niagara Falls. The focus of the assessment is on those areas and regions impacted by changes to the regulation of outflows from Lake Superior including almost 17,500 kilometres (10,900 miles) of shoreline. Impacts in the upper watersheds of these lakes are not generally being studied because the impacts there from changes in the regulation plan are negligible. However, net basin supplies used to test new regulation plans under more extreme events (e.g., climate change) will include changes in runoff from the upper portions of the watersheds due to changes in precipitation.

2. Plan Evaluation

2.1 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, to the extent possible, the real world implications of its decisions using management guidelines based on 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 the 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.

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. The key environmental question posed by the Board, and the one the IERM was designed to address, is what would the environmental impacts be of water levels outside of the historical regime? This would cover levels created by plans radically different from the current Lake Superior regulation plan or by water supplies more persistently wet or dry than any in recorded history. By the nature of the question, the IERM had to model impacts that had never occurred and for which there were no data. The only data that could be collected would be limited by the study budget, the geographic expanse of the Great Lakes, and the duration of the study (in most cases, the IERM is based on observations from one year).

The IERM is designed to put forth sound hypotheses about impacts from never before seen conditions to serve two purposes. The first purpose is to create cautionary guidelines for the Board in designing its regulation plan, essentially saying, “based on professional judgment and limited data, try to avoid these water level conditions”. But in fact, the Board has found good reasons other than environmental for recommending a plan very similar to the current plan, so the new plan is unlikely to impact the environment. The second and most important purpose is to frame a rational learning process for managing at never before seen water levels by enumerating specific concerns defined for a specific geographic area and water level regime. The performance indicator algorithms and Coping Zone criteria in the IERM thus provide a specific set of assumptions about the impacts of future, unprecedented water levels that can be used to design the structured learning process required for adaptive management. The adaptations that would occur almost certainly cannot be made by regulating Lake Superior differently, but the IERM could be used by coastal zone managers to better understand ecosystem vulnerabilities and the way they might respond to possible unprecedented conditions.

2.2 Uncertainties

The IUGLS Board will design a new regulation plan based on how the plan performs in computer models. These models are the IERM2 ecological response model and the Shared Vision economic response model. The models have been integrated into a comprehensive Shared Vision Model (SVM) which will be used by the Study Board and Plan Formulators to assist in the evaluation of proposed Lake Superior water level regulation plans.

The data and assumptions in the IERM2 model are designed to replicate conditions and outcomes in the real world, but, as with all modeling, there is uncertainty with respect to how well the models represent reality. Much of the uncertainty comes from our limited ability to correctly specify a set of ‘performance indicators’ (PIs) that are meant to: 1) represent the key environmental changes under a variety of environmental conditions and lake levels, 2) quantitatively assess these PIs based on incomplete information and datasets, 3) know when and how future water supplies will deviate outside the historic range of water levels over the past 109 years (i.e., extreme water level events), and 4) whether or not the PIs correctly represent the environmental response to these extreme water level events.

Moreover, the ecological integrity of the Great Lakes is uncertain as the region is faced with numerous ongoing threats from invasive species, pollution, and development. Responses to invasive species would require both treatment of the current effects of invasives already lodged in the Great Lakes as well as a reduction in future invasions. Efforts to clean-up the Great Lakes have been on-going for decades, and while improvements have been made, significant issues remain and new issues are continually emerging. It should be noted that the IERM2 does not include ecological response processes to changes that might occur in these other stresses. It only considers responses to changes in water level regime, assuming no changes in these other exogenous stressors.

Under climate change, there is a high degree of uncertainty associated with future long-term water level predictions in the Great Lakes. Even though paleo-ecological water level data are available for the past 4500 years, 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 limited experience as to how these extreme water level events would change environmental conditions in the Great Lakes.

This is another form of model uncertainty; in this case, the uncertainty goes beyond how well the model results fit existing data to how well the model can be used to predict ecological responses to conditions outside the range of historical data. For extreme events, we have limited historical data upon which to design and validate predictive functions. For example, even though within current historical ranges, the recent decline in Great Lakes water levels over the past decade may provide some insight as to how wetland plant and animal communities may respond to more extreme events. By understanding process-response mechanisms, best professional judgment can be applied, but there are large uncertainties, and flexibility will have to be built into the resulting decisions.

Recognizing that uncertainties limit the ability of a model to be "perfect" at the start, the IERM2 model was designed to accurately predict ecological responses under current conditions and identify when future changing water level conditions start to adversely impact the ecosystem. More importantly, the IERM2 model was designed to be flexible enough to be easily modified to reflect changing environmental responses to future water level conditions. Over the long term, the IERM2 model is designed to be an adaptive management tool that will help guide future adaptive management decisions.

The Study Board has the potential to recommend changes in a regulation plan and devise a plan that provides greater flexibility to adapt to unforeseen circumstances and can be modified in response to changing climatic conditions. In fact, the Board is developing an adaptive management approach to the plan 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. Ecosystem Evaluation

3.1 General Approach

The ecosystems of the upper Great Lakes (UGL) 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 pre water-level regulation environmental data for the Upper Great Lakes are so limited, it is not practical (or possible) to document all of the dynamic responses of a complex coastal ecosystem to changes in water level. The Upper Great Lakes coastal ecosystem is considered to be relatively unimpaired and more recently, regulated Lake Superior water levels have approximated "natural" water level regimes[1].

[1] The term water level regime as used in the document refers to water level variation using terms that are adapted from the natural flow regime paradigm in rivers. Water level variability is typically described by the magnitude (range), frequency, timing (seasonality), duration, and rate of change of water levels through time (see Poff et al. 1997).

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 support diverse biotic communities and ecosystem functions. For the purpose of this study, water level regimes are defined as the magnitude, frequency, timing (seasonality), duration, and rate of change of water levels through time. The fundamental approach used in this study can be summarized as follows:

- Understand the vulnerability of various ecosystem components to water level regime changes in the Upper Great Lakes;
- Quantify the relationship between changing water level regimes (magnitude, frequency, timing, duration and rate of change) and key ecosystem functions and components by evaluating ecological performance indicators at multiple representative sites throughout the UGL basin;
- Develop and apply an integrated ecological response modeling framework (IERM2) tool to identify and establish site-specific and regional water-level criteria or thresholds above which, or below which, harm will be done to various ecosystem components and, by extension, to the Upper Great Lakes ecosystem;
- Use the IERM2 tool to identify criteria or threshold exceedances that might occur in response to proposed water level regulation plans; and
- Identify vulnerabilities and potential opportunities for ecological improvement as a function of changing water-level regimes (adaptive management).

The development of the IERM2 model for the Upper Great Lakes system was accomplished in collaboration with the Site Coordinators and other ETWG members to identify water-level ranges and thresholds that minimize adverse impacts to biotic communities and ecosystem function by:

1. Developing an understanding of existing research with respect to water level regime impacts on specific ecological components (i.e., wetland vegetation, fish, wetland birds);
2. Identifying ecological “Performance Indicators” (PIs) that are representative of these components and have the potential for being significantly impacted by water level regime;
3. Developing conceptual “algorithms” that can be used to qualitatively understand the response of selected PIs to water level regime, including a preliminary assessment of PI-specific thresholds;
4. Developing and applying computational algorithms to simulate the response of each PI to current and plausible future water level regimes, including the impacts of alternative regulation plans; and
5. Applying best professional judgment and expertise by the Site Coordinators to define thresholds (or “Coping Zones”) for each selected PI.

Due to limited data, time, and resources available to compile and integrate pre-existing and newly collected datasets into the IERM2 framework, it was not feasible to represent ecological responses across all Upper Great Lakes coastal zones. Instead, a set of local wetland and shoreline sites have been selected based on regional representativeness and the availability of data and previous research to constitute the basis for an integrated ecological analysis.

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.

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 plausible hydrologic scenarios yield water level regimes that exceed those threshold conditions.

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

	Impact Score	Biological Condition
Pristine / Natural Variability	1	**Natural or native condition** Native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within range of natural variability
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
Critical Threshold →		
	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
Degraded	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.

The evaluation of potential ecosystem impacts is a complex task made more difficult by the dynamic nature of the Great Lakes ecosystem. Direct and indirect impacts to biological communities and ecosystem functions in coastal margin and nearshore areas could be potentially significant. These areas include shallow low-slope embayments (generally < 3 m water depth) and coastal margin ecosystems dependent on direct hydrologic connection to the Lakes. Within the Upper Great Lakes, ecological components include: coastal wetlands, beaches, dunes, tributaries, islands, and the nearshore/coastal margin aquatic habitats and biotic communities that use those habitats. The EWTG has identified these shallow-water areas as being especially vulnerable to changes in water-level regime.

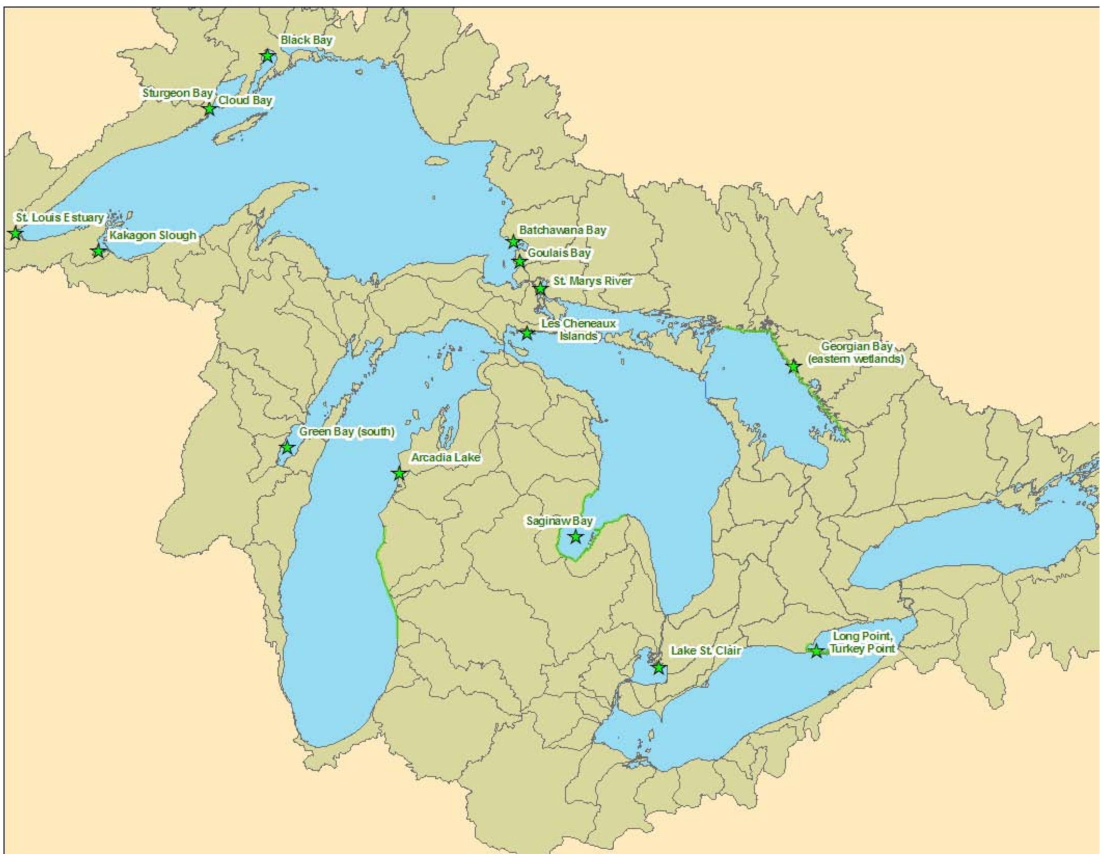

Figure 2. Map showing the locations of the final Study sites.

Study sites were 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). Study sites were grouped by shoreline type, and representative sites from wetland and tributary-mouth complexes were evaluated by the same team of Site Coordinators to ensure consistency between Lakes and regions. In response to the initial peer-review process, additional representative wetland and tributary-mouth complexes were added to Lake Superior in response to the comment that the number of sites on Lake Superior was insufficient to detect potential impacts of lake level regulation.

At each study site, ecological response functions relating environmental PI responses to changes in water level regime were developed by ETWG Site Coordinators. These response functions are used to link the descriptors of biological condition (based on environmental PIs) to descriptors of water level variability to identify possible thresholds of concern. These response functions and thresholds form the basis of the quantitative analysis that has been incorporated in the IERM2 model. The PI responses are weighted equally irrespective of the relative geographic area represented by each PI. An ecological description is provided for each PI which allows for an unbiased “case-by-case” evaluation and comparison of proposed water-level regulation plans.

The IERM2 modeling report has an appendix that contains PI Fact Sheets that describe the PIs, water level response curves, thresholds, and Coping Zones for each field site. Based on the earlier peer review, additional information has been included in the PI Fact sheets that documents the uncertainties associated with the methodology, use of specific data sets, and best professional judgment for each PI. A detailed description of the PIs, water level response functions, thresholds, Coping Zones, and how these various pieces of information were programmed into the model is presented in the IERM2 model report.

3.3 Coping Zones

The Adaptive Management Working Group (AMWG) has introduced the idea of “Coping Zones” based on the Description of Biological Condition shown in Table 1. The AMWG 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” is used to describe the various stages of impact or degradation to a system. For the purposes of environmental evaluation, the following definitions apply:

- Coping Zone “A”: In Table 1 the first two conditions represent the “natural state” of the ecosystem that has historically been generally 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 condition represented by the yellow shaded area just below the horizontal dashed line in Table 1 represents more substantive changes to the structure of the biotic community, which will generally be the result of more extreme periods, but could still be within the envelope of historic natural variability. The fourth condition represented by the orange shaded area below the single solid line in Table 1 represents 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. Both conditions are assigned to Coping Zone "B", recognizing that in some cases "Zone B" conditions still fall within the envelope of historic natural variability.

- 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 UGL ecosystem. In many cases the degradation may be permanent and irreversible. "Zone C" is an undesirable condition.

The environmental thresholds developed by the Site Coordinators have been converted into environmental Coping Zone criteria and incorporated into the IERM2 model. Low- and high-water Coping Zone criteria, as well as criteria based on seasonal and inter-annual variability, have been established for Zones "A", "B", and "C" for PI at each study site to the extent possible. It is important to note that the Coping Zone criteria not only are defined by a specific threshold water level, but by a 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. The validation process is described in more detail in the IERM2 model report.

4. IERM2 Model Implementation

The IERM2 model is a stand alone model that produces results and output independent from the spreadsheet-based Shared Vision Model, which features the suite of economic metrics and Coping Zones. To simplify the plan evaluation process, it was necessary to integrate the two models so that environmental and economic benefits and impacts could be evaluated simultaneously by the plan formulators and the IUGLS Study Board.

To facilitate model integration, a spreadsheet-based "Coping Zone Calculator" was developed that duplicates the key environmental responses and output of the stand-alone IERM2 model. The Calculator produces a tabular output that lists the calculated environmental Coping Zones for each PI as a function of a water level or flow time series. Coping Zones "B" or "C" are identified when conditions exceed the hydrologic Coping Zone criteria (i.e. thresholds) identified by the Site Coordinators as being ecologically significant. The IERM2 model and Coping Zone calculator not only identifies the water level or flow triggers, but also the time (or duration) at which water levels or flows exceed a specified threshold. The spreadsheet-based Coping Zone Calculator has been "dropped into" the Shared Vision Model and the outputs integrated for each plan formulation run. Both environmental and economic benefits and impacts can now be evaluated simultaneously using the integrated SVM model.

In summary, the IERM2 modeling tool quantifies, integrates, and visually summarizes the vulnerabilities of key ecological performance indicators by Lake, by ecological component (e.g. wetland vegetation, fish, birds, and invertebrates), and by region (e.g. Saginaw Bay, Georgian Bay, Lake St. Clair, Lake Superior). Results from the IERM2 model and Coping Zone calculator can be easily applied to multiple scales and can be used to evaluate ecological responses to proposed water level regulation plans during extreme water level events. The IERM2 model is designed to be flexible and can be adapted to different baseline conditions. As a result of this inherent flexibility in model design, the IERM2 model can also be used to forecast environmental responses to alternative adaptive management scenarios.

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Documentation of the Integrated Ecological Response Model (IERM2) for the International Upper Great Lakes Water Levels Study

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EXECUTIVE SUMMARY

The International Upper Great Lakes Study (IUGLS) Board is in the fourth year of a five-year study for the International Joint Commission (IJC) to evaluate the overall impacts of current and alternative Lake Superior regulation plans and potential future basin water supply scenarios on a range of interests on the Upper Great Lakes system (Lake Superior, Lake Michigan, Lake Huron, Lake St. Clair, Lake Erie, and their connecting channels). The Ecosystem Technical Work Group (ETWG) has been tasked with informing the Study Board's discussions and estimates on the potential ecological impacts of these plans and scenarios. In order to forecast and assess these potential impacts in a timely manner, the ETWG has undertaken the development of an "Integrated Ecological Response Model" for the Upper Great Lakes (IERM2). This report documents the development of the IERM2 and an outgrowth of the model – the Coping Zone Calculator – that forms the environmental component of the Study's Shared Vision Model (SVM). It also presents an illustration of the preliminary application of the IERM2 Coping Zone Calculator to some existing scenarios available in the Shared Vision Model (SVM). The approach moving forward will be to use this framework within the SVM to support the ongoing IUGLS decision process and Adaptive Management planning.

The primary objective of developing the IERM2 framework was to synthesize and integrate available ecological research and data into a tool that can quantify the relationships between alterations of water level regime (either natural or human-regulated) and key indicators of the ecological response of coastal and nearshore ecosystems in the Upper Great Lakes. The conceptual model and ecological performance indicators discussed herein represent an approach that is designed to construct a quantitative assessment that builds on the findings of the ETWG white paper (Ciborowski et al. 2009) and the concept of ecological thresholds (or "Coping Zones") that has been proposed for the IUGLS (ETWG 2009). The IERM2 provides the information needed to inform the near-term evaluation of water level regulation in the Upper Great Lakes through incorporation of the IERM2 into the Shared Vision Model for the Upper Great Lakes system. In addition, the IERM2 model development and application process can be used to inform the planning and implementation of monitoring intended to support long-term adaptive management of the Upper Great Lakes ecosystem, as discussed in Chapter 6.

Due to limited data, time and resources available to compile and integrate pre-existing and newly collected datasets into the model framework, it is not feasible to represent ecological responses across all Upper Great Lakes coastal zones. Instead, a set of local wetland and shoreline sites have been selected based on available data and previous research to constitute the basis for the integrated ecological analysis. A map of the Upper Great Lakes sites currently under evaluation is provided in Figure ES-1. A summary of the ecological components modeled in the IERM2 at each study site is presented in Table 2-1 of this document.

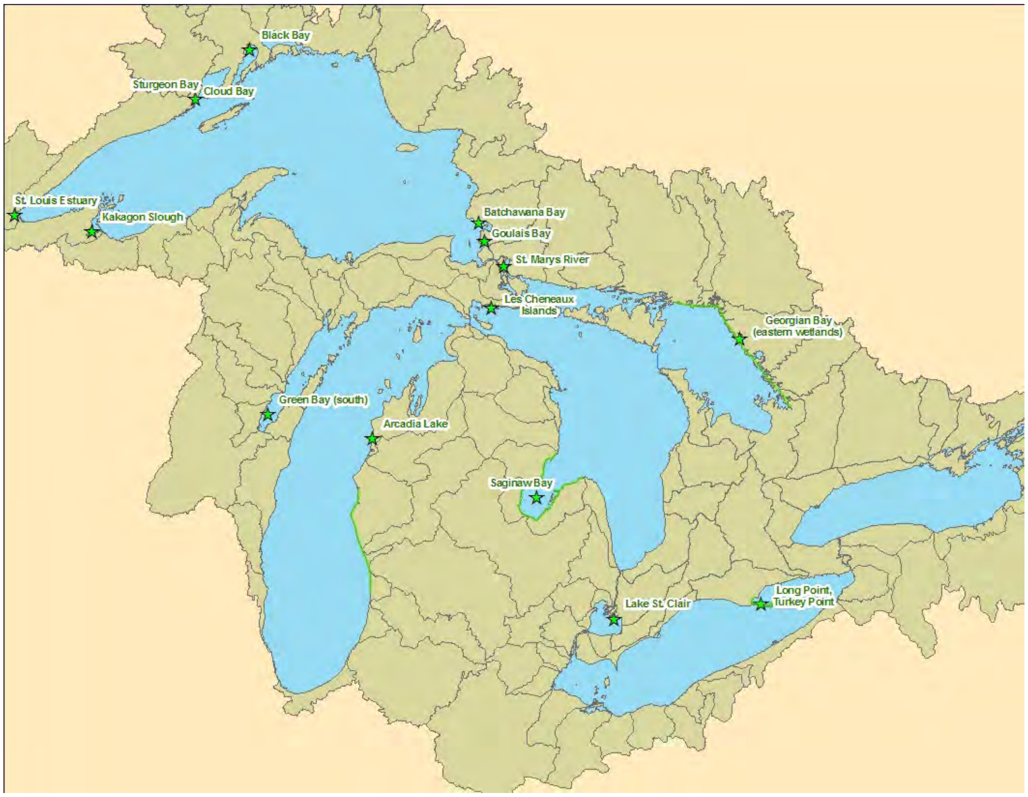

Figure ES-1. Map of ETWG Study Site Locations

The development of the IERM2 model for the Upper Great Lakes system followed a conceptual model presented in Figure ES-2 below. Conversion of this conceptual model into a quantitative analysis tool was accomplished in collaboration with the Site Coordinators and other ETWG members through the following steps: 1) identification of ecological "Performance Indicators" (PIs) that are representative of each study site ecological components and have the potential for being significantly impacted by water level regime; 2) development and application of computational algorithms to simulate the response of each PI to current and plausible future water level regimes, including the impacts of alternative regulation plans; and 3) application of best professional judgment and expertise by the Site Coordinators to define thresholds (or "Coping Zones") for each selected PI. A complete description of the IERM2 development process, including ecological PI definition and sub-model descriptions, is presented in Chapter 2 of this report.

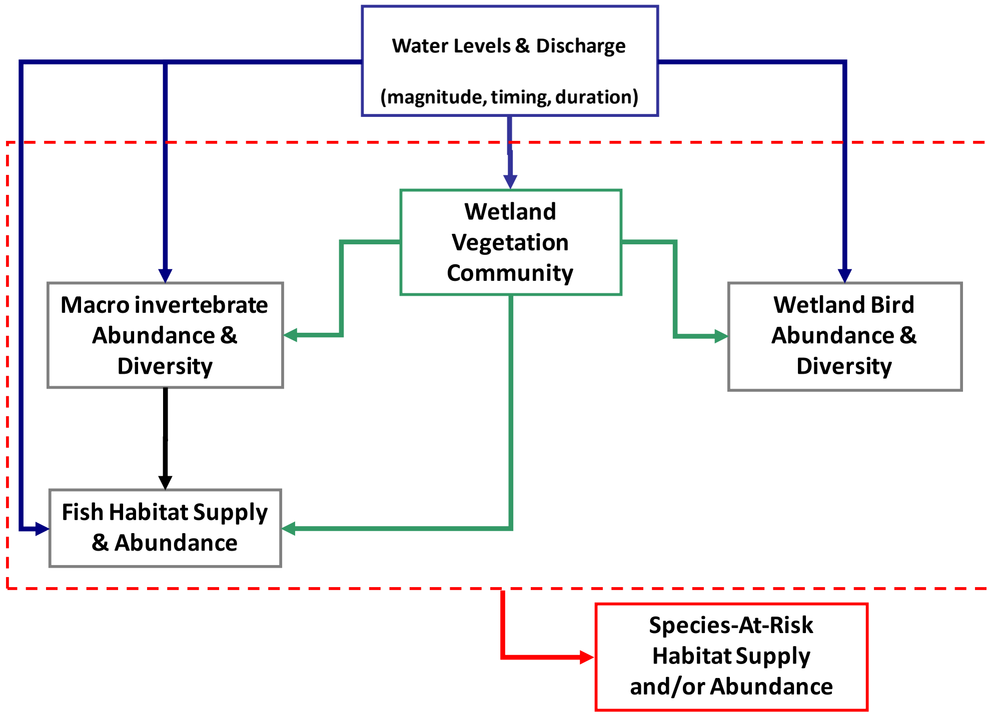

Figure ES-2. IERM2 Conceptual Linkages between Ecological Components and Sub-models

A key focus of the IERM2 synthesis and integration effort was to develop, or at a minimum hypothesize, the thresholds at which changes in water level regime (i.e., magnitude, timing, and duration) could cause significant long-term harm to a particular ecological component (ETWG 2009). The concept of thresholds is generally consistent with the "Coping Zone" approach that has been introduced by the Plan Formulation and Evaluation Group (PFEG) and the Adaptive Management Workgroup (AMWG 2010). To blend the ecosystem threshold concept with the Coping Zone concept, the ETWG defined a continuum of biological condition (see Figure 3-1 in this report) based on previous work by Davies and Jackson (2006) that is consistent with the Coping Zone approach (ETWG 2009). The six impact levels defined in Figure 3-1 of this report can be recast in the context of Coping Zones as follows:

- "Zone A" – natural variability with respect to water level regime (ecological impact score of 1 or 2);
- "Zone B" – moderate changes to biotic community structure, but minimal changes to ecosystem function (ecological impact score of 3 or 4); and
- "Zone C" – major changes to biotic community structure, and moderate to major changes in ecosystem function (ecological impact score of 5 or 6).

Of course, the key aspect of the analysis is specification of the water level regime conditions that cause a given ecosystem (Study Area in this case) to transition from one zone to the next. Based on a thorough review of the PI algorithm/results in the

IERM2 and expert judgment, the Site Coordinators interacted with LimnoTech to identify *threshold* levels (i.e., specific water level or flow conditions) and *duration* triggers (i.e., specific timeframes) for transition of ecological component(s) from “Zone A” to “Zone B” and from “Zone B” to “Zone C” for a particular year in a long-term hydrologic/hydraulic scenario. In addition to developing 29 criteria based on the Coping Zone concept, four additional criteria were developed to assess the severity of water level range compression for Lake Superior and Lake Michigan-Huron using continuous performance metrics. These range compression metrics are expressed as plan-to-PreProject ratios, rather than using Zone A/B/C designations. A summary of the 33 IERM2 Coping Zone criteria and range compression metrics developed for this study is presented in Table 3-1 of this report.

The Coping Zone criteria presented in Table 3-1 form the basis for development of a “Coping Zone Calculator”, which has provided an efficient standalone spreadsheet tool for evaluating and comparing alternative regulation plan/basin supply scenarios (see Chapter 3). Working collaboratively with the Shared Vision Action Team (SVAT), the Coping Zone Calculator is also being integrated directly into the SVM for plan formulation and evaluation of ecological responses relative to other Study interests.

The process of developing and evaluating alternative regulation plans and plausible future net basin supply scenarios is ongoing as of the writing of this document (June 2011). Therefore, it was not possible to produce a comprehensive evaluation of regulation plans and basin supply conditions with the IERM2 model for this report. In lieu of a complete application of the modeling framework, a preliminary application was conducted for the purpose of demonstrating the utility of the IERM2 Coping Zone and range compression analysis and likely outcomes for key hydrologic/hydraulic scenarios.

As part of the IERM2 application, two versions of Pre-Project were evaluated: 1) *with* the Long Lac and Ogoki (LLO) diversions, and 2) *without* the LLO diversions. The Pre-Project case with diversions represents the Upper Great Lakes system as it would have been historically if regulation at Sault Ste. Marie did not occur but the other diversions were maintained. The case without diversions represents a completely natural (i.e., no human impact) water level condition for Lake Superior; however, water levels for the lake systems below Lake Superior (Michigan-Huron, Lake St. Clair, and Erie) are not completely natural because the Chicago Area Waterways (CAWS) diversion is still included in this scenario. Therefore, neither Pre-Project case represents true “natural” water level conditions for Lake Michigan-Huron and the downstream lakes.

“Zone C” results are summarized in Table ES-1 for both Pre-Project cases. There are no “Zone C” occurrences reported for Lake Superior, Lake St. Clair, or Lake Erie for either Pre-Project scenario. For the Pre-Project case with diversions, there are minimal occurrences of “Zone C” for St. Marys River criterion SMH-04 and for the low water level criteria developed for Georgian Bay wetlands (LMH-07 and LMH-08). (Refer to Table 3-1 for detailed descriptions of these criteria.) The “Zone C” occurrences for LMH-07, which represents the "current conditions" threshold for eastern Georgian Bay wetlands, occur primarily during the severe drought period associated with the 1930s (as well as year 1966). It is important to note that due to glacial isostatic adjustment (GIA) the land surface and wetland outlets would have been approximately 20 cm lower in the 1930s relative to the Lake Huron outlet, as compared to present-day conditions. Therefore, low water level conditions experienced during the actual 1930s drought period would not have qualified as a "Zone C" condition. Given this context, the results obtained for the Pre-Project case with no diversions are consistent with the expectations of minimal "Zone C" occurrences for the 1900-2008 historical period.

Table ES-1. Coping Zone Analysis for Pre-Project Cases Based on Historical Net Basin Supplies (1900-2008)

Region	Pre-Project (**with** LLO diversions)		Pre-Project (**without** LLO diversions)	
	Criteria with "Zone C"s	Count of "Zone C" Years	Criteria with "Zone C"s	Count of "Zone C" Years
Lake Superior	(none)		(none)	
St. Marys River	SMH-04	1	SMQ-02 SMH-04	1 5
Michigan-Huron / Georgian Bay	LMH-07 LMH-08	3 6	LMH-07 LMH-08	5 19
Lake St. Clair	(none)		(none)	
Lake Erie	(none)		(none)	

The IERM2 Coping Zone Calculator was also run for regulation plan "77A" as applied to historical (1900-2008) net basin supply conditions. The "Zone C" results for Plan 77A are summarized in Table ES-2. There are no "Zone C" occurrences reported for Lake Superior, Lake St. Clair, or Lake Erie for Plan 77A. Criteria SMH-04, LMH-07, and LMH-08 have the same number of "Zone C" occurrences as for the Pre-Project (no diversion) case. For the St. Marys River, criterion SMQ-01 has one additional "Zone C" occurrence relative to the Pre-Project case. Criterion SMQ-01 identifies "Zone C" as conditions where flow in the St. Marys River during the month of June is insufficient (< 1,700 m^3/s) to promote lake sturgeon spawning in the River for 5 consecutive years. For Plan 77A, flows of less than 1,700 m^3/s occur during the 5-year period of 1922-1926. By comparison, the Pre-Project case generates flows below this threshold for only a 4-year period (1923-1926).

Table ES-2. Coping Zone Analysis for Plan 77A Based on Historical Net Basin Supplies (1900-2008)

Region	Criteria with "Zone C"s	Count of "Zone C" Years	Change in Years Relative to Pre-Project (*with diversions*)
Lake Superior	(none)		
St. Marys River	SMQ-01 SMH-04	1 1	1 additional "Zone C" (no change)
Michigan-Huron / Georgian Bay	LMH-07 LMH-08	3 6	(no change) (no change)
Lake St. Clair	(none)		
Lake Erie	(none)		

As alluded to above, the range compression metrics for Lake Superior and Lake Michigan-Huron (SUP-01, SUP-02, LMH-01, and LMH-02 – see Table 3-1) can be conveniently expressed as ratios by using the Pre-Project scenario as a benchmark for natural water level range conditions. The range compression metrics generate results for only a subset of years within a 109-year simulation period – i.e., when peak water level conditions and subsequent drawdown events are identified from the Pre-Project case. Ratios for each metric are calculated simply by dividing the raw metric score for a given plan applied to a specific net basin supply (NBS) scenario by the Pre-Project metric score for that same NBS scenario. Figure ES-3 compares the mean ratios across the 109-year period for Plan 77A for all four range compression metrics. These results suggest that relative to the natural condition, Plan 77A has reduced the magnitude of Lake Superior peak water levels and post-peak drawdown events on average by approximately 20% and 30%, respectively. By comparison, the impact of Plan 77A on Lake Michigan-Huron peak water levels and post-peak drawdown events is minimal. This is expected because the regulation of Lake Superior generally has only a very small effect on long-term water level fluctuations in Lake Michigan-Huron.

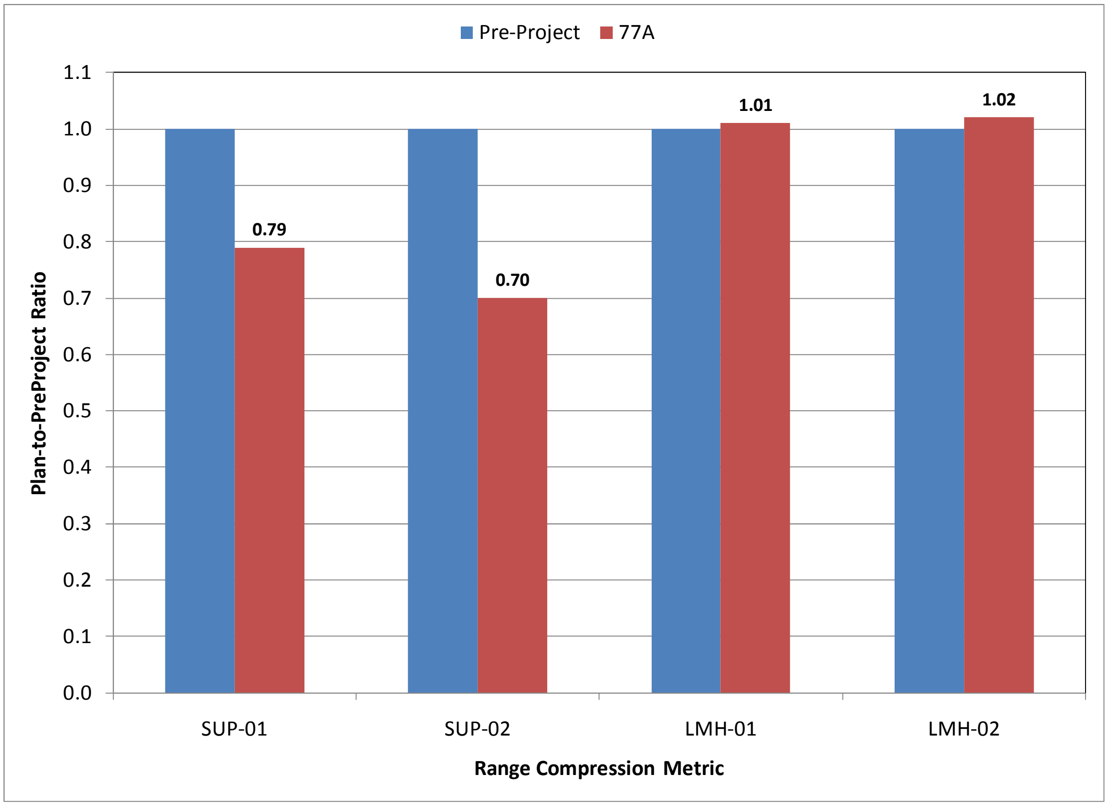

Figure ES-3. Comparison of Range Compression Metric Results for Plan 77A and Pre-Project

Given the analysis of Plan 77A with historical supplies, it is then instructive to compare the Coping Zone results for this plan with results for the suite of alternative plans developed to date for the IUGLS. The results of this analysis are summarized in Table ES-3 as the change in "Zone C" occurrences for each alternative plan relative to Plan 77A (consistent with the approach recommended in Section 3.5). The results in Table ES-3 reflect that only three of the Coping Zone criteria (SMQ-01, LMH-07, and LMH-08) have a different number of "Zone C" occurrences for any of the alternative regulation plans. As an example, the "Zone C" results in Table ES-3 suggest that nearly all of the alternative plans perform as well as or better than Plan 77A across the three sensitive criteria based on application of the plans to the historical NBS case.

Table ES-3. Comparison of "Zone C" Occurrences for Regulation Plans Relative to Plan 77A (based on historical net basin supplies)[1]

Criteria ID [2]	PP	77B	122, 124-128	129	130, 123	55M49	Nat60	PFN3	Bal25
Lake sturgeon spawning in St. Marys River (SMQ-01)	+1	0	0	+1	0	0	0	+1	+1
Eastern Georgian Bay wetlands, current conditions (LMH-07)	0	0	+1	+1	+1	0	0	+1	+1
Eastern Georgian Bay wetlands, 50-year forecast conditions (LMH-08)	0	0	0	+1	+1	0	0	+1	-1

[1] Negative values shown in red indicate the number of additional "Zone C" occurrences that are reported for a given plan relative to Plan 77A. Positive values shown in green indicate how many fewer "Zone C" occurrences are reported for a given plan relative to Plan 77A. Empty cells indicate no change in "Zone C" conditions for a criterion relative to Plan 77A.

[2] Only criteria that demonstrate "Zone C" sensitivity to choice of regulation plan are shown.

Plan-to-PreProject ratio results for the four range compression criteria are summarized in Table ES-4. These results represent the average of all ratios generated for the 109-year hydrologic/hydraulic simulation associated with each regulation plan for the historical NBS scenario. Green and red cells in Table ES-4 are used to highlight the more significant differences for alternative plans relative to Plan 77A as follows:

- Green cells indicate average ratios that are more than 5% *closer to* the Pre-Project benchmark ratio of 1.00 relative to Plan 77A; and
- Red cells indicate average ratios that are more than 5% *further away from* the Pre-Project benchmark ratio of 1.00 relative to Plan 77A.

Table ES-4. Comparison of Range Compression Metric Ratios for Regulation Plans (based on historical net basin supplies)1

Criteria ID	77A	PP	77B	122, 124-128	129	130	55M49	Nat60	PFN3	Bal25
SUP-01	0.79	1.00	0.89	~ 0.81	0.80	0.79	0.77	0.85	0.67	0.90
SUP-02	0.70	1.00	0.85	0.77	0.76	0.75	0.70	0.80	0.57	0.93
LMH-01	1.01	1.00	1.01	0.98	0.98	0.98	1.08	0.99	1.01	0.99
LMH-02	1.02	1.00	1.02	0.95	0.96	0.98	1.14	0.99	1.00	0.99

[1] Values highlighted in green indicate ratios that are more than 5% closer to the Pre-Project (PP) benchmark (ratio = 1.0) relative to Plan 77A ratio. Values highlighted in red indicate ratios that are more than 5% further away from the PP benchmark relative to the Plan 77A ratio.

Based on the summary results presented in Tables ES-3 and ES-4, the performance of the regulation plans (as applied to the historical NBS scenario) with respect to the IERM2 Coping Zone criteria and range compression metrics can be summarized as follows:

- Only three Coping Zone "zone-based" criteria currently demonstrate sensitivity to the choice of regulation plan for the historical NBS scenario: lake sturgeon spawning in the St. Marys River (SMQ-01), and the two criteria related to eastern Georgian Bay wetland connectivity and vegetation condition (LMH-07 and LMH-08).
- Alternative plans to Plan 77A either generate fewer "Zone C" occurrences or demonstrate no difference in the number of "Zone C" occurrences. (The only exception is plan "Bal25", which incurs one additional "Zone C" occurrence for criterion LMH-08.)
- In terms of minimizing compression of the water level range in Lake Superior, several alternative plans appear to perform better than Plan 77A. Specifically, plans 77B, Nat60, and Bal25 all have SUP-01 and SUP-02 ratios that are more than 5% closer to Pre-Project than Plan 77A. Plan "Bal25" in particular significantly improves the SUP-02 metric. Plan "PFN3" is the only plan shown in Table ES-4 that appears to compress the Lake Superior water level range more than Plan 77A. This characteristic makes plan "PFN3" undesirable from an ecological perspective despite the fact that it decreases the number of "Zone C" occurrences for several of the zone-based criteria.
- In general, Plan 77A and alternative plans have little impact on Lake Michigan-Huron water level ranges relative to the Pre-Project benchmark. However, plan "55M49" actually increases the magnitude of both periodic peak water levels and post-peak drawdown events, an effect that may also be undesirable for the ecosystem.

The results for the historical NBS scenario suggest that there are limited differences between alternative regulation plans in terms of "Zone C" conditions; however, some alternative plans demonstrate a relatively significant increase in the Lake Superior water level range (i.e., moving towards a more natural condition) relative to Plan 77A. Chapter 4 of this report presents and discusses additional results and findings for the application of the candidate regulation plans to nine alternative NBS scenarios. Those results indicate that differences in plan performance (i.e., with respect to "Zone C" occurrences and range compression metrics) become more pronounced under more extreme supply conditions. This emphasizes the importance of evaluating plan robustness across the full suite of plausible NBS scenarios, as opposed to focusing solely on the historical NBS scenario.

Although the above IERM2 Coping Zone analysis is not comprehensive, the comparisons provide a demonstration of how the results of the IERM2 Coping Zone Calculator can be used to help guide plan formulation and evaluation. Summaries of this nature can be used by the Study Board via the Shared Vision Model to weigh the relative benefits and drawbacks of regulation plans with respect to the Upper Great Lakes ecosystem during the plan evaluation and decision process.

1. BACKGROUND & INTRODUCTION

1.1 STUDY OVERVIEW

The International Upper Great Lakes Study Board is in the fourth year of a five-year study for the International Joint Commission to evaluate the overall impacts of current and fencepost Lake Superior regulation plans on the Upper Great Lakes system (Lake Superior, Lake Michigan, Lake Huron, Lake St. Clair, Lake Erie, and their connecting channels). The International Upper Great Lakes Study (IUGLS or Study) is considering the potential future impact of regulation plans and basin water supply scenarios on a range of interests, including hydropower, commercial navigation, recreational boating, and the environment. The results of these evaluations have been incorporated into the Shared Vision Model (SVM), which will serve as the primary decision-making tool for the IUGLS Study Board.

The Ecosystems Technical Working Group (ETWG) has been tasked with informing the Study Board's discussions and estimates on the potential ecological impacts from various lake level regulation alternatives and basin water supply scenarios. In order to forecast and assess these potential impacts in a timely manner, the ETWG has undertaken the development of an "Integrated Ecological Response Model" for the Upper Great Lakes (IERM2) that has a similar structure to the original IERM, which was developed and applied for the Lake Ontario-St. Lawrence River (LOSL) water levels and flows study (LimnoTech 2005).

The IERM2 is similar to the LOSL IERM in that its purpose is to generate plausible forecasts of ecological outcomes for selected performance indicators (PIs) based on different scenarios of water level/flow regimes that have been developed from alternative water regulation criteria superimposed on a range of potential basin water supply scenarios. The IERM2 also provides a platform for visualization to facilitate a simpler and more understandable transfer of results to help inform decisions and facilitate communication on potential ecological impacts to various stakeholders. However, because of the size and complexity of the shoreline ecosystems of the Upper Great Lakes and the need to use data sets of opportunity, the application and interpretation of the IERM2 results is different from the LOSL version. This report documents the IERM2 development and application process and how the findings synthesized in the IERM2 have been incorporated into the IUGLS SVM.

1.2 OBJECTIVES

The overarching objective of developing and applying the IERM2 framework was to quantify, to the extent feasible, the relationships between alterations of water level or flow regime (either natural or human regulated) and key indicators of the ecological response of nearshore ecosystems in the Upper Great Lakes (including Lake Superior, Lake Michigan, Lake Huron, Lake St. Clair, Lake Erie, and their connecting channels). Thus, the IERM2 provides a way of integrating the available data and knowledge of the ETWG and ecological site researchers into a quantitative representation of what is known (and unknown) about the effects of hydrologic regimes on nearshore ecosystems in the Upper Great Lakes. The IERM2 provides the information needed to inform the near-term evaluation of water level regulation in the Upper Great Lakes through incorporation of the IERM2 into the Shared Vision Model for the Upper Great Lakes system. In addition, the IERM2 model development and application process can be used to inform the planning and implementation of monitoring intended to support long-term adaptive management of the Upper Great Lakes ecosystem. Adaptive management is an important feature of effectively managing Upper Great Lakes coastal ecosystems because:

1. There is considerable uncertainty concerning the nature and extent of future changes in water level and flow regime (e.g., resulting from climate change);

2. There is uncertainty about future socio-economic conditions that may affect future environmental service demands on the Great Lakes; and

3. Insufficient ecological data and theory exist to fully understand and predict ecosystem changes resulting from future alterations in water level and flow regime (i.e., magnitude, timing, and duration).

The IERM2 framework is intended to provide a starting point for understanding ecological impacts resulting from specific changes in water level and flow regime. The results obtained from the current model can be used to focus the limited resources available for monitoring on specific components of the ecosystem and hydrologic/hydraulic conditions where adverse impacts are likely to be most significant and detectable. As additional monitoring data are collected, those data can in turn be used to revise and update the ecological responses represented in the IERM2 framework to provide improved predictive capability. In this way, the model can be updated and improved in an iterative fashion as part of the overall adaptive management process.

The overall objective of quantifying the relationships between water level / flow regime and indicators of ecological response was accomplished through the approach outlined in Section 1.3. In order to accomplish the primary objective of informing the Study's regulation plan evaluation process, ecological performance indicators and expert judgment were used to develop a set of "Coping Zone" criteria. These criteria provide quantitative descriptions of water level and flow conditions that are expected to adversely impact key ecological components of the overall Great Lakes coastal ecosystem. Therefore, the Coping Zone criteria provide the basis for evaluating potential ecological benefits and impacts for alternative regulation plans across a range of net basin supply conditions for the Upper Great Lakes.

1.3 ROLE & APPROACH FOR THE IERM2 FRAMEWORK

With regard to environmental impacts, the ETWG has been charged with developing a quantitative understanding of the sensitivity and vulnerability of key ecological performance indicators (PIs) to alternative regulation plans when applied to a range of net basin water supplies, including plausible future extreme water supply and level conditions resulting from climate change. The IERM2 was developed to synthesize and integrate available ecological research and data into a quantitative tool that can quantify the relationships between alterations of water level regime (either natural or human regulated) and key indicators of the ecological response of nearshore ecosystems in the Upper Great Lakes. The conceptual model and ecological performance indicators discussed herein represent an approach that is designed to construct a quantitative assessment that builds on the findings of the ETWG white paper (Ciborowski et al. 2009) and the concept of ecological thresholds (or "Coping Zones") that has been proposed for the IUGLS (ETWG 2009).

A key focus of the IERM2 synthesis and integration effort is to develop, or at a minimum hypothesize, the thresholds at which changes in water level regime (i.e., magnitude, timing, duration) could cause significant long-term harm to a particular ecological component (ETWG 2009). The concept of thresholds is generally consistent with the "Coping Zone" approach that has been introduced by the Plan Formulation and Evaluation Group (PFEG) and the Adaptive Management Workgroup (AMWG 2010). Due to limited time and resources available to compile and integrate pre-existing and newly collected datasets into the model framework, it is not feasible to represent ecological responses across all Upper Great Lakes coastal zones. Instead, a set of local wetland and shoreline sites have been selected to represent the ecological response for a given region (e.g., northern shore of Lake Superior). The selection of sites for inclusion in the IERM2 was based on two main criteria: 1) the site either represents unique physical and ecological conditions within the region, or it can be considered representative of a class of sub-ecosystems within the region; and 2) previous research efforts provide the opportunity to construct a quantitative relationship between water level regime and one or more indicators of ecological performance. A "Site Coordinator" (or site research team) was identified for each site. The Site Coordinators worked with LimnoTech to develop water level regime – ecological response relationships for incorporation into the IERM2 and to produce Fact Sheets on their sites that described the relationships and defined thresholds/durations that serve as the basis for the Coping Zone analysis. A map of the Upper Great Lakes sites currently under evaluation is provided in Figure 1-1.

The development of the IERM2 model for the Upper Great Lakes system was accomplished in collaboration with the Site Coordinators and other ETWG members through the following steps:

1. Developing an understanding of existing research with respect to water level regime impacts on specific ecological components (i.e., wetland vegetation, fish, wetland birds);
2. Identification of ecological "Performance Indicators" (PIs) that are representative of these components and have the potential for being significantly impacted by water level regime;

3. Development of conceptual "algorithms" that can be used to qualitatively understand the response of selected PIs to water level regime, including a preliminary assessment of PI-specific thresholds;
4. Development and application of computational algorithms to simulate the response of each PI to current and plausible future water level regimes, including the impacts of alternative regulation plans; and
5. Application of best professional judgment and expertise by the Site Coordinators to define thresholds (or "Coping Zones") for each selected PI.

This model development process was supported by a series of ETWG workshops and one-on-one WebEx conferences. These interactions provided an opportunity to explore potentially useful supporting data and relationships based on existing studies, to identify major gaps and field studies for summer 2010 to fill those gaps, and to develop and verify PI algorithms based on iterations with the Site Coordinators.

Figure 1-1. ETWG Upper Great Lakes Study Site Locations

Relationships between ecological performance indicators (PIs) and water level regime have been kept as simple and transparent as possible in order to best support the dissemination and evaluation of the results via the Shared Vision Model. In order to incorporate the IERM2 modeling results into the SVM in a way that would best support the decision-making process of the Study Board, a "Coping Zone Calculator" was developed to compute and report Coping Zone results for each ecological component being modeled.

1.4 SCOPE OF DOCUMENT

This report describes the development of the IERM2 modeling framework and provides a description of the ecological sub-models and performance indicators in Chapter 2. An introduction to the overall conceptual model for the Upper Great Lakes system is provided, followed by a discussion of specific ecological components and performance indicators (PIs) that have been identified for Lake Superior, the St. Marys River, Lakes Michigan and Huron (including Georgian Bay), Lake St. Clair, and Lake Erie. Chapter 3 describes the Coping Zone analysis and associated calculator tool that was developed as a key outcome of the IERM2 model building process. The chapter also discusses how the results of the Coping Zone analysis can be interpreted to support plan formulation and decision-making. Chapter 4 presents some example application results of the Coping Zone Calculator applied to available scenarios. It should be recognized that this report is being produced prior to the development and SVM analysis of all scenarios that will feed into the decision process. Hence, it does not represent a final or complete application of the IERM2 model and the Coping Zone Calculator. Given that plan formulation and evaluation is an ongoing process, Chapter 5 describes how ETWG, LimnoTech and the Site Coordinators will continue to interact with PFEG and the Study Board as they develop and evaluate new future Great Lakes basin supply conditions and candidate Lake Superior regulation plans. Finally, Chapter 6 provides specific recommendations for monitoring to facilitate adaptive management of Great Lakes coastal ecosystems based on the findings of the current study and IERM2 modeling effort.

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2. IERM2 PERFORMANCE INDICATOR DEVELOPMENT

This chapter describes the development of ecological performance indicators and associated sub-models to serve as the foundation for the IERM2 model framework. The chapter begins with a review of the overall conceptual model in Section 2.1. A detailed description of the ecological sub-models and performance indicators contained in the IERM2 is presented in Section 2.2. Section 2.3 contains a description and examples of the IERM2's output and visualization capabilities for performance indicator results.

2.1 CONCEPTUAL MODEL

An overall conceptual model (Figure 2-1) was developed to serve as the foundation for developing and applying quantitative relationships between water level regime and ecological performance indicators (PIs) in the IERM2 framework. A series of meetings between the modeling team and individual ETWG Site Coordinators was conducted to develop an understanding of the link between water levels and various ecological components, including habitat connectivity, wetland vegetation community structure, fish habitat quantity and quality, and wetland bird habitat quantity and quality. Table 2-1 provides a matrix of the Upper Great Lakes sites that were being evaluated and the ecological components that could potentially be represented by one or more performance indicators for those sites.

In many cases, the performance indicators developed to represent particular ecological components are specific to the local site where the data are collected. However, some opportunities to extend research conducted at a local scale to a regional scale were identified, and these opportunities are discussed below on a case by case basis. For example, the response of wetland vegetation communities to wetting and drying cycles demonstrates reasonable consistency across certain regions. The consistency in this response supports the extrapolation of relationships established between water level regime and community structure from one site to other sites, provided that the necessary bathymetry/topography data are available. For example, this is the approach that was used to model the aggregated wetland vegetation response for Saginaw Bay wetlands.

Wetland vegetative communities provide the foundation for the structure and function of the wetland ecosystem. A diverse and healthy vegetative community provides necessary habitat for nearshore fish species, wetland birds, macroinvertebrates, and other faunal groups. Fish species that function within wetland ecosystems for part or all of their life cycle utilize wetland vegetation for predation refuge, for spawning, for nursery habitat, and as a source of energy (i.e., consumption of macroinvertebrates and forage fish). Because wetland vegetation has a cascading effect on the faunal components of the ecosystem, it is important to quantitatively link faunal responses to vegetation where possible. As illustrated in Figure 2-1, this linkage involves not only providing information on the vegetative community response to the faunal models, but integrating this information with changes of water depth within these communities. For both wetland fish and bird species, the availability and abundance of particular vegetation zones is important, but the presence/absence of water within those zones during critical spawning or breeding periods is also crucial. For example, a particular wetland site may provide 10 hectares of bulrush marsh that can support northern pike spawning, but this zone cannot be utilized for spawning unless sufficient water depth is available to permit pike access during the spawning window.

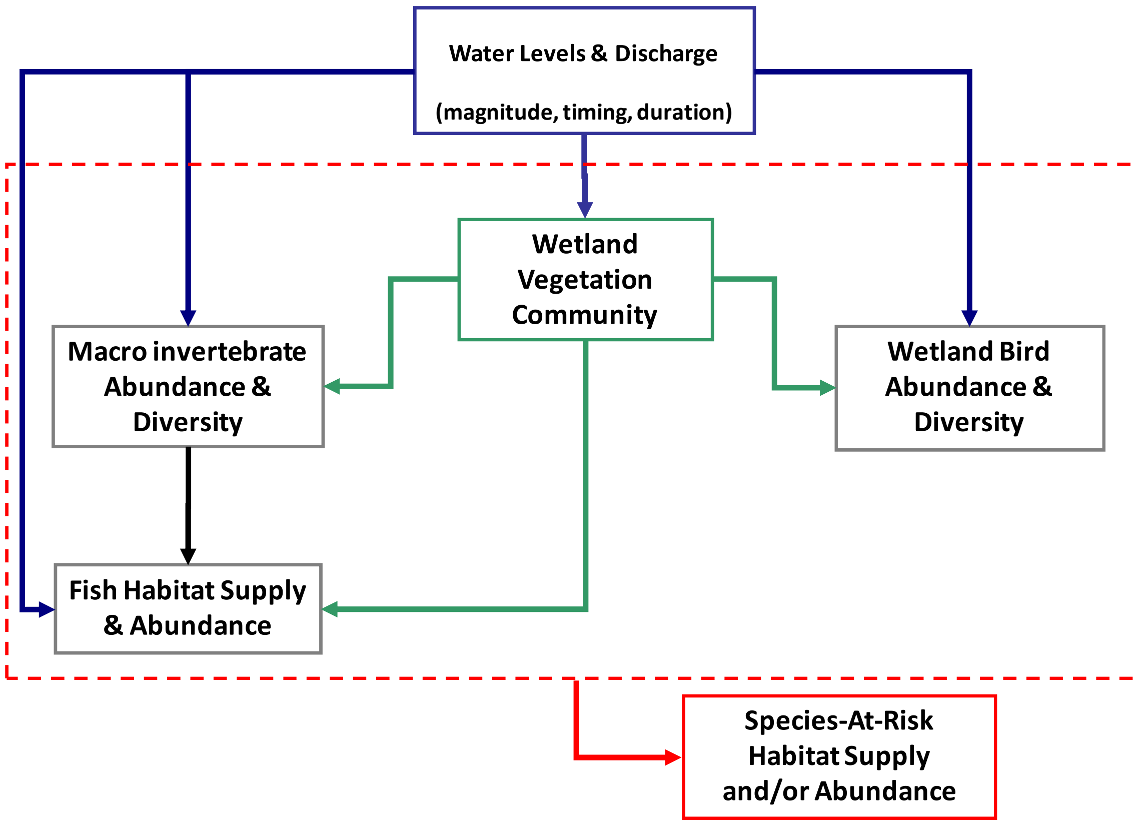


Figure 2-1. IERM2 Conceptual Linkages between Ecological Components and Sub-models

Table 2-1. Ecological Components Evaluated by ETWG Study Site

Lake Region	Location(s)	General Description	Site Coordinator / Researcher(s)	Wetland Vegetation Community	Habitat Connectivity	Fish Habitat & Food Supply	Wetland Bird Habitat Supply	Invasive Species
Lake Superior	Chequamegon Bay (Kakagon Slough)	Wild rice abundance	Meeker	X				
	Northern shore tributary mouths	Tributary connectivity	Johnson		X			
	St. Louis River estuary	Macroinvertebrate abundance & diversity	Brady			X		
	Black Bay Sturgeon Bay, Cloud Bay	Wetland vegetation, northern pike habitat	Foster, Harris	X		X		
	Au Train River	Wetland vegetation communities	Albert	X				
	Batchawana Bay	Wetland vegetation community, fish habitat	Chow-Fraser	X	X	X		
Lake Michigan	Arcadia Lake	Wetland vegetation communities	Wilcox	X		X		
	Eastern shore wetlands	Fish habitat suitability, macroinvertebrates	Uzarski, Cooper, Murry			X		
	Green Bay (south)	Macroinvertebrate abundance & diversity	Brady			X		
	Eastern shore drowned river mouths	Sediment-water nutrient flux	Steinman			X		
St. Marys River	St. Marys River (rapids, Lake George, etc.)	Variety of vegetation, fish habitat, invasive species PIs	Bain, et al.	X	X	X	X	X

Table 2-1. Ecological Components Evaluated by ETWG Study Site - Continued

Lake Region	Location(s)	General Description	Site Coordinator / Researcher(s)	Wetland Vegetation Community	Habitat Connectivity	Fish Habitat & Food Supply	Wetland Bird Habitat Supply	Invasive Species
Lake Huron & Georgian Bay	Les Cheneaux Islands (Mackinac Bay, Duck Bay)	Wetland vegetation communities	Albert	X				X
	Les Cheneaux Islands	Macroinvertebrate diversity				X		
	Eastern Georgian Bay wetlands	Wetland connectivity to Bay, submergent vegetation abundance	Chow-Fraser	X	X			
	Saginaw Bay (based on Fish Point)	Wetland vegetation communities	Wilcox	X				
	Saginaw Bay	Macroinvertebrate abundance & diversity	Uzarski, Cooper, Murry			X		
		Fish abundance & diversity	Uzarski, Cooper, Murry			X		
Lake St. Clair / St. Clair River	Lake St. Clair and Delta	Fish habitat quantity	Mackey			X		
		Wetland vegetation community	Albert, Mackey	X				X
Lake Erie	Long Point, Turkey Point	Wetland vegetation community, fish habitat	Mortsch, Doka, Cabrera, Gertzen, Deadman	X		X		
Regional1	Various wetland sites across Great Lakes region	Wetland bird habitat supply	Niemi, Howe				X	

[1] "Regional" refers to sub-models and performance indicators that are being developed based on available data from multiple wetland sites.

2.1.1 Wetland Vegetation

The response of Great Lakes wetland vegetation communities to water level regime has been a subject of study for the past several decades. For example, a detailed and targeted study of the impact of historical water level patterns on Lake Ontario wetland vegetation communities was conducted by Wilcox and others for the IJC Lake Ontario – St. Lawrence River (LOSL) water level study (Wilcox et al. 2005, 2008; Wilcox and Xie, 2007, 2008). Studies of wetland vegetation patterns and shifts in the Upper Great Lakes have also been conducted, including some studies that targeted understanding the long-term impacts of water level regime (Wilcox et al. 1992, Wilcox and Meeker 1995, Wilcox and Nichols 2008). Existing wetland vegetation data and/or models for the Upper Great Lakes study sites that represent linkage to water level regime are presented in Table 2-2. A more detailed description of the sub-models and performance indicators used to represent vegetation for each site is provided in Section 2.3.

Table 2-2. Summary of Wetland Vegetation Modeling Approaches

Lake Region	Site Location(s)	Vegetation Types/Zones Represented	Approach / Basis for Predictive Sub-model
Superior	Kakagon Slough (Chequamegon Bay)	• Wild rice	Wild rice coverage observed for 1986-89 as a function of water depth and drawdown (Meeker 1999)
Superior	Black Bay, Sturgeon Bay	• Bulrush marsh	Relationships based on historical aerial imagery and water level history
Superior	Batchawana Bay	• Emergent • Submerged	Relationship between emergent/submergent cover and water depth
Michigan	Arcadia Lake Marsh	• Meadow marsh	Rules-based modeling based on plant sampling (1995, 2002) and analysis of historical aerial imagery (similar to Mortsch et al. 2006, Wilcox and Xie 2007)
St. Marys River	Lower St. Marys River	• Emergent • Submerged	Estimate coverage of submersed vegetation based on preferred depth range
Huron	Les Cheneaux Islands (Mackinac Bay, Duck Bay)	• Meadow marsh • Emergent (bulrush) marsh	Rules-based modeling approach informed by site data (similar to Mortsch et al. 2006)
Huron	Georgian Bay (eastern wetlands)	• Emergent • Submerged	Relationship between emergent/submergent cover and water depth
Huron	Saginaw Bay (based on Fish Point)	• Meadow marsh • Bulrush marsh	Rules-based model based on plant community data for 1988-1993; extrapolated to Saginaw Bay
Lake Erie	Long Point, Turkey Point	• Trees/shrubs • Meadow marsh • Emergent marsh • Submerged	Rules-based modeling approach (Mortsch et al. 2006)

2.1.1.a Overview of Approach

Specific performance indicators for wetland vegetation represent the surface area coverage or density of individual vegetation zones, including meadow marsh, emergent marsh, and/or submersed zones. The intent of the wetland vegetation sub-models is to assess the potential for significant loss of one or more important habitat zones (e.g., bulrush-dominated emergent zone) under plausible future water level regimes. For example, if climate change results in a decrease in long-term inter-annual water level fluctuations, invasive species such as *Phragmites australis* (common reed) are likely to overtake emergent vegetation zones that are currently dominated by native bulrush species.

It is well-known that vegetation species and zones in Great Lakes coastal wetlands respond to long-term fluctuations in water level (Wilcox et al. 2005). Quantifying the linkage between vegetation zone response and wetting/drying intervals and water depth is challenging because the most significant changes occur as a lagged response based on a multi-year and even multi-decadal history of water level conditions. In addition, other factors such as local wave energy and regional groundwater effects can have a significant influence on vegetation response for some systems. Recent efforts to quantify the response of vegetation zones to recent/historical lake level conditions include rules-based models developed to simulate Lake Ontario wetland vegetation response (Wilcox et al. 2005, LimnoTech 2005) and to support climate change assessments for vegetative communities in Long Point, Lake Erie (Mortsch et al. 2006). These models are predicated on a set of rules that are used to assign a vegetation zone (e.g., meadow marsh, emergent marsh) to a particular elevation based on the flooding/dewatering history of that elevation and current water depth.

Rules-based models based on wetting/drying intervals and water depth were developed to simulate vegetation response for several of the Upper Great Lakes Sites, including Kakagon Slough; Arcadia Lake Marsh; Les Cheneaux wetlands (Mackinac Bay, Duck Bay); Saginaw Bay; and Long Point in Lake Erie. The vegetative community responses for other sites, such as Georgian Bay and Batchawana Bay, were simulated primarily based on the minimum or average water depth for a given year. Regardless of the approach taken for simulating wetland vegetative response for a given site, the availability of sufficient topography/bathymetry data to support the calculations was critically important. The use of existing or newly collected topography/bathymetry data to support wetland vegetation sub-models is discussed in the next section.

2.1.1.b Supporting Physical Data

The collection of Upper Great Lakes marsh sites presented in Table 2-2 is expected to provide a good overall representation of how vegetation zones in the various lakes and regions would respond to plausible future water level regimes. However, as discussed above, site-specific bathymetry data are crucial to developing the quantitative assessment of wetland vegetation zone response needed for a particular site or collection of sites. This is because bathymetry/topography strongly depends on the region and the specific geomorphology of a site or collection of sites. The need for bathymetry data for the various sites was addressed in a variety of ways:

- Use of existing (one-dimensional) elevation transects;
- Use of previously existing "two-dimensional" coarse-scale or fine-scale bathymetry points or contours (e.g., collected via single beam or multi-beam sonar devices); and
- Use of fine-scale bathymetry data that were collected during the 2010 field season.

Existing elevation transects and other supporting data are available for Kakagon Slough, the Les Cheneaux Islands wetland sites, and Fish Point (within Saginaw Bay). Existing fine-scale bathymetry data are available for a subset of eastern wetlands in Georgian Bay, as well as Arcadia Lake, Black Bay, Sturgeon Bay, Long Point, and several wetland complexes in the vicinity of the St. Louis River Estuary and inner Green Bay. In addition, a combined nearshore topographic/bathymetric dataset was developed by LimnoTech for Saginaw Bay based on depth contours available from NOAA and a LiDAR dataset available from the U.S. Army Corps of Engineers. This dataset is being used in combination with Doug Wilcox's vegetation data for Fish Point (Wilcox and Nichols 2008) to simulate large-scale vegetation zone responses to water level fluctuations for Saginaw Bay. New and pre-existing bathymetry data are being used to estimate the fraction of wetland area contained within a set of continuous elevation contour "bins", similar to the approach used for the Lake Ontario wetland sub-model for the LOSL Study (LimnoTech 2005).

2.1.2 Fish Habitat

Performance indicators for fish habitat represent several factors that affect the quantity and suitability of habitat for key life stages, including spawning and young-of-year and juvenile development. These factors include:

- Coverage/density of specific vegetation zones (e.g., emergent zone dominated by bulrush);
- Depth of water within specific vegetation zones during key time periods (e.g., spawning period in spring); and
- Energy supply, based on macroinvertebrate abundance and diversity within specific vegetation zones.

These three factors are being addressed to varying degrees for each of the Upper Great Lakes study sites, either indirectly through the use of vegetation zone PIs or through explicit indicators of fish habitat. Specific fish habitat PIs are being developed for Black Bay and Sturgeon Bay in Lake Superior, the St. Marys River, Georgian Bay (as wetland connectivity), Saginaw Bay, Lake St. Clair, and Long Point in Lake Erie.

2.1.3 Wetland Bird Habitat

Wetland bird habitat quantity and quality is being assessed for select Upper Great Lakes study sites based on the areal coverage of vegetation zones used by a set of representative obligate wetland species. The approach was been designed to estimate an overall "ecological condition index", which can be used to evaluate the impact of a particular regulation plan and basin supply scenario on the overall response of the wetland bird community.

2.2 ECOLOGICAL SUB-MODEL DESCRIPTIONS

The following sub-sections provide a brief description of the sub-models and associated performance indicators that have been developed for each of the major lake regions and individual study sites. The linkages between wetland vegetation zone predictions and performance indicators for fish and wetland birds are also discussed. In many cases, performance indicators developed to represent particular ecological components are specific to the local site where the data are collected. However, opportunities to extend research conducted at a local scale to a regional scale were identified, and these opportunities are discussed below on a case by case basis. In addition, several performance indicators for macroinvertebrates, fish, and wetland birds were developed from regional datasets and can be appropriately applied to various wetland sites across the Upper Great Lakes. These regional indicators are specifically discussed in Section 2.3.1.

A complete listing of the ecological performance indicators represented in the IERM2 framework is provided in Table 2-3. Detailed Fact Sheets are available for each performance indicator in Appendix A, and the "Fact Sheet ID" column in Table 2-3 provides the link to the appropriate sheet.

Table 2-3. Ecological Performance Indicators Represented in IERM2

Lake Region	Site Location(s)	PI Description	Units	Fact Sheet ID	Researcher(s)
Lake Superior	Chequamegon Bay (Kakagon Slough)	Wild rice surface area	ha	01	Meeker
	Black Bay	Bulrush marsh area	ha	02	Foster, Harris
	Sturgeon Bay	Bulrush marsh area	ha	02	Foster, Harris
	St. Louis River estuary (3 wetland sites)	Macroinvertebrate species richness	index	03	Brady
		Fish habitat richness	index	04	Brady
	Batchawana Bay	Emergent + submergent vegetation area	ha	05	Chow-Fraser
Lake Michigan	Green Bay (4 inner bay sites)	Macroinvertebrate species richness	index	03	Brady
		Fish habitat richness	index	04	Brady
	Arcadia Lake	Wetland meadow marsh surface area	ha	06	Wilcox
	Arcadia Lake	Sediment-water peak phosphorus flux	kg/day	07	Steinman

Table 2-3. Ecological Performance Indicators Represented in IERM2 - Continued

Lake Region	Site Location(s)	PI Description	Units	Fact Sheet ID	Researcher(s)
Lake Huron & Georgian Bay	Eastern Georgian Bay wetlands	Wetland connectivity to Georgian Bay (spring and fall spawning periods)	% area connected	08	Chow-Fraser
		Submerged aquatic vegetation (SAV) potential	% of wetland area	09	Chow-Fraser
	Les Cheneaux Islands wetlands	Meadow marsh surface area	ha	10	Albert
		Bulrush surface area	ha	10, 11	Albert
		Macroinvertebrate species composition diversity	index	14	Uzarski, Cooper, Murry
	Saginaw Bay	Meadow marsh surface area	ha	12	Wilcox
		Bulrush marsh surface area	ha	12	Wilcox
		Macroinvertebrate density	$\#/m^2$	13	Uzarski, Cooper, Murry
		Macroinvertebrate diversity (richness)	index	13	Uzarski, Cooper, Murry
		Wetland fish total abundance (inner bulrush zone)	index	15	Uzarski, Cooper, Murry
		Wetland fish species richness (inner & outer bulrush zone)	index	15	Uzarski, Cooper, Murry
		Wetland fish assemblage evenness (outer bulrush zone)	index	15	Uzarski, Cooper, Murry
		Sediment-water peak phosphorus flux	kg/day	07	Steinman
		Wetland bird – ecological condition index (includes SAR)	index (1-10)	20	Niemi, Howe
Lake St. Clair	Lake St. Clair and Delta	Fish suitable habitat area	% area accessible	16	Mackey
		Meadow/emergent marsh area[1]	n/a	10	Mackey, Albert

Table 2-3. Ecological Performance Indicators Represented in IERM2 - Continued

Lake Region	Site Location(s)	PI Description	Units	Fact Sheet ID	Researcher(s)
Lake Erie	Long Point / Turkey Point	Meadow/emergent marsh vegetation area	ha	17	Mortsch, Doka, Cabrera, Gertzen, Deadman
		Open water surface area	ha	17	
		Submerged aquatic vegetation surface area	ha	18	
		Fish suitable habitat area for various guilds	ha	19	
		Wetland bird – ecological condition index (includes SAR)	index (1-10)	20	
St. Marys River	St. Marys River (rapids)	Sea lamprey unsuitable spawning habitat in Rapids	Suitability index (0-1 scale)	21	Bain et al.
	St. Marys River (rapids)	Native fish habitat in Rapids	ha	22	Bain et al.
	St. Marys River (rapids)	Fish stranding in Rapids [2]	suitability index (0-1 scale)	23	Bain et al.
	St. Marys River (entire river)	Lake sturgeon suitable spawning habitat	% increase	24	Bain et al.
	St. Marys River (Lake George)	Lake George Channel flushing flows	% of transects	25	Bain et al.
	St. Marys River (entire river)	Cisco (lake herring) spawning habitat	Suitability index (0-1 scale)	26	Bain et al.
	St. Marys River (entire river)	Black tern nesting success	Suitability index (0-1 scale)	27	Bain et al.
	St. Marys River (entire river)	Submerged aquatic vegetation	Suitability index (0-1 scale)	28	Bain et al.
	St. Marys River (Lake Nicolet)	Emergent wetland area in Lake Nicolet	ha	29	Bain et al.
St. Marys River	St. Marys River (entire river)	River backwater habitat connectivity	Suitability index (0-1 scale)	30	Bain et al.

[1] A specific performance indicator metric is not included in the IERM2 model for St. Clair River delta vegetation; however, a Coping Zone criterion has been developed to represent this ecosystem component.

[2] Performance indicator not explicitly included in IERM2 because sub-daily hydraulic information is required. This PI will be considered in terms of gate operations for the Compensating Works.

Following the PI conceptualization phase, the main steps involved in the development and quantification of a given PI are as follows:

1. **Processing of bathymetric/topographic datasets (if necessary) –** this step involved obtaining raw field data (e.g., individual points) and converting the data into a seamless digital elevation model (DEM) for use in developing elevation contour "bins" to serve as the basis for wetland vegetation and water depth calculations in the IERM2. This typically involved 1) developing a triangular irregular network (TIN) from available point measurements of elevation, 2) revising/clipping the TIN to eliminate bad data points or processing artifacts, 3) converting the TIN to a raster dataset that represents the DEM, and 4) summarizing the DEM as total surface area per 1-cm elevation "bin".

2. **Developing a draft PI algorithm within IERM2 –** this step involved conceptualizing and then implementing an algorithm that directly or indirectly relates PI response to water level and/or river discharge conditions. Many of the vegetation PIs have a direct link to both inter-annual water level fluctuations and seasonal water level as a driver for local water depth. PIs that have a response that is driven by vegetation conditions generally have an indirect linkage to water levels.

3. **Testing and finalizing the PI algorithm within IERM2 –** this step involves extensive testing of the draft PI algorithm by running simulations for a range of regulation plan and Great Lakes basin supply conditions. This step is critical with respect to identifying any coding errors within the model, but it is equally important for understanding the limitations of the algorithm and the supporting bathymetric/topographic data.

4. **Defining "Coping Zone criteria" –** the approach taken by the ETWG via the IERM2 and by the IUGLS in general is to identify critical hydraulic (e.g., water level or flow) conditions that are likely to result in significant harm to the ecological component(s) represented by one or more performance indicators. The classification term "Zone C" is being used in the context of the Coping Zone approach development by the Plan Evaluation Group (PEG) and the Adaptive Management Group (AMG). Because the Coping Zones will be used to inform decisions concerning a Lake Superior regulation plan and to understand potential ramifications of climate change, it is critical that one or more Coping Zone criteria be identified for each PI and incorporated into the IERM2. Further discussion of Coping Zone criteria is provided in Chapter 3.

5. **Developing a PI Fact Sheet –** a Fact Sheet was developed for each performance indicator by the Site Coordinators in collaboration with LimnoTech modelers. The Fact Sheet documents the following information concerning the PI: metric, ecological importance/niche, temporal and spatial validity, specific link to hydrology and algorithm used in the IERM2, calibration and validation approach, threshold approach, and references to supporting documents and literature. The complete set of Fact Sheets

representing the performance indicators summarized in Table 2-3 is provided in Appendix A.

2.2.1 Regional Performance Indicators

A subset of ecological performance indicators (PIs) were developed based on broad regional studies and datasets and are therefore well-suited for potential application to wetland sites across the Upper Great Lakes region. This subset includes PIs for wetland birds (index of ecological conditions), as well as PIs for fish and macroinvertebrate abundance and diversity.

2.2.1.a Fish and Macroinvertebrates

A set of habitat-based relationships were developed for both macroinvertebrates and fish for the Upper Great Lakes based on data collected as part of the Great Lakes Environmental Indicators (GLEI) study during 2002-03 (Danz et al. 2005, Niemi et al. 2009). Potential regional performance indicators identified from this analysis include:

- Invertebrate taxa richness (Figure 2-2);
- Abundance of key invertebrate taxa or species (i.e., Odonata, "climbers");
- Richness of vegetation-preferring fish;
- Relative abundance of piscivorous fish and bluegill sunfish; and
- Fish habitat richness (Figure 2-3).

All of the potential performance indicators listed above are related to habitat zone type, including emergent, mixed, and submerged vegetation and open water. The various relationships for these indicators illustrate a common theme that the emergent, mixed emergent/floating, and submergent vegetation zones provide optimal habitat for maintaining wetland macroinvertebrate and fish abundance and diversity. All of the relationships to habitat type demonstrate patterns similar to that shown in Figure 2-2 for macroinvertebrate diversity, where open water demonstrates lesser habitat value than emergent/mixed and submergent vegetation zones. Preferences for specific types of vegetation may also exist, but are more difficult to discern from the available data. Ultimately, macroinvertebrate diversity index (Figure 2-2) and fish habitat richness (Figure 2-3) were included in the IERM2 model as representative performance indicators for the full set of macroinvertebrate and fish relationships developed based on the GLEI datasets. A more detailed discussion of the macroinvertebrate diversity PI and the fish habitat richness PI are provided in Fact Sheet #03 and Fact Sheet #04, respectively, in Appendix A.

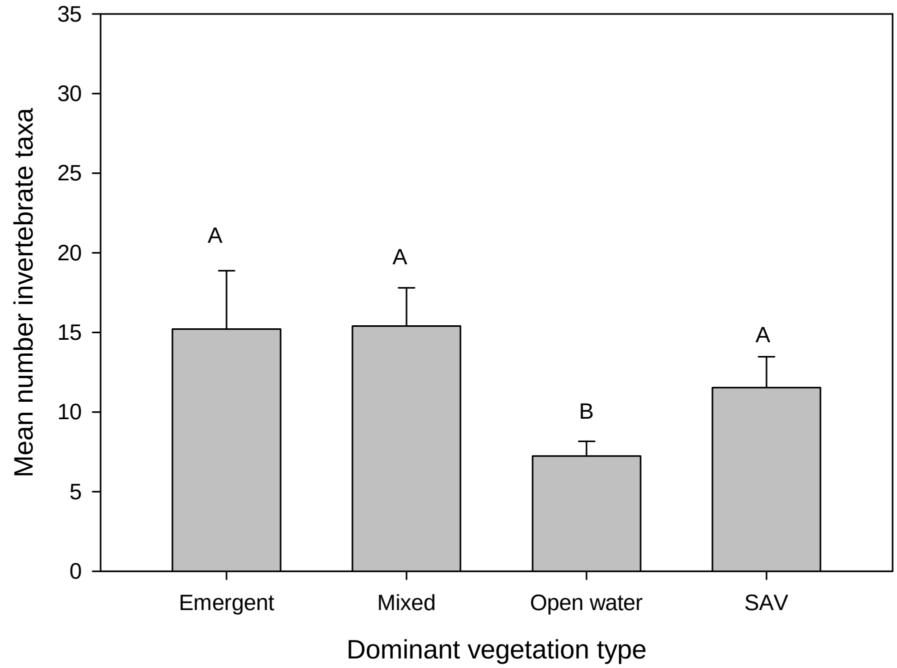


Figure 2-2. Macroinvertebrate Diversity as a Function of Habitat/Vegetation Type

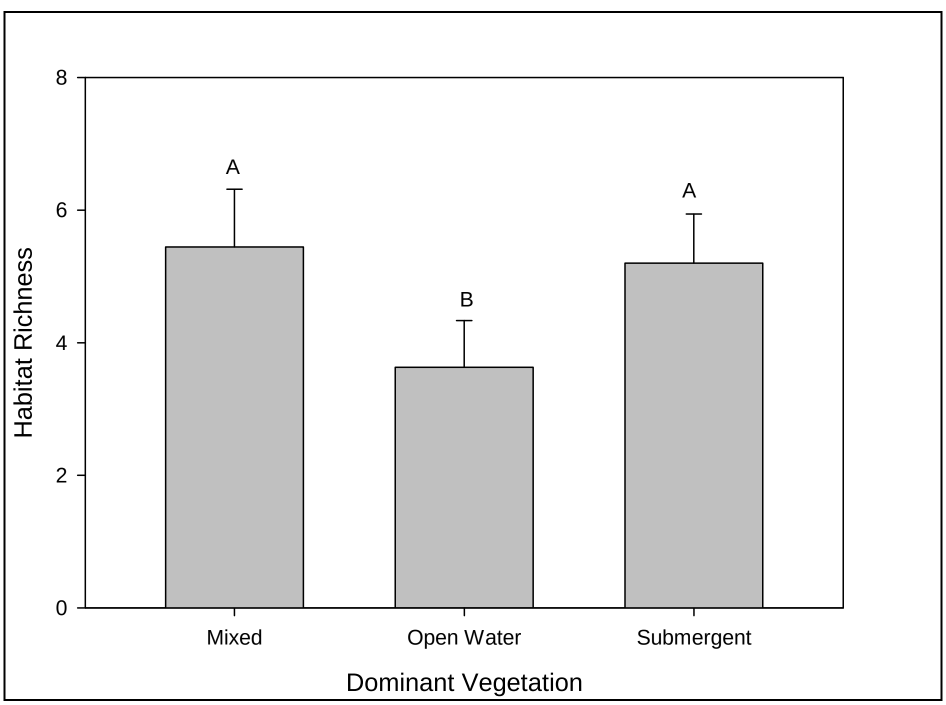


Figure 2-3. Fish Habitat Richness as a Function of Habitat/Vegetation Type

The regional performance indicator relationships described above can potentially be applied to any wetland site represented in the IERM2 framework that meets the following criteria: 1) sufficient bathymetry and topography data are available to represent the current and potential future extent of the wetland complex, and 2) the areal coverage of key vegetation zones can be predicted. For wetland sites that meet these criteria, habitat-specific values (such as those shown in Figure 2-2) can be multiplied by the total area of the habitat type, and then a weighted average can be calculated across the entire wetland site. As a simple example, assume the macroinvertebrate diversity index (as shown in Figure 2-2) is 15 for emergent/mixed vegetation and roughly 7 for open water. If a particular wetland site is predicted to have 50% emergent/mixed coverage and 50% coverage by open water, then the weighted indicator response would be calculated as 11. This approach can be used to evaluate the relative response of these habitat-based metrics for various regulation plan / Basin supply scenarios.

A second set of regional performance indicators for macroinvertebrates and fish was developed by Don Uzarski, Matt Cooper, and Brent Murry based on datasets available from Saginaw Bay wetlands and wetlands located along the eastern shore of Lake Michigan. The regional performance indicators developed from these datasets are similar in nature to those described above from the GLEI analysis and include:

- Macroinvertebrate abundance as a function of bulrush marsh (*Schoenoplectus*) zone vs. unvegetated zone (Figure 2-4) – based on Saginaw Bay data;
- Macroinvertebrate diversity as a function of bulrush marsh (*Schoenoplectus*) zone vs. unvegetated zone (Figure 2-5) – based on Saginaw Bay data;
- Macroinvertebrate diversity as a function of inter-annual water level changes within the bulrush marsh zone (based on Les Cheneaux Islands data);
- Fish species diversity (i.e., richness and evenness) as a direct function of water level (based on Saginaw Bay data); and
- Fish abundance as a function of seasonal water level increases (based on Saginaw Bay data).

The results shown in Figures 2-4 and 2-5 suggest that macroinvertebrate abundance and diversity are a factor of two greater within the bulrush marsh compared to an unvegetated area. These results, as well as the results for the other performance indicators listed above, provide additional support for the importance of maintaining a healthy bulrush marsh zone within wetlands where bulrushes are present (Saginaw Bay, Les Cheneaux Islands, Green Bay, etc.).

It is also important to note that the results shown in Figures 2-4 and 2-5 are very consistent with the relationships developed from the GLEI datasets. For example, the macroinvertebrate diversity relationships plotted in Figures 2-2 and 2-5 both demonstrate a 100% increase in diversity for bulrush/emergent vegetation relative to the unvegetated/“open water” zone. The consistencies between similar macroinvertebrate and fish indicators developed from completely separate datasets provides confidence that the relationships developed are realistic and can be appropriately applied across a range of wetland sites in Lake Michigan and Lake Huron.

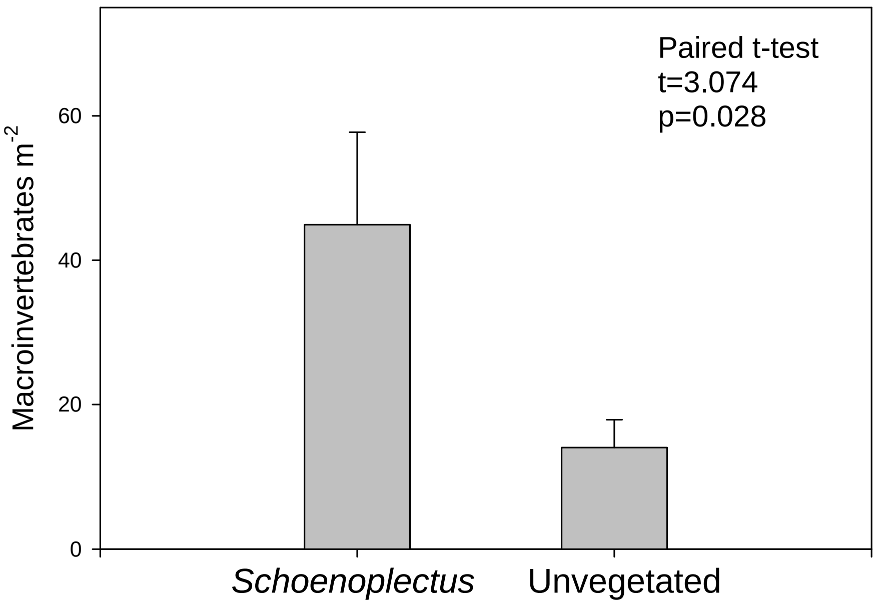


Figure 2-4. Macroinvertebrate Abundance vs. Vegetation Zone Type

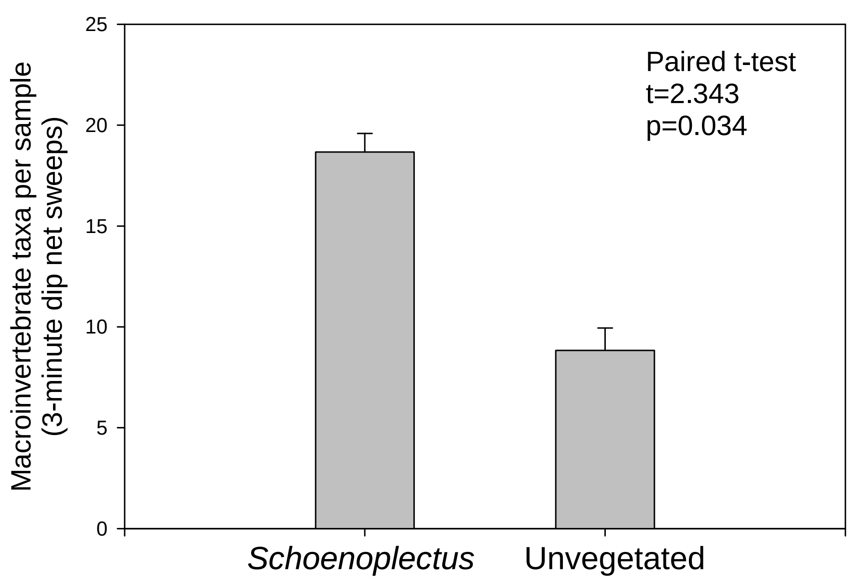


Figure 2-5. Macroinvertebrate Diversity vs. Vegetation Zone Type

2.2.1.b Wetland Bird Abundance

Extensive wetland bird observational data were collected as part of the Great Lakes Environmental Indicators (GLEI) study during the 2002-03 period (Hanowski et al. 2007; Howe et al. 2007a, 2007b; Niemi et al. 2009). These data, which represent wetlands across the U.S. coastline of the Upper Great Lakes, provide detailed information on the density of various obligate wetland bird species within specific habitat types, including tree, shrub, meadow marsh, emergent, and "open water". Because the GLEI data are representative of a broad geographic area, the relationships developed from these data can be applied with confidence to wetlands along the U.S. coastline of the Upper Great Lakes given that 1) sufficient physical (i.e., bathymetric/topographic) data are available, and 2) predictions of the extent of key vegetation zones (i.e., meadow marsh, emergent) can be made. It should be noted that it is not valid to generalize the wetland bird habitat information provided by the GLEI study across all Canadian wetlands in the Upper Great Lakes. For example, recent studies have demonstrated that bird species typically found in Canadian wetlands of Lakes Erie and Ontario are not found in eastern Georgian Bay (Cartwright-Smith and Chow-Fraser 2011).

A suite of obligate wetland bird species were selected to be representative across the range of habitats in Great Lakes coastal wetlands and to include several species at risk. A total of thirteen species were selected, including five species at risk:

- American Bittern;
- Black Tern (species at risk);
- Blue-Winged Teal;
- Common Moorhen;
- Least Bittern (species at risk);
- Marsh Wren;
- Pied-billed Grebe;
- Sedge Wren;
- Sora;
- Virginia Rail (species at risk);
- Yellow Warbler;
- Yellow Rail (species at risk); and
- King Rail (species at risk).

Species densities (# per hectare) were estimated for each major habitat type from the GLEI datasets. These densities can be integrated with predictions of the surface area of major habitat types (i.e., meadow marsh, emergent) in a wetland for a given year to estimate the total number of individuals that could be supported by that wetland area.

The "ecological condition index" (ECI) approach is used to integrate population estimates for the 13 species into a single indicator representing overall wetland bird community health. The ECI is developed by relating the number of individuals for a given species to an index ranging from 1 to 10, with 1 representing a very poor overall condition and 10 representing an optimal condition. For example, Figure 2-6 plots the population size for Sedge Wren as a function of the ECI. An optimal condition (ECI = 10) occurs when the Sedge Wren population is approximately 160 individuals. A very poor condition (ECI = 0) occurs when only 10 individuals are expected to be found at a given wetland location.

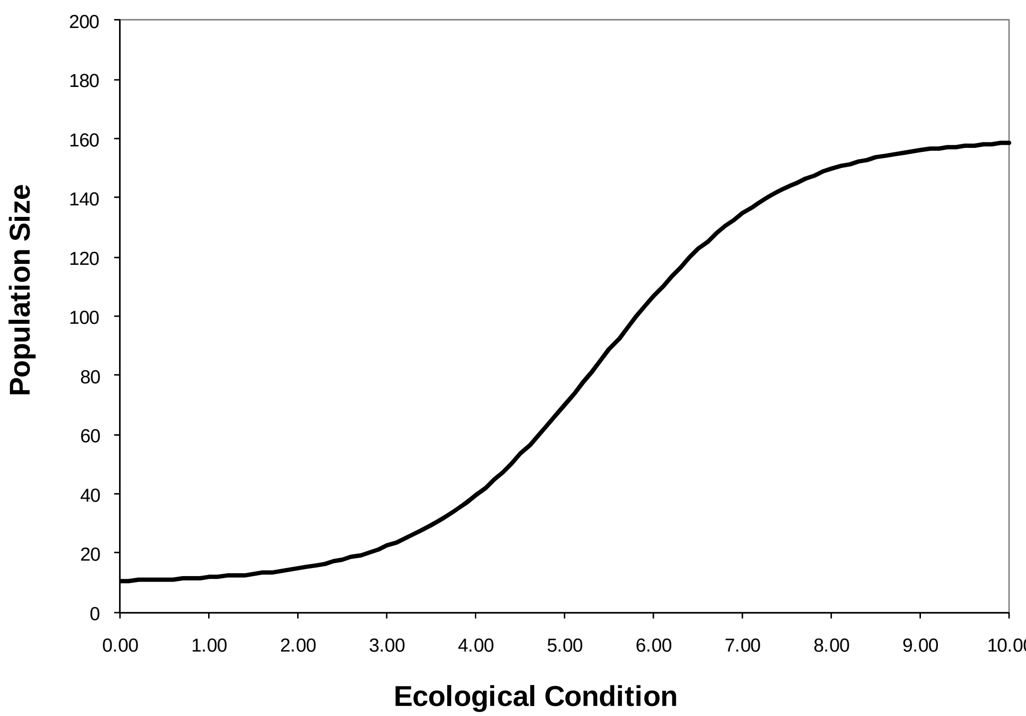


Figure 2-6. Sedge Wren Population Size vs. "Ecological Condition Index" (ECI)

The species-specific relationship between the ECI and population size is described by the following probability function:

$$P_i(C) = \beta_1 + \beta_2 * \frac{e^{\beta_4 * (C - \beta_3)}}{1 + e^{\beta_4 * (C - \beta_3)}} \qquad (2\text{-}1)$$

where C represents the ECI (1-10 scale), $P_i(C)$ is the estimated population for species i, β_1 is the species population at C=0, β_2 is the optimal species population at C=10, β_3 is the ECI at which the average of β_1 and β_2 occurs, and β_4 is a slope coefficient. The coefficients developed for each of the 13 species are listed in Table 2-4.

Table 2-4. Wetland Bird Species Coefficients for ECI Function

Species Name	Species Code	β_1	β_2	β_3	β_4
American Bittern	AMBI	0.0	40.0	10.0	0.300
Black Tern	BLTE	0.0	50.0	8.0	1.0
Blue-winged Teal	BWTE	0.0	60.0	6.0	1.0
Common Moorhen	COMO	0.0	30.0	7.0	1.0
King Rail	KIRA	0.0	20.0	10.0	1.0
Least Bittern	LEBI	0.0	50.0	9.0	1.0
Marsh Wren	MAWR	20.0	150.0	3.0	1.0
Pie-billed Grebe	PBGR	0.0	50.0	6.0	1.0
Sedge Wren	SEWR	0.0	50.0	8.0	1.0
Sora	SORA	0.0	80.0	6.0	1.0
Virginia Rail	VIRA	0.0	40.0	7.0	1.0
Yellow Rail	YERA	0.0	20.0	10.0	1.0
Yellow Warbler	YWAR	10.0	150.0	4.0	1.0

Given the ECI functions for each of the 13 species and estimates of species populations for a given wetland in a given year, an overall ECI is calculated by performing a least squares optimization on the 13 functions. In general, water level scenarios that allow for short- and long-term inter-annual variability in water levels will maintain the greatest diversity in wetland bird habitats (i.e., for all 13 species). Therefore, these conditions will typically produce the highest "index of ecological condition" scores. In contrast, a water level scenario that compresses the range of water levels will result in the meadow marsh and/or emergent marsh zones being contracted, thus reducing overall wetland bird community health. This condition will result in a lower ECI being calculated for a given wetland site. Steen et al. (2006) have similarly suggested that minimizing water-level fluctuations may negatively affect wetland bird populations that are adapted to aquatic microhabitats for foraging and nesting.

A complete discussion of the wetland bird "ecological condition index" PIs can be found in Fact Sheet #20 in Appendix A.

2.2.1.c Nutrient Fluxes

A set of experiments was conducted during summer 2010 to assess the importance of water level fluctuations with respect to release of nutrients (e.g., phosphorus, nitrogen) from sediments found within wetland environments. Experiments were conducted for cores collected at a range of water depths from Saginaw Bay wetlands and drowned river mouth wetlands located along the eastern coast of Lake Michigan. Cores collected from these locations were desiccated and then re-wet. The mass flux rates for soluble reactive phosphorus (SRP), nitrate, and ammonia were determined for each core and used to develop a relationship between the status of the original core (i.e., depth of inundation) and peak flux rate. The results of these experiments suggested that a peak release of SRP occurs when sediments that were previously dewatered are re-wetted. A more detailed discussion of the significance of this phenomenon can be found in the corresponding Fact Sheet #07 in Appendix A.

Based on the results of the desiccation/re-wetting experiments, a PI was developed in the IERM2 for SRP peak mass flux in coastal wetland systems. This PI was configured for and applied to Saginaw Bay wetlands and Arcadia Lake Marsh in Lake Michigan. These sites were selected based on the availability of sufficient topographic/bathymetric datasets and to be consistent with the locations of the cores used to conduct the experiments (i.e., Arcadia Lake Marsh is considered to be representative of drowned river mouth wetlands in eastern Lake Michigan).

The SRP release rate results obtained for Saginaw Bay and Lake Michigan drowned river mouth wetlands were used to develop an algorithm for simulating the peak release rate (kg/day) that can be expected for these wetlands in a given year. The following rules were developed to assign SRP release rates to specific elevations:

- Wetland elevations that were re-wetted in a given year after being dewatered for at least one growing season were assigned the highest release rates: 37.9 $mg/m^2/d$ for Saginaw Bay, and 11.3 $mg/m^2/d$ for Arcadia Lake.
- Wetland elevations that were inundated the previous growing season with a maximum water depth of less than 13 cm were assigned release rates of 1.33 $mg/m^2/d$ for Saginaw Bay, and 3.04 $mg/m^2/d$ for Arcadia Lake.
- Wetland elevations that were inundated the previous growing season with a maximum water depth of greater than 13 cm were assigned the average lowest release rate: 0.58 $mg/m^2/d$ for Saginaw Bay, and 1.06 $mg/m^2/d$ for Arcadia Lake.

These rules were used to assign release rates to each wetland elevation, and those release rates were integrating across the total area of the wetland(s) to estimate a total peak mass flux (in kg/day) for each year. This approach was applied separately for Saginaw Bay wetlands and Arcadia Lake Marsh.

It is important to note that the meaning and ecological significance of the peak phosphorus release rate is not clear at this point. Additional research and experimentation are needed to understand the implications for this performance indicator. In light of these limitations, the phosphorus release PI was not used as the basis for developing any Coping Zone criteria to support the decision-making process. Rather, this PI was used only as additional support for an inter-annual water level fluctuation criterion for Lake Michigan-Huron that was developed based on independent macroinvertebrate diversity PIs (criterion LMH-03 in Table 3-1).

2.2.2 Lake Superior

For Lake Superior, performance indicators (PIs) have been developed for Kakagon Slough, Black Bay, Sturgeon Bay, and Batchawana Bay, and several wetlands located in the St. Louis River Estuary. The PIs for each of these sites are described below.

2.2.2.a Kakagon Sloughs (Chequamegon Bay)

The Kakagon Sloughs are located along the southern shore of Lake Superior in northern Wisconsin and are connected to Chequamegon Bay. The wetlands within Kakagon Sloughs are unique due to the significant presence of wild rice in this area (Meeker 1999). Although this area is relatively small in terms of total surface area (< 10 ha), the wild rice has important cultural significance to First Nations tribes in the region.

Sampling for wild rice and other vegetation types was conducted by Jim Meeker during the 1986-89 period, which included a relatively low water period in 1988 following a relative high water level year in 1986. These data were collected along a transect extending from the upland area into the Kakagon Slough channel. The data collected during this period indicate that the percent cover of wild rice varies as a function of growing season water depth and that this function can be well represented by a normal distribution curve (Figure 2-7). Based on the wild rice sampling conducted in 1986-87 and 1989, the maximum percent cover for a typical year was approximately 30%. The 1988 low water year occurred after two years of growing season water levels declining by about 45 cm, and the peak wild rice cover for this year was approximately 40% (at a water depth of 0.7 meter). These observations are consistent with the expectation that wild rice will gain a temporary competitive advantage during receding water levels in Lake Superior (Meeker 1999).

The algorithm for the wild rice PI was developed to capture the major features of the wild rice data for 1986-89. A normal distribution curve describing percent cover as a function of depth was fit to the data, as shown in Figure 2-7. The peak of the normal distribution, which occurs at approximately 0.7 meter of water depth, was assumed to be 26% for a typical year. However, the distribution was adjusted to have a peak of roughly 40% for years where a cumulative decline of 45 cm or greater had been observed over a 2-year period. Therefore, the wild rice % cover function is adjusted upward specifically for "low water" years, while the default function (peak = 26%) is used for all other years. The peak annual water level (based on the mean monthly water level time series) is used along with the transect bathymetry for Kakagon Slough to determine the water depth at various points along the transect, which is approximately 17 meters wide. These percent cover estimates and associated lateral distances (i.e., along the transect) are then multiplied by a longitudinal distance of 5 km to compute the total surface area of wild rice (in hectares) along Kakagon Slough on an annual basis.

A complete discussion of the wild rice PI for Kakagon Slough can be found in Fact Sheet #01 in Appendix A.

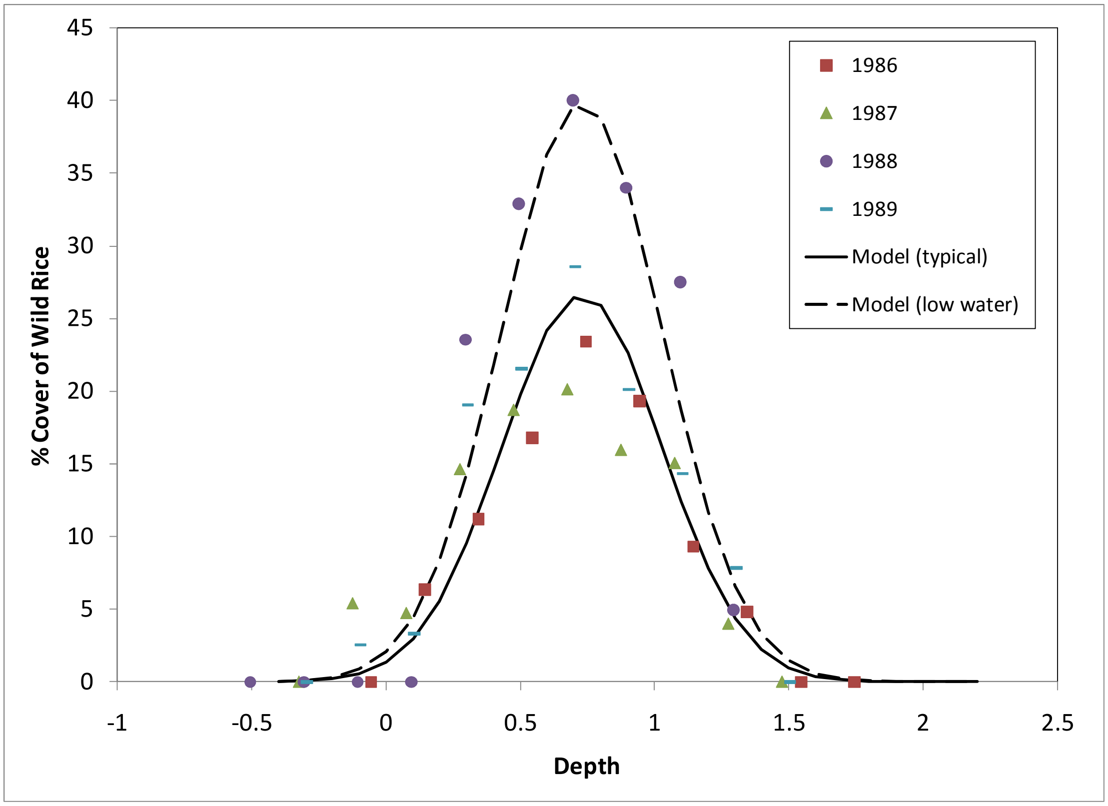


Figure 2-7. Wild Rice Cover as a Function of Water Depth

2.2.2.b Black Bay & Sturgeon Bay

Black Bay and Sturgeon Bay are located along the northern shore of Lake Superior and are provincially important wetlands in Ontario (Harris and Foster 1998, 2002). Bulrush marsh is the most common emergent wetland community on the north shore of Lake Superior. In Black Bay and Sturgeon Bay, the bulrush marsh is likely important nursery habitat for key fish species that utilize wetlands for habitat, including northern pike. Black Bay and Sturgeon Bay represent different physical environments; Black Bay is a large, shallow bay with fringing wetlands, while Sturgeon Bay is representative of more intermittent marsh along shorelines where bedrock is an important factor.

Surveys were conducted in Black Bay and Sturgeon Bay during summer 2010 in order to collect bathymetric data to characterize the geometry of these sites. LimnoTech converted the bathymetric datasets to triangular irregular networks (TINs) and then to a digital elevation model (DEM) raster dataset using ESRI's ArcGIS software. Manual editing and clipping of the datasets was performed to eliminate artificial elements created by the conversion to TIN. The final DEM was used to create a listing of 1-cm elevation contour bins and associated areas.

The specific performance indicator (PI) developed for Black Bay and Sturgeon Bay is total area of bulrush emergent marsh. Vegetation surveys were conducted in summer

2010 at the same time as the bathymetric surveys to identify the upper and lower elevation limits of bulrush marsh at each site. In Black Bay, bulrush marsh is present in the 182.5-182.8 meter (IGLD85) range. In Sturgeon Bay, bulrush marsh is present in the 182.1-183.0 meter (IGLD85) range. The upper and lower bounds of bulrush area for each were compared to Lake Superior average water level over the past 10 years to determine an approximate water depth range for this zone. The depth range for Black Bay was estimated to be 0.45 – 0.83 meter, and the depth range for Sturgeon Bay was estimated to be 0.35 – 1.25 meters.

The bulrush marsh PIs for Black Bay and Sturgeon are calculated within the IERM2 framework for a given regulation plan / basin supply scenario as follows:

1. A rolling average is calculated for Lake Superior mean monthly water levels over the previous 10-year period (including all 12 monthly water levels per year);
2. The depth ranges for Black Bay and Sturgeon Bay and average water level calculated in step #1 are used to calculate the expected elevation range for the bulrush emergent marsh.
3. The total area (in hectares) within the predicted elevation range for bulrush marsh is calculated based on the "binned" areas developed from the DEM. The total area is reported as the annual output for the bulrush marsh PI for each wetland area.

A complete discussion of the northern pike / bulrush habitat PIs for Black Bay and Sturgeon Bay can be found in Fact Sheet #02 in Appendix A.

2.2.2.c St. Louis River Estuary

Bathymetry and topography data were collected and processed for three wetland complexes in the vicinity of the St. Louis River Estuary (SLRE): Fond Du Lac, Pokegama Bay, and Allouez Bay (Figure 2-8). The physical datasets for these sites were processed and incorporated into the IERM2. Specific vegetation performance indicators were not developed for these sites; however, predictions of vegetation distribution were required as inputs for the macroinvertebrate diversity and fish habitat richness PIs that were developed based on the GLEI datasets (see detailed discussion in Section 2.3.1 and Fact Sheets #03 and #04 in Appendix A). Annual estimates of meadow marsh, emergent marsh, and open water areas were calculated for each of the three SLRE wetland complexes using the "rules-based" model that was discussed in Section 2.2.1. The specific rules used to assign vegetation types based on flooding/dewatering intervals and water depth were taken from the original rules-based model developed for Long Point (Mortsch et al. 2006).

Figure 2-8. St. Louis River Estuary - Wetland Sites

2.2.2.d Batchawana Bay

Coastal wetlands along the northeastern shoreline of Lake Superior occur in protected embayments. Due to high wind and wave action, as well as intense winter ice-scour, these wetlands do not naturally contain dense vegetation stands. Any vegetation that does exist serves as a valuable spawning and nursery habitat for many fishes. Batchawana Bay, located in the northeastern shoreline, contains some of the largest stands of this type of sparse wetland habitat in eastern Lake Superior (Figure 2-9).

Detailed data were collected during the 2010 field season to characterize the bathymetry for four wetland areas within Batchawana Bay. Four individual digital elevation models (DEMs) were developed to represent these wetland locations. Information regarding the coverage of emergent and submerged vegetation communities was also collected. This information was overlaid on the DEM datasets to develop curves representing the percent coverage of emergent and submerged vegetation as a function of Lake Superior water level during the growing season. These relationships were integrated into the IERM2 as a single performance indicator that quantifies the total area of aquatic plant cover based on the combined cover of emergent and submerged vegetation. Additional details regarding this PI are available in Fact Sheet #05 in Appendix A.

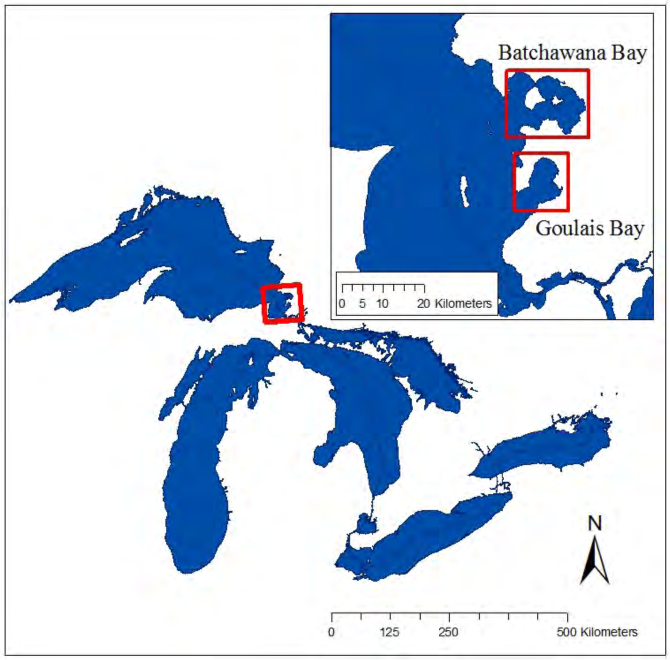


Figure 2-9. Location of Batchawana Bay in Lake Superior

2.2.3 St. Marys River

The St. Marys River is comprised of a riverine environment that routes water from the Lake Superior outlet at Sault Ste. Marie to Lake Huron. Researchers from Cornell University and Lake Superior State University developed a suite of performance indicators for vegetation, fish habitat, and wetland bird habitat based on information available from existing studies (Harris et al. 2009, Bain 2007, Derecki 1984). Specific PIs developed include the following:

1. **Prevention of sea lamprey spawning/nursery habitat in the St. Marys rapids** (suitability index (0-1 scale) as a function of flows through the rapids);
2. **Native fish spawning/nursery habitat in the St. Marys rapids** (total area (in hectares) as a function of flows through the rapids);
3. **Fish stranding in the St. Marys rapids** (suitability index (0-1 scale) as a function of flow ramping rate);
4. **Lake sturgeon suitable spawning habitat area** (% increase as a function of June discharge);
5. **Presence of periodic flushing flows within the Lake George Channel** (suitability index (0-1 scale) as a function of May-June discharge);
6. **Cisco (lake herring) spawning habitat** (suitability index (0-1 scale) as a function of Lake Huron water level during April-November);
7. **Black tern nesting success** (suitability index (0-1 scale) as a function of Lake Huron water level change during June-August).

8. **Submerged aquatic habitat (potential area)** (suitability index (0-1 scale) as a function of Lake Huron average May-September water level);
9. **Emergent wetland area in Lake Nicolet** (total area in hectares as a function of Lake Huron average annual water level); and
10. **St. Marys River backwater habitat connectivity** (suitability index (0-1 scale) as a function of Lake Huron annual average water level).

The background, ecological significance, and algorithms for each of the performance indicators are provided in a separate report developed by Mark Bain and co-authors (Bain et al. 2010), as well as the individual Fact Sheets (#21 through #30) provided in Appendix A.

It should be noted that the "fish stranding" PI (listed as #3 above) was not incorporated into the IERM2 because it requires information concerning the rate at which gates are opened or closed for the Compensating Works in the St. Marys River. Because gates are opened or closed manually within a day's time, the fish stranding cannot be appropriately represented in the IERM2 and instead provides an operational consideration for specified time periods where gate changes are made.

2.2.4 Lake Michigan

For Lake Michigan, performance indicators (PIs) have been developed for Arcadia Lake Marsh and several wetland sites within inner Green Bay. The PIs for each of these sites are described below.

2.2.4.a Arcadia Lake Marsh

Arcadia Lake is located along the eastern Lake Michigan shoreline between Manistee, MI and Traverse City, MI. The lake represents a drowned river mouth wetland type dominated by meadow marsh that is representative of similar drowned river mouth wetlands along the eastern shoreline, including Pentwater River, Pere Marquette River, Lincoln, Little Manistee River, and Betsie River.

Meadow marsh is a critical wetland habitat zone for Arcadia Lake and other drowned river mouths along the eastern Lake Michigan shoreline. The meadow marsh zone represents important habitat for fish, wetland birds, and other faunal groups. In addition, this vegetation zone has the potential to be negatively impacted by changes in water level regime. In particular, compression of periodic high and low water levels in Lake Michigan could significantly compress this zone similar to what has occurred on Lake Ontario as a consequence of water level regulation (Wilcox and Xie 2007). Therefore, meadow marsh has been identified as a key performance indicator for Arcadia Lake Marsh.

A "rules-based" model for wetland vegetation has been developed to predict meadow marsh area in Arcadia Lake based on observed/predicted flooding and dewatering history. This approach is very similar to that taken for predicting meadow marsh areas for Lake Ontario wetlands as part of the IJC's Lake Ontario – St. Lawrence River (LOSL) water levels study (Wilcox and Xie 2007). Bathymetry and topography data collected during summer 2010 have been used to develop a digital elevation model (DEM) for Arcadia Lake extending from the deeper portions of the lake to the upland extent of the wetland area. The DEM was used to create a set of elevation contour "bins" in similar fashion to Saginaw Bay and other wetland site vegetation models described in this report. The specific flooding/dewatering rules for the meadow marsh zone, which are summarized in the matrix provided in Table 2-5, were established based on air photo interpretation for 17 years during the 1954-2010 period.

The following approach is used to calculate the areal coverage of the meadow marsh-dominated zone in Arcadia Lake:

1. The Lake Michigan annual maximum water level is identified for each model simulation year. This elevation is defined as 1) the elevation above which all areas have been effectively dewatered for the current growing season, and 2) the elevation below which all areas have effectively been flooded for the current season.
2. Meadow marsh areas are assigned to elevations characterized by the flooding/dewatering and water depths conditions marked by "MM" in Table 2-5.
3. The total area of meadow marsh is calculated for a given year by summing all of the surface area associated with elevations that were characterized as being dominated by meadow marsh in step #2.

The current set of rules for predicting meadow marsh coverage (Table 2-5) have been applied to predict the annual total meadow marsh area in Arcadia Lake based on the Lake Michigan observed monthly water levels for the 1900-2006 historical period. Complete documentation of the meadow marsh PI for Arcadia Lake Marsh can be found in Fact Sheet #06 in Appendix A.

Table 2-5. Matrix of Vegetation Assignment Rules for Arcadia Lake Marsh

Height "Above" Water Line:		**Number of years dewatered:**														
		0	1	2	3	4	5	6	7	8	9	10	11	21	31	40
Min	Max	0	1	2	3	4	5	6	7	8	9	10	20	30	40	999
-101	-999	n/a	MM	MM	MM	MM	MM	T	T	T	T	T	T	T	T	T
-91	-100	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-81	-90	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-71	-80	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-61	-70	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-51	-60	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-41	-50	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-31	-40	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-21	-30	n/a	EM	EM	EM	EM	EM	MM	MM	MM	MM	MM	MM	MM	MM	MM
-11	-20	n/a	EM	EM	EM	EM	EM	MM	MM	MM	MM	MM	MM	MM	MM	MM
0	-10	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM

Height "Below" Water Line:		**Number of years flooded:**														
		0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-21	-31	-40
Min	Max	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-20	-30	-40	-999
1	10	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
11	20	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
21	30	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
31	40	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
41	50	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
51	60	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
61	70	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
71	80	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
81	90	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
91	100	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
101	110	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
111	120	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
121	130	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
131	140	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
141	150	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
151	160	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
161	170	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
171	180	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
181	190	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
191	200	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL

2.2.4.b Green Bay

Bathymetry and topography data were collected and processed for four wetland sites in inner Green Bay: Oconto, Long Tail Point (Dead Horse Bay), Egg Harbor, and Sawyer Harbor (Figure 2-10). The physical datasets for these sites were processed and incorporated into the IERM2. Specific vegetation performance indicators were not developed for these sites; however, predictions of vegetation distribution were required as inputs for the macroinvertebrate diversity and fish habitat richness PIs that were developed based on the GLEI datasets (see detailed discussion in Section 2.3.1 and Fact Sheets #03 and #04 in Appendix A). Annual estimates of meadow marsh, emergent marsh, and open water areas were calculated for each of the four Green Bay wetland complexes using the "rules-based" model that was discussed in Section 2.2.1. The specific rules used to assign vegetation types based on flooding/dewatering intervals and water depth were taken from the original rules-based model developed for Long Point (Mortsch et al. 2006).

Figure 2-10. Green Bay - Coastal Wetland Sites

2.2.5 Lake Huron & Georgian Bay

For Lake Huron, performance indicators (PIs) have been developed for 1) wetland connectivity and submerged aquatic vegetation diversity in eastern Georgian Bay, 2) wetland vegetation surface area and macroinvertebrate diversity for wetlands in the Les Cheneaux Islands region, and 3) a suite of wetland vegetation, fish, macroinvertebrate, and wetland bird performance indicators in Saginaw Bay.

2.2.5.a Eastern Georgian Bay

Eastern Georgian Bay represents the world's largest freshwater archipelago and has the most extensive series of coastal wetland complexes within the Great Lakes. This shoreline is characterized by over 12,000 distinct wetland units comprising approximately 16,000 ha of total wetland area. A typical wetland complex along the shoreline of eastern Georgian Bay is a protected embayment with a relatively narrow connection to the Bay and Lake Huron. As a result, there is a potential for loss of connectivity between the wetland and the lake if significant declines in Lake Huron water levels occur for an extended period. In addition, significant declines in water level have the potential to reduce the surface area where diverse stands of submerged aquatic vegetation (SAV) can grow, resulting in a loss of fish habitat.

The performance indicators developed for eastern Georgian Bay are as follows:

1. Total percentage of additional wetland area disconnected from Georgian Bay / Lake Huron; and
2. Total percentage of wetland area transformed to low submergent plant diversity.

The wetland connectivity PI was addressed by randomly sampling 103 wetland sites along the eastern Georgian Bay shoreline (Figure 2-11). For each wetland surveyed, the sill elevation for the channel connecting the protected embayment wetland to Georgian Bay was measured. The random sampling approach undertaken is expected to provide a distribution of sill elevations that is representative of all connected wetlands along the eastern shoreline.

The results of the wetland surveys were used to develop a function that quantifies the percentage of additional total wetland area disconnected from Georgian Bay (and therefore not accessible by fish) as a function of Lake Huron water level (Figure 2-12). It should be noted that Matchedash Bay was excluded from the dataset and relationship shown in Figure 2-12 because it was an outlier with a total area of 1,027 ha, as compared to a typical area range of less than 1.0 ha to 122 ha for most wetlands sampled. A connectivity PI was defined for the spring and fall periods when connectivity is likely most crucial with respect to fish spawning habitat and water levels are not at the peak summertime high. Within a given year, mean spring and fall Lake Huron water levels are calculated for the April-May and September-October periods, respectively.

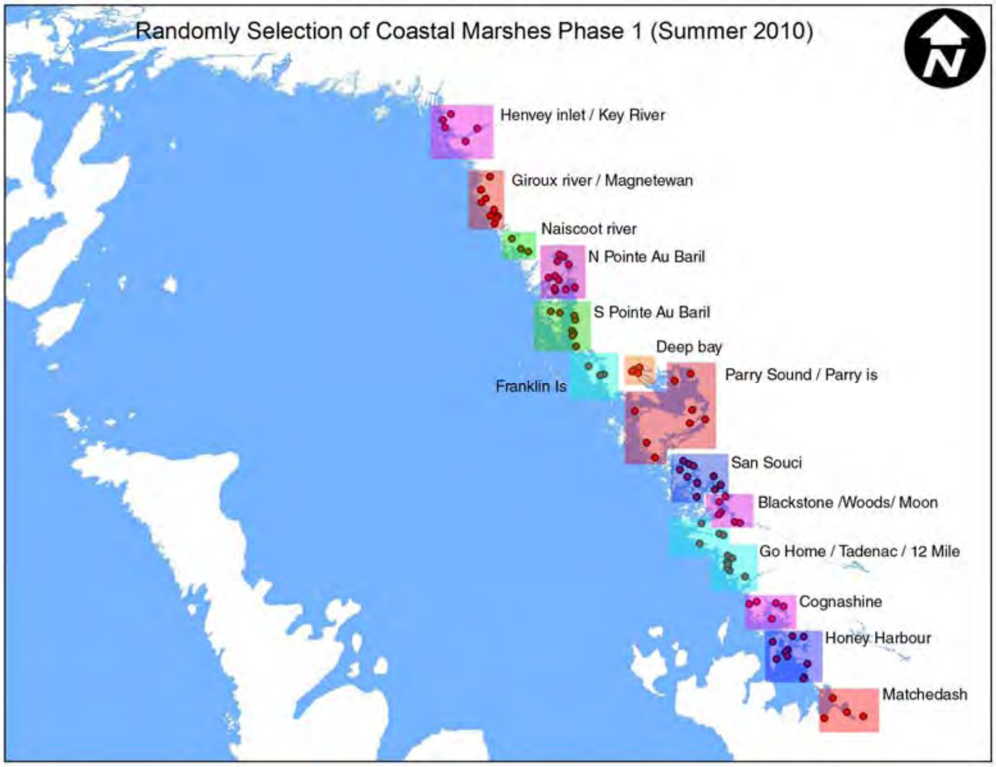


Figure 2-11. Randomly Sampled Wetland Sites in Eastern Georgian Bay

It is important to note that the wetland connectivity PI developed for eastern Georgian Bay only accounts for additional adverse impacts occurring at water levels *below* 176 meters, and it does not represent the significant losses in fish habitat that have occurred as a result of water levels declining from 177 meters in 1999 to approximately 176 meters during the early 2000s. For example, in one case study, a 70 cm drop in Lake Huron water level between 1981 and 2007 resulted in a 39 to 81% loss of the low marsh habitat utilized by fish in five marshes in Severn Sound. Sufficient elevation data are not available for representative wetland sites with outlet elevations above 176 meters to quantify these recent losses in fish habitat across eastern Georgian Bay; however, these data could potentially be obtained as part of future studies and used to estimate these losses. As shown in Figure 2-12, the rate of additional fish habitat loss as water levels decline further below 176 meters is approximately 15% per meter. Therefore, it is critical that water levels be maintained above 176 meters in order to minimize further loss of fish habitat in the eastern Georgian Bay region. Additional details regarding the wetland connectivity PI are provided in Fact Sheet #08 in Appendix A.

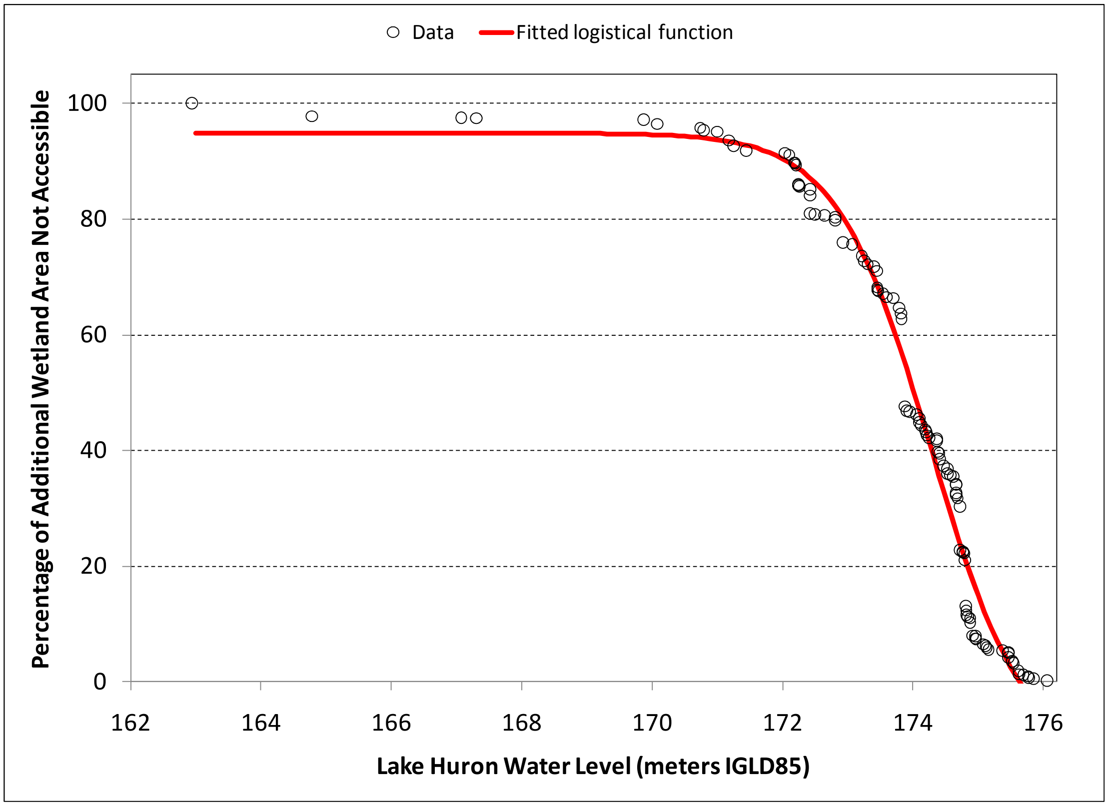
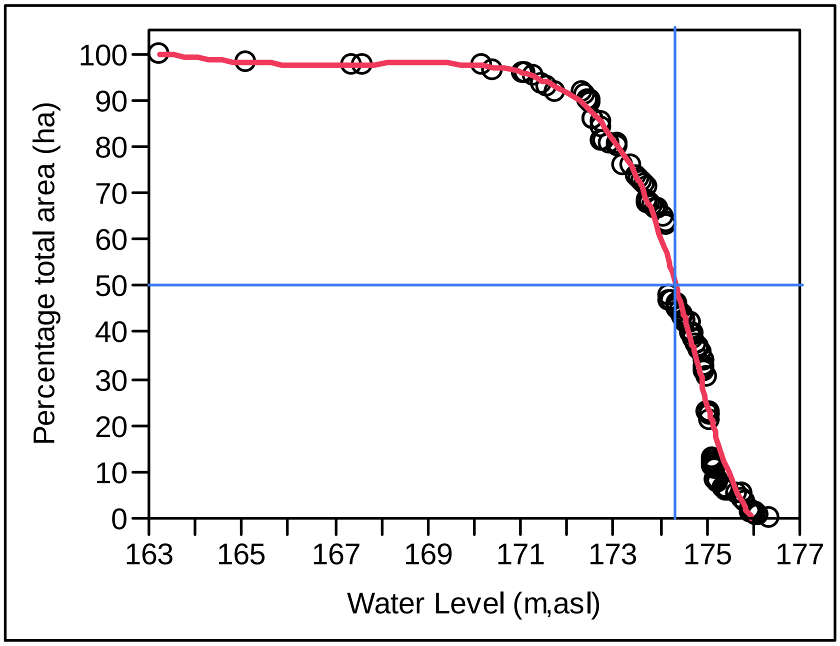


Figure 2-12. Georgian Bay Wetland Area Connectivity as a Function of Lake Huron Water Level

The performance indicator for SAV "transformed area" was developed based on the same set of 103 wetland sites described above for the wetland connectivity PI. Elevation data for these sites were visually inspected to determine the shallowest depth at the entrance to the wetland. It was assumed that a minimum hydrological connection of 30 cm was necessary to maintain an adequate connection of the wetland to Georgian Bay, and that any drop below this elevation would result in aquatic vegetation in the wetland being transformed to undesirable habitat for fish (based on a loss of diversity for submergent vegetation). For the 103 wetlands in this study, the lake elevation that corresponds to 30 cm above the maximum depth at each wetland entrance was determined (i.e., the "tipping points"). These tipping points were sorted by descending order to determine the percentage of wetlands that would become transformed to low diversity SAV as a function of water levels between 163 and 176 m above sea level (ASL). The total cumulative wetland area expressed as a percentage was calculated and plotted against Lake Huron water levels (Figure 2-13). Matchedash Bay was excluded from this relationship because it was an outlier, as described above for the wetland connectivity PI. Additional details regarding the aquatic vegetation transformation PI are provided in Fact Sheet #09 in Appendix A.



Note: The red line is a spline fit (lambda =1). The blue lines indicate that the water level that corresponds to 50% of transformed coastal wetlands is 174.45 m above sea level (n=103).

Figure 2-13. Percentage of Georgian Bay Wetlands "Transformed" as a Function of Lake Huron Water Level

2.2.5.b Saginaw Bay

Saginaw Bay represents a productive ecosystem along the southwestern Lake Huron shoreline and is a critical area for fish reproductive habitat, as well as other life cycle phases. Due to its importance as its own "sub-ecosystem", Saginaw Bay has been characterized by a wealth of physical and ecological data. These datasets were leveraged to develop a suite of ecological performance indicators representing wetland vegetation, macroinvertebrate abundance and diversity, fish species diversity, and wetland bird ecological condition. Saginaw Bay represents a greater number of performance indicators and covers a broader geographic area than any other study site in Lake Michigan-Huron; therefore, the PIs developed for Saginaw Bay could play an important role in understanding larger scale ecological responses to possible future water level scenarios.

The NOAA Coastal Services Center (CSC) website was reviewed to obtain the latest Light Detection and Ranging (LiDAR) dataset for Saginaw Bay. A LiDAR dataset from a flyover conducted in 2004 for the entire coast of Saginaw Bay was obtained. The bare earth returns for this dataset were extracted and used to develop a terrain dataset representing the topographic surface of the Bay shoreline. In order to develop a complete digital elevation model (DEM) for Saginaw Bay, 1-foot depth contours were obtained from the Michigan Geographic Data Library (MiGDL) website (http://www.mcgi.state.mi.us/mgdl/?action=thm). Appropriate datum conversions were made and the bathymetric contours were merged with the LiDAR-based topography to produce a seamless DEM (5-meter resolution) representing the majority of the Saginaw Bay coastline (Figure 2-14). The final DEM was used to create elevation contour “bins” to support performance indictor sub-models for Saginaw Bay.

Figure 2-14. Saginaw Bay Digital Elevation Model (5-meter resolution)

Ecological datasets are available from Saginaw Bay wetlands to describe vegetation, macroinvertebrate abundance and diversity, and wetland fish abundance and diversity. The relevant datasets and associated performance indicators for macroinvertebrates and fish are described in Section 2.3.1.a. Vegetation zone data are available from surveys conducted in the Fish Point area of Saginaw Bay during the 1988-93 period by Doug Wilcox. The data available from these surveys were used to define a rules-based model for predicting dominant vegetation zones at a given elevation as a function of 1) the number of years since flooding or dewatering last occurred, and 2) model-predicted water depth. The rules-based model described in the Green Book (Mortsch et al. 2006) was adapted based on the Fish Point data to construct relationships for the following vegetation zones:

- Trees/shrubs (“T”);

- Meadow marsh (“MM”);
- Bulrush marsh, wet (“BM (wet)”); and
- Bulrush marsh, dry (“BM (dry)”).

The final matrix is implemented within IERM2 and serves as the basis for assigning a dominant vegetation zone to each Saginaw Bay elevation contour for each simulation year (Table 2-6). Specific vegetation PIs for Saginaw Bay have been defined as total area of bulrush emergent marsh and total area of meadow marsh, as shown in Table 2-3. Additional details regarding these vegetation PIs are provided in Fact Sheet #12 in Appendix A.

The results of the rules-based vegetation model for Saginaw Bay are also used as the basis for the following faunal performance indicators:

- Macroinvertebrate abundance and diversity (refer to Section 2.3.1.a, and Fact Sheet #13);
- Fish abundance and diversity (refer to Section 2.3.1.a, and Fact Sheet #15); and
- Wetland bird – index of ecological condition (refer to Section 2.3.1.b, and Fact Sheet #20).

The faunal performance indicators tell a consistent story with respect to the importance of maintaining health and diverse wetland vegetation zones in Saginaw Bay. Maintaining natural seasonal and inter-annual fluctuations in Lake Michigan-Huron water levels promotes diversity in vegetation (including varying water depth conditions within vegetation zones) that maintains an abundant and diverse macroinvertebrate community. A thriving macroinvertebrate community in turn provides the basis for a healthy forage fish community, which provides the food supply necessary for maintaining predator fish populations.

Table 2-6. Matrix of Vegetation Assignment Rules for Saginaw Bay Wetlands

Height "Above" Water Line:		Number of years dewatered:														
		0	1	2	3	4	5	6	7	8	9	10	11	21	31	40
Min	Max	0	1	2	3	4	5	6	7	8	9	10	20	30	40	999
-101	-999	n/a	BM (wet)	BM (dry)	MM	MM	MM	T	T	T	T	T	T	T	T	T
-96	-100	n/a	BM (wet)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-91	-95	n/a	BM (wet)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-86	-90	n/a	BM (wet)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-81	-85	n/a	BM (wet)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-76	-80	n/a	BM (wet)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-71	-75	n/a	BM (wet)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-66	-70	n/a	BM (wet)	BM (dry)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-61	-65	n/a	BM (wet)	BM (dry)	BM (dry)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-56	-60	n/a	BM (wet)	BM (dry)	BM (dry)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-51	-55	n/a	BM (wet)	BM (dry)	BM (dry)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-46	-50	n/a	BM (wet)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	T	T
-41	-45	n/a	BM (wet)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	T	T
-36	-40	n/a	BM (wet)	BM (wet)	BM (dry)	BM (dry)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	T	T
-31	-35	n/a	BM (wet)	BM (wet)	BM (dry)	BM (dry)	BM (dry)	MM	MM	MM	MM	MM	MM	MM	T	T
-26	-30	n/a	BM (wet)	BM (wet)	BM (wet)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)
-21	-25	n/a	BM (wet)	BM (wet)	BM (wet)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)
-16	-20	n/a	BM (wet)	BM (wet)	BM (wet)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)
-11	-15	n/a	SAV-FL	BM (wet)	BM (wet)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)	BM (dry)
-6	-10	n/a	SAV-FL	SAV-FL	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)
0	-5	n/a	SAV-FL	SAV-FL	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)

Height "Below" Water Line:		Number of years flooded:														
		0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-21	-31	-40
Min	Max	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-20	-30	-40	-999
1	10	n/a	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY
11	20	n/a	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY
21	30	n/a	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY	TY
31	40	n/a	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	SAV-FL	SAV-FL
41	50	n/a	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	SAV-FL	SAV-FL
51	60	n/a	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	SAV-FL	SAV-FL
61	70	n/a	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	SAV-FL	SAV-FL
71	80	n/a	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	BM (wet)	SAV-FL	SAV-FL
81	90	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
91	100	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
101	110	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
111	120	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
121	130	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
131	140	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
141	150	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
151	160	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
161	170	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
171	180	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
181	190	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
191	200	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL

2.2.5.c Les Cheneaux Islands (Mackinaw Bay, Duck Bay)

Mackinaw Bay and Duck Bay represent two large wetland complexes within the Les Cheneaux Island region (Figure 2-15). Vegetation and transect bathymetry data were collected in these wetlands during the 1980s by Dennis Albert, and additional data collection were collected at these sites during summer 2010. Performance indicators are based on the total area of 1) the bulrush emergent marsh zone, and 2) the meadow marsh zone. The surface area of these zones for Mackinaw Bay and Duck Bay are expected to be maintained at sufficient levels as long as inter-annual variability is present in Lake Michigan-Huron water levels and extreme high or low water levels do not occur for prolonged time periods. However, compression of the Michigan-Huron water level range or extended periods of extreme low water conditions could result in significant reduction of these key habitat zone areas and potentially also allow invasive cattail (*Typha* spp.) species to replace native emergent vegetation.

Figure 2-15. Les Cheneaux Islands Wetland Site Locations

The modeling approach follows the rules-based procedure used in the IERM for the International Joint Commission (IJC) Lake Ontario-St. Lawrence (LOSL) study, which assigns portions of the elevation model to different vegetation types based on how many years since last flooded and how many years since last dewatered (Wilcox and Xie 2007, LimnoTech 2005). Bathymetry and topography data collected by Scudder Mackey and Dennis Albert during summer 2010 were used to develop digital elevation models (DEMs) for Mackinaw Bay and Duck Bay extending from the deepest areas of these embayments (approximately 175.0 meters) to the extent of the wetland area (i.e., near the edge of trees). The DEM was used to create a set of elevation contour "bins" in similar fashion to Saginaw Bay and other wetland site vegetation models described in the accompanying Fact Sheets.

The following approach is used in the IERM2 model to calculate the areal coverage of the emergent marsh and meadow marsh dominated zones in Mackinaw Bay and Duck Bay:

1. The Lake Huron annual maximum water level is identified for each model simulation year. This elevation is defined as 1) the elevation above which all areas have been effectively dewatered for the current growing season, and 2) the elevation below which all areas have effectively been flooded for the current season.
2. Meadow marsh-dominated areas are assigned to elevations characterized by the flooding/dewatering and water depths conditions marked by "MM" in Table 2-7.
3. Emergent marsh-dominated areas are assigned to elevations characterized by the flooding/dewatering and water depths conditions marked by "EM" in Table 2-7.
4. The total areas of meadow marsh and emergent marsh are calculated for a given year by summing all of the surface area associated with elevations that were characterized as being dominated by meadow/emergent marsh in steps #2 and #3 above.

The current set of rules as described above for predicting meadow marsh and emergent marsh coverage (Table 2-7) are applied in the model to predict the annual total *combined* area (in hectares) for Mackinaw Bay and Duck Bay for a given hydrologic/hydraulic scenario. Further discussion of the meadow marsh and emergent marsh PIs for the Les Cheneaux Islands wetland sites can be found in Fact Sheets #10 and #11 in Appendix A.

Table 2-7. Matrix of Vegetation Assignment Rules for Les Cheneaux Islands Wetlands

Height "Above" Water Line:		Number of years dewatered:														
		0	1	2	3	4	5	6	7	8	9	10	11	21	31	40
Min	Max	0	1	2	3	4	5	6	7	8	9	10	20	30	40	999
-101	-999	n/a	MM	MM	MM	MM	MM	T	T	T	T	T	T	T	T	T
-91	-100	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-81	-90	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-71	-80	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-61	-70	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-51	-60	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-41	-50	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-31	-40	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-21	-30	n/a	EM	EM	EM	EM	EM	MM	MM	MM	MM	MM	MM	MM	MM	MM
-11	-20	n/a	EM	EM	EM	EM	EM	MM	MM	MM	MM	MM	MM	MM	MM	MM
0	-10	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM
Height "Below" Water Line:		Number of years flooded:														
		0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-21	-31	-40
Min	Max	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-20	-30	-40	-999
1	10	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
11	20	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
21	30	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
31	40	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
41	50	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
51	60	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
61	70	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
71	80	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
81	90	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
91	100	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
101	110	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
111	120	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
121	130	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
131	140	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
141	150	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
151	160	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
161	170	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
171	180	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
181	190	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
191	200	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL

In addition to the vegetation PIs, a macroinvertebrate diversity index was also developed to represent the overall condition of Les Cheneaux Islands wetlands with respect to an energy source for fish production. The justification and algorithm for this PI are described in detail in Fact Sheet #14 in Appendix A.

2.2.6 Lake St. Clair

Lake St. Clair and the St. Clair River delta collectively represent one of the most productive fisheries within the Great Lakes. A relatively shallow shelf that exists along the northeastern edge of Lake St. Clair and around the delta provides spawning and nursery habitat for many species of fish that have commercial and recreational importance (Figure 2-16).

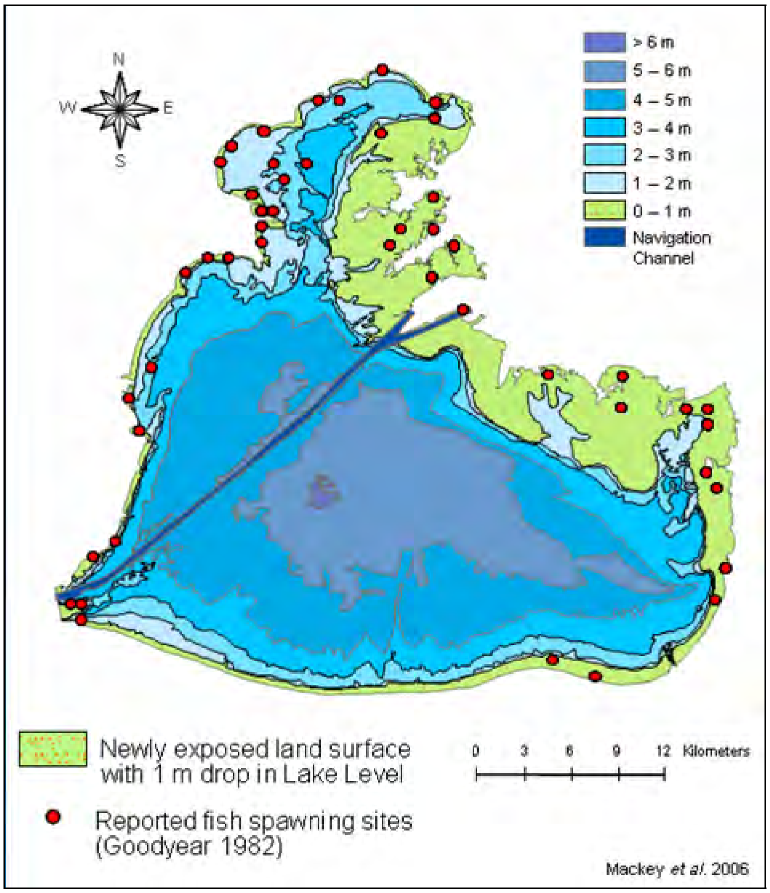


Figure 2-16. Lake St. Clair Bathymetry (adapted from Mackey et al. 2006)

As shown in Figure 2-16, the water depth of this "shelf" area is less than 1 meter below chart datum (174.4 meters – IGLD85). Significant, extended declines in Lake St. Clair water levels could dewater a large portion of this area and result in a substantial loss in fish spawning and nursery habitat. In addition, based on observations from the low water periods in the early to mid 2000s, significant and extended declines in water levels are likely to result in replacement of native emergent vegetation (high quality habitat) with the invasive *Phragmites australis* (common reed) (low quality habitat). Loss of native vegetation at the expense of invasive vegetation species could significantly compromise the habitat value in the Lake St. Clair and the St. Clair River delta.

A fish habitat PI has been developed for Lake St. Clair that calculates the percentage of available fish habitat as a function of the mean annual (January-December) water level, as shown in Figure 2-17. Based on this relationship, if the mean annual Lake St. Clair water level decreased to 174.5 meters, there would be a 20% loss in fish habitat area (i.e., 80% of habitat available) for that particular year. Likewise, a mean annual water level for Lake St. Clair of approximately 174.1 meters would result in a 40% loss of habitat area. Exceedances of this threshold are expected to result in a significant impact on the overall Lake St. Clair fishery, including the potential extirpation of fish species.

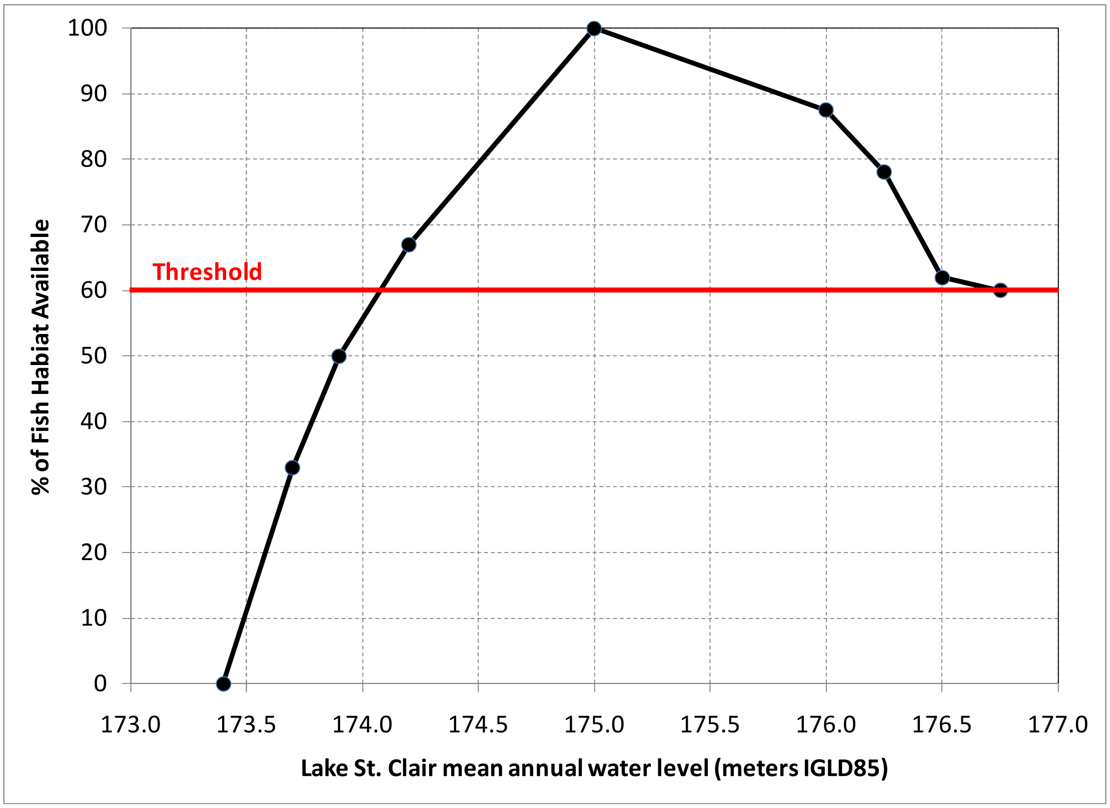


Figure 2-17. Lake St. Clair Fish Spawning Habitat vs. Mean Annual Water Level

A related consideration for Lake St. Clair is limiting the spread and domination of invasive wetland plants (e.g., *Phragmites*), which replace high-value habitat provided by native vegetation with habitat that is of low quality or even unusable for wetland fish and birds. A specific PI sub-model was not developed to represent wetland vegetation in Lake St. Clair due because the necessary topographic/bathymetric data were not readily accessible. However, a Coping Zone criterion ("LSC-01", see Table

3-1) was developed to address invasive vegetation concerns for this system, and this criterion effectively serves as the vegetation PI for this system. The threshold water level and duration associated with this criterion are consistent with the low water level criterion ("LSC-02") developed for the fish spawning habitat PI that is discussed above.

2.2.7 Lake Erie

Previous modeling of wetland vegetation and fish habitat supply for Long Point Bay, Lake Erie was conducted as part of the climate change study conducted by Environment Canada and the University of Waterloo (Mortsch et al. 2006). The previous modeling effort has been supplemented with additional fine-scale bathymetry/topography data, and the updated models were leveraged to attempt to develop simple predictive relationships between water level regime and fish habitat supply. Simulations of fish habitat supply are based on the rules-based, predictive modeling for wetland emergent vegetation zones (e.g., meadow marsh, emergent marsh) and predicted water depth within these zones, and a predictive model for submerged vegetation density and fish habitat supply availability. Additional information and support for the individual Long Point PIs can be found in the following Fact Sheets available in Appendix A:

- Emergent vegetation and open water surface area (Fact Sheet #17);
- Submerged vegetation surface area (Fact Sheet #18); and
- Fish habitat supply area (Fact Sheet #19).

The model predictions for emergent vegetation in Long Point Bay were also used to predict the wetland bird response across the wetland complex based on the "index of ecological condition" approach described in Section 2.3.1 and Fact Sheet #20 in Appendix A.

2.3 SIMULATION & VISUALIZATION APPROACH

In order to conduct an IERM2 simulation to generate results for the suite of ecological PIs, a 109-year monthly time series must be specified for the following:

- Lake Superior water level;
- St. Marys River discharge;
- St. Marys River – number of gates open for the Compensating Works;
- Michigan-Huron water level;
- Lake St. Clair water level; and
- Lake Erie water level.

In general, these monthly water level and discharge time series will be generated based on a scenario that applies a regulation plan to a specific 109-year basin supply time series (e.g., Plan 77a applied to the 1900-2006 historical supply sequence). However, it is possible to input water level time series based on offline assumptions in order to test the response of the model.

An IERM2 simulation will generate a single result for each simulation year for each PI represented in the model. Therefore, a 109-year time series of results will be available for each PI for a given simulation. In addition, IERM2 applies an "aggregation" method for each PI that reduces the 109-year time series to a single value that is intended to be representative of the overall outcome for the simulation. The IERM2 provides a suite of visualization tools for evaluating the suite of PI responses for a given water level scenario(s), including target diagrams for PI ratios, and time series plots. Each of these visualization tools is discussed briefly in the following sub-sections.

2.3.1 Target Diagram for PI Ratios

The PI aggregate scores generated by the IERM2 for various water level scenarios (i.e., regulation plan / basin supply combination) can also be used to calculate a "PI ratio" by:

$$PIRatio = \frac{PIAggScore_{Alt}}{PIAggScore_{Base}} \tag{2-2}$$

where $AggScore_{Alt}$ and $AggScore_{Base}$ are aggregate scores calculated for user-defined "alternative" and "baseline" regulation plans, respectively. Ratios are calculated for each PI represented in the IERM2 and can be visualized on a "target" diagram by selecting the "Standard Target" plot type in the main IERM2 visualization window (Figure 2-18). The yellow circle in the target diagram represents a ratio of unity, which indicates that the alternative plan generates the same metric score as the baseline plan. The "bulls eye" located in the center of the diagram indicates ratios that are greater than or equal to 2.0 (i.e., the alternative plan score is at least a factor of two greater than the score for the baseline plan), and the outer black circle indicates a ratio of zero. Therefore, points that are displayed inside the yellow circle indicate that the alternative plan performs better than the baseline plan for those PIs, while points that fall between the yellow and the black circles indicate poorer performance for the alternative plan.

The target diagram visualization can be customized by selecting different baseline/alternative plans, viewing the "slices" as PI groups (e.g., vegetation) or lake regions (e.g., Lake Superior), and toggling on/off the various PI groups and lake regions. The "target" diagram provides an efficient tool for evaluating plan results (i.e., PI ratios) across all performance indicators, and it also allows the user to "drill down" into more detailed results by double-clicking on a given PI point.

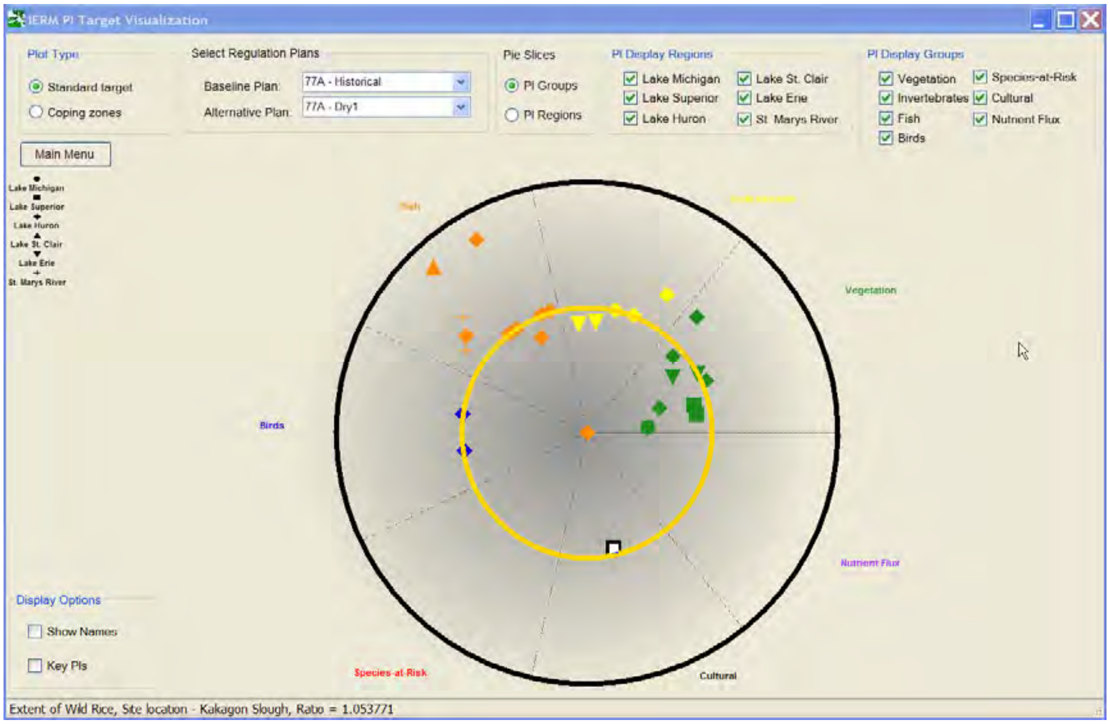


Figure 2-18. IERM2 Target Diagram for Performance Indicator Ratios

2.3.2 PI Time Series Comparison Plots

The target diagram for PI ratios (Figure 2-18) is designed such that the user can readily “drill down” into more detailed results by double-clicking on the point that represents a given performance indicator. This approach can be used to access the IERM2 time series comparison plot shown in Figure 2-19. The time series comparison plot provides a visualization of the annual PI results for a selected “baseline” and “alternative” water level scenario. In addition, the water level or discharge time series that drive the PI response (either directly or indirectly) for each plan are plotted in the lower half of the window. The time series comparison window provides the flexibility to change the ETWG study site and the PI that is being visualized; therefore, the time series plot can be used to evaluate results for multiple PIs without the need to return to the target visualization.

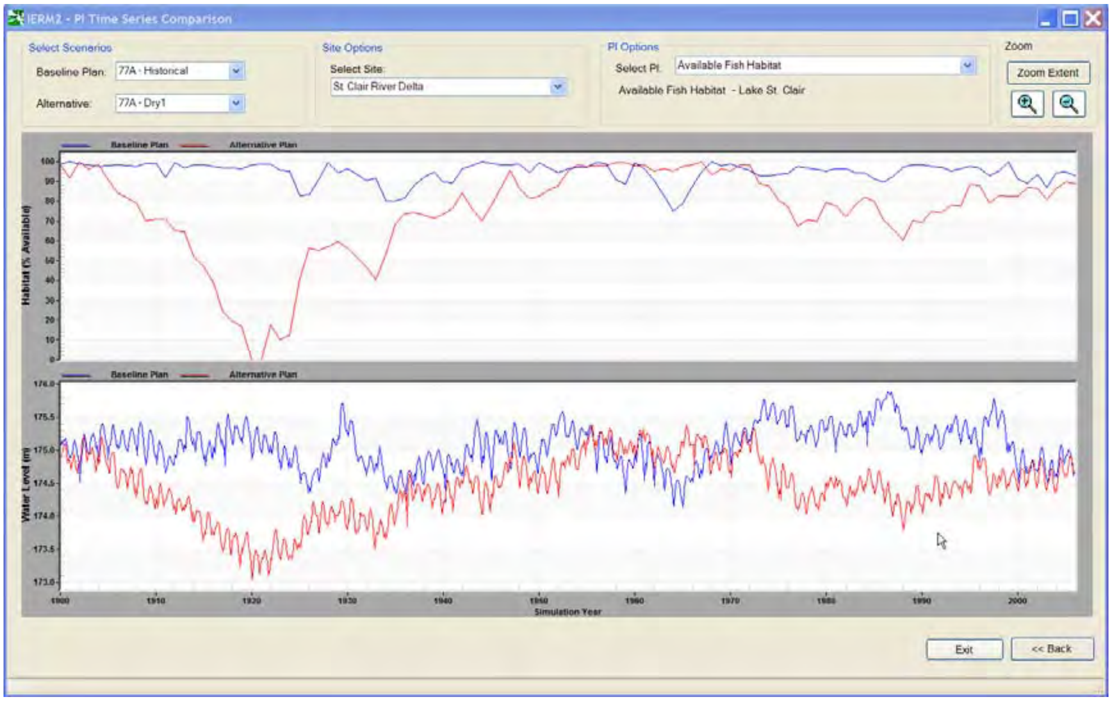


Figure 2-19. IERM2 Time Series Comparison Plot

3. IERM2 COPING ZONE ASSESSMENT

As described in Chapter 1, the approach being undertaken by the International Upper Great Lakes Study (IUGLS) to evaluate the potential impact of water level regime on the environment and economic sectors (navigation, hydropower, etc.) is unique relative to other recent Great Lakes water level regulation studies. For the current study, "Coping Zones" have been defined to reflect the amount of harm or stress being applied to a particular indicator of performance. The Ecosystem Technical Working Group (ETWG) defined a continuum of biological condition based on previous work by Davies and Jackson (2006) that is consistent with the Coping Zone approach (ETWG 2009). Figure 3-1 depicts the continuum of biological condition based on a series of "impact" levels ranging from 1 to 6. The impact levels can be recast in the context of Coping Zones as follows:

- "Zone A" – natural variability with respect to water level regime (ecological impact score of 1 or 2);
- "Zone B" – moderate changes to biotic community structure, but minimal changes to ecosystem function (ecological impact score of 3 or 4); and
- "Zone C" – major changes to biotic community structure, and moderate to major changes in ecosystem function (ecological impact score of 5 or 6).

The critical threshold for an ecological performance indicator occurs when moving from "Zone B" to "Zone C", which coincides with the transition from ecological impact level 4 to level 5. The threshold is therefore defined as the point where significant changes in the structure of a biotic community occur resulting in moderate or major changes to ecosystem function. Because thresholds and Coping Zones will be used to inform decisions concerning a Lake Superior regulation plan and to understand potential ramifications of climate change, it was critical that Coping Zone criteria be developed to the extent possible for each key ecological PI and incorporated into the IERM2.

The following sections describe the development, implementation, limitations, and sensitivity of specific Coping Zone criteria to represent the individual performance indicators represented in the IERM2 model, as well as the recommended analysis and visualization approaches for evaluating Coping Zone results. Section 3.4 describes the development of a spreadsheet-based "Coping Zone Calculator" that provides a tool that can be used to rapidly assess Coping Zone criteria within the Shared Vision Model (SVM) framework. Recommendations for evaluating scenario results generated using the Coping Zone Calculator, either as a standalone tool or within the SVM, are provided in Section 3.5.

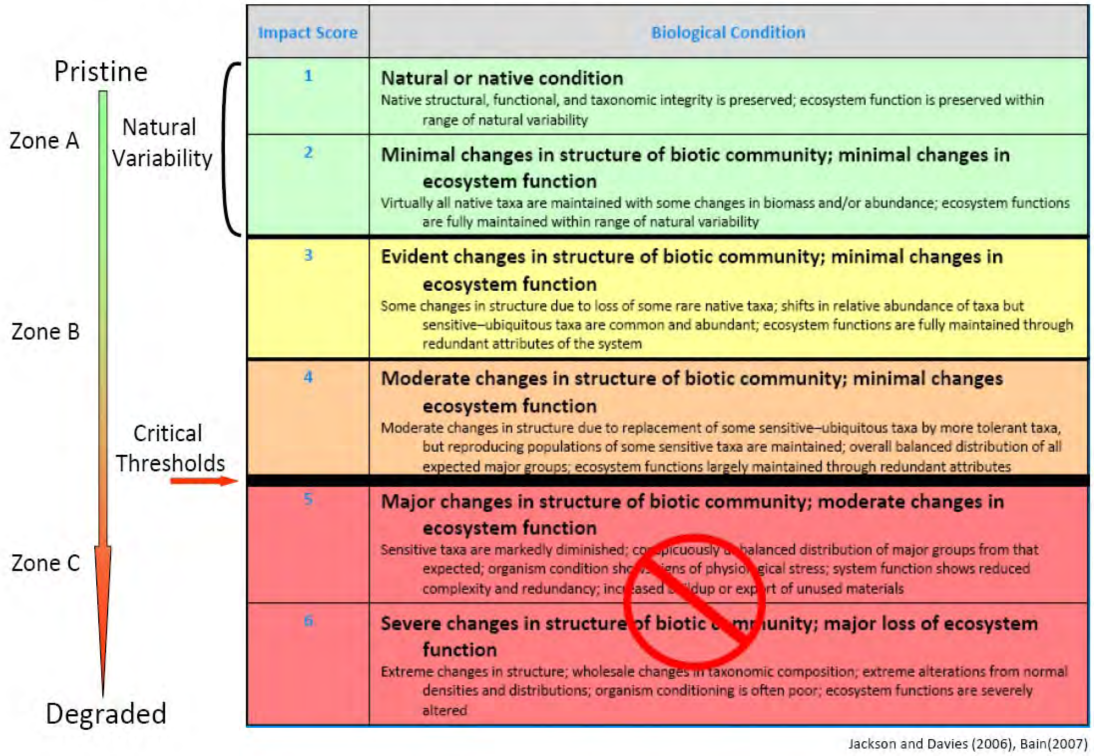


Figure 3-1. Coping Zone and Threshold Approach for Ecological Performance Indicators (adapted from ETWG 2009)

3.1 DEVELOPMENT OF CRITERIA

Chapter 2 described the development of an overall conceptual model and the detailed sub-models and performance indicators (PIs) that have been constructed and incorporated into the IERM2 model. The suite of PIs included in the IERM2 can be used to generate a detailed set of simulation results for a given hydrologic/hydraulic scenario (i.e., based on a basin supply scenario and specific regulation plan rules). However, the detailed results generated for the individual ecological PIs do not directly provide the information needed to support plan formulation and decision-making for the IUGLS. As described in Chapter 1, the overarching goal of developing “Coping Zones” for the Upper Great Lakes ecosystem is to identify specific hydrologic/hydraulic conditions that are expected to cause significant long-term harm to the ecological component(s) represented by individual PIs. Therefore, the Coping Zone approach provides the information necessary to assess the relative performance of regulation plans with respect to ecosystem impacts across a range of net basin supply (NBS) conditions.

For the suite of ecological PIs, the term “threshold” has been commonly used to describe the specific water level or flow condition at which significant long-term harm is expected to occur to a particular ecosystem component(s). However, it was recognized early in the process that it is also necessary and important to estimate the *duration of time* that the water level (or flow) must be maintained at or beyond the threshold level. A majority of the “Coping Zone” (CZ) criteria presented in this section were developed as rules that combine information concerning the threshold water level (or flow or gate openings) and the duration of time at that threshold required to trigger a “Zone B” or “Zone C” occurrence. A smaller subset of the CZ criteria assess the severity of range compression in Lake Superior and Lake Michigan-Huron using continuous performance metrics, rather than specific Zone A/B/C designations.

The development of CZ criteria associated with the ecological PIs was based on the expert judgment of the Site Coordinators, taking into consideration the results obtained for the associated PIs and supporting sub-models. Draft criteria were originally developed and provided by the Site Coordinators in early November 2010. The rules associated with the Coping Zone criteria underwent iterations between LimnoTech and the Site Coordinators during December 2010 and January 2011, and a near-final set of criteria was compiled in February 2011. A final iteration on the CZ criteria was conducted in May 2011 following discussions with the Study Board, the Site Coordinators, and experts external to ETWG. This final iteration included the elimination of the “Zone C” condition originally developed for sea lamprey spawning in the St. Marys River (criterion SMG-01), and the development of continuous metrics to evaluate the severity of range compression in Lake Superior (criteria SUP-01, SUP-02) and Lake Michigan-Huron (criteria LMH-01, LHM-02).

“Zone C” and “Zone B” rules were developed for 29 of the 33 IERM2 Coping Zone criteria, and these rules are documented in Table 3-1 in the Appendix. The four CZ criteria that specifically address the severity of range compression in Lake Superior and Lake Michigan-Huron are expressed as plan-to-PreProject ratios, as described in Table 3-1. In addition to providing the specific Coping Zone rules or metric descriptions, Table 3-1 lists the researcher who proposed the criterion and provides cross-references to the PI fact sheets that are associated with the criterion. The criteria are grouped by lake/river region, with the first three characters of the identifier indicating the water level, flow, or gate condition that is evaluated:

- “SUP” – refers to criteria based on Lake Superior mean monthly water levels;
- “SMG” – refers to St. Marys River criteria based on the number of gates opened at the Compensating Works;
- “SMQ” – refers to St. Marys River criteria based on mean monthly discharge rate in the river;
- “SMH” – refers to St. Marys River criteria based on Lake Huron mean monthly water levels;
- “LMH” – refers to criteria based on Lake Michigan-Huron mean monthly water levels;
- “LSC” – refers to criteria based on Lake St. Clair mean monthly water levels; and
- “ERI” – refers to criteria based on Lake Erie mean monthly water levels.

The rules in Table 3-1 are described in as an explicit fashion as possible, in order to avoid any ambiguity in their interpretation and application to hydrologic/hydraulic scenarios. The specific implementation of these rules within the IERM2 "Coping Zone Calculator" is discussed in Section 3.2. It is important to recognize that while the 33 Coping Zone criteria are evaluated individually for simplicity and transparency, many criteria are paired with one or more other criteria in terms of representing a particular ecosystem component. Examples include:

- SUP-01 and SUP-02 are intended to jointly evaluate compression of water level range in Lake Superior (criteria LMH-01 and LMH-02 are analogous for Lake Michigan-Huron);
- SUP-03 and SUP-04 represent low and high Lake Superior water level conditions and should be used together to evaluate potential impacts to wild rice in Kakagon Slough.
- LMH-07 and LMH-08 represent current and future (i.e., 50-year forecast) "Zone C" conditions for eastern Georgian Bay wetlands;
- LSC-02 and LSC-03 represent low and high water Lake St. Clair conditions and should be used together to evaluate potential impacts to fish habitat in the Lake St. Clair Delta.
- ERI-01a, ERI-01b, and ERI-02 address extreme low and high water level conditions and loss of inter-annual water level variability, and the specific impact of these conditions on emergent vegetation in Lake Erie.
- ERI-02a and ERI-02b address extreme low and high water level conditions and their specific impact on wet vegetated (i.e., fish habitat) area in Lake Erie.
- ERI-03a and ERI-03b address extreme low and high water level conditions and their specific impact on spawning habitat supply for four different fish guilds in Lake Erie.

Of particular note is the inclusion of both LMH-07 and LMH-08, two nearly identical Coping Zone criteria that were developed to assess the impact of prolonged low water level conditions on coastal wetlands in eastern Georgian Bay. Criterion LMH-07 was originally developed with 176.0 meters defined as the low-water threshold associated with the "Zone C" condition. However, it was recognized that glacial isostatic adjustment (GIA) is significant in the eastern Georgian Bay region, with uplift rates of approximately 24 cm per century at Parry Sound, ON relative to the Lake Huron outlet (http://www.iugls.org/the-glaciers-are-long-gone-but-theyre-still-affecting-water-levels.aspx). Ongoing uplift in the region will tend to exacerbate impacts on wetlands during extended low water periods in the future. Therefore, the LMH-08 criterion was developed as a GIA-modified version of criterion LMH-07. The "Zone C" threshold for this criterion was set at 176.12 cm to represent the critical condition 50 years in the future (i.e., with a 12 cm rise in the land surface). Criteria LMH-07 and LMH-08 can be used in tandem to assess both current and GIA-affected future impacts on coastal wetlands in eastern Georgian Bay. It is important to note that considerable loss of fish habitat has already occurred in eastern Georgian Bay wetlands as a result of the extended period of low water levels during the early 2000s. During the 9-year period covering 2000-08, the water level during the months of March-October averaged approximately 176.0 meters. The “Zone C” definition for Criterion LMH-07 identifies 176.0 meters as a minimum water level threshold that should not be exceeded in order to prevent further loss of fish habitat (i.e., beyond the losses already incurred during the 2000-08 period). Fact Sheets #08 and 09 in Appendix A provide additional detail and justification for the eastern Georgian Bay criteria.

3.1.1 Approach for “Zone C” Criteria

A significant challenge in generating the Coping Zone criteria for the Upper Great Lakes was developing a consistent conceptual definition for a “Zone C” condition associated with the ecosystem. When the ecosystem reaches a “Zone C” condition, the biological communities and functions are significantly degraded. The literature suggests that if water level regimes return to “Zone A” or “Zone B” levels after a “Zone C” condition, the ecosystem does not return to its pre-existing state, but rather to an altered state. It is incorrect to assume that as water levels return to “Zone A” conditions, that the ecosystem will be the same. The end result 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” conditions for other sectors.

A defining feature of the ecosystem is its resiliency to short-term natural or anthropogenic stressors. The Upper Great Lakes ecosystem has adapted to historical water level fluctuations, including periodic extreme low and high supply conditions. In fact, these natural perturbations are essential for maintaining plant and animal diversity in coastal wetland systems of the Great Lakes. The ecosystem is certainly vulnerable to long-term degradation if natural water levels and flows are manipulated in such a way as to significantly reduce inter-annual and seasonal variability or artificially extend periods of extreme low or high water levels. Moreover, “Zone C” conditions may occur in response to extremes caused by natural variation in net basin supplies. If naturally caused, the ETWG would not advocate manipulating or moderating natural highs or lows to eliminate “Zone C” occurrences in order to “protect” the environment.

“Zone C” conditions have generally not been observed during the historical period of record in the Upper Great Lakes (i.e., 1900-2008). Therefore, expert judgment must be combined with experience on other similar ecosystems, such as Lake Ontario (Wilcox and Xie 2007), to quantify thresholds and durations associated with “Zone C” conditions in the Upper Great Lakes. A general guideline used during the development and refinement of “Zone C” criteria was that the Pre-Project scenario should have very few (if any) years predicted to be in “Zone C”. This guideline is based on the general expectation that natural water levels in the Upper Great Lakes for the period of record (1900-2008) would not be expected to be the cause of significant and long-term degradation of the ecosystem. Using similar logic, the existing regulation plan (77A) would not be expected to generate a large number of

"Zone C" occurrences across the suite of Coping Zone criteria. This is especially true for Lake Michigan-Huron (including Georgian Bay), Lake St. Clair, and Lake Erie because Lake Superior regulation has had a relatively small impact on water levels in these regions of the Upper Great Lakes.

3.1.2 Approach for "Zone B" Criteria

In many cases, the Coping Zone criteria originally proposed by the Site Coordinators provided only rules for assessing "Zone C" conditions. To the extent possible, "Zone B" rules were collaboratively developed by LimnoTech and the individual Site Coordinators. In many cases, "Zone B" rules were developed to simply reflect a shorter duration than that associated with the "Zone C" condition. For example, "Zone C" is assigned for criterion "SUP-03" when the peak summertime water level in Lake Superior drops below 182.56 meters for 3 or more consecutive years. The "Zone B" condition is predicated on the same water level threshold (182.56 m), but it is triggered if Lake Superior water levels drop below this threshold for any year within a rolling 4-year period (i.e., for the three preceding years and the current year). Due to the somewhat arbitrary approach used for defining "Zone B" rules, these rules should generally be considered less certain and less useful for decision-making purposes relative to their "Zone C" counterparts.

Table 3-1. Summary of IERM2 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
SUP-01	Lake Superior	*(not applicable)*	Range Compression Metric #1: plan-to-Pre-Project ratio for the maximum peak summertime water level when the Pre-Project peak is greater than 0.37 meter above the 109-year mean water level.	n/a [1]	Wilcox	Minimize range compression for Lake Superior (Goal: plan-to-PreProject ratios should be as close to 1.0 as possible)
SUP-02	Lake Superior	*(not applicable)*	Range Compression Metric #2: plan-to-Pre-Project ratio of the maximum drawdown of summertime high water levels occurring within 5 years of a 'peak' water level (when the maximum drawdown for Pre-Project is at least 0.45 meter).[2]	n/a [1]	Wilcox	Minimize range compression for Lake Superior (Goal: plan-to-PreProject ratios should be as close to 1.0 as possible)
SUP-03	Lake Superior	Peak summertime water level drops below 182.56 meters for any year within a 4-year period.	Peak summertime water level drops below 182.56 meters for 3 or more consecutive years.	01	Meeker	Maintain viability of wild rice population
SUP-04	Lake Superior	Peak summertime water level rises above 184.0 meters for any year within in a 4-year period.	Peak summertime water level rises above 184.0 meters for 3 or more consecutive years.	01	Meeker	Maintain viability of wild rice population
SUP-05	Lake Superior	Mean spring (Apr-May) water level is more than 0.67 meter below the mean level for the preceding 10-year period for any 5 years within a 7-year window.	Mean spring (Apr-May) water level is more than 0.67 meter below the mean level for the preceding 10-year period for 7 or more consecutive years.	02	Harris, Foster	Prevent significant decline in northern pike abundance
SUP-06	Lake Superior	Mean spring (Apr-May) water level is more than 1.12 meters below the mean level for the preceding 10-year period for any 5 years within a 7-year window.	Mean spring (Apr-May) water level is more than 1.12 meters below the mean level for the preceding 10-year period for 7 or more consecutive years.	02	Harris, Foster	Prevent significant decline in northern pike abundance
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

Table 3-1. Summary of IERM2 Coping Zone Criteria - Continued

Criterion Identifier	Lake Region	"Zone B" Condition	"Zone C" Condition or Range Compression Metric	PI Fact Sheet IDs	Proposed By	General Objective
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
LMH-01	Lake Michigan-Huron	*(not applicable)*	Range Compression Metric #1: plan-to-PreProject ratio for the maximum peak summertime water level when the Pre-Project peak is greater than 0.65 meter above the 109-year mean water level.	12 (also 11, 03, 04, and 20)	Wilcox	Minimize range compression for Lake Michigan-Huron (Goal: plan-to-PreProject ratios should be as close to 1.0 as possible)

Table 3-1. Summary of IERM2 Coping Zone Criteria - Continued

Criterion Identifier	Lake Region	"Zone B" Condition	"Zone C" Condition or Range Compression Metric	PI Fact Sheet IDs	Proposed By	General Objective
LMH-02	Lake Michigan-Huron	*(not applicable)*	Range Compression Metric #2: plan-to-PreProject ratio of the maximum drawdown of summertime high water levels occurring within 5 years of a 'peak' water level (when the maximum drawdown for Pre-Project is at least 0.75 meter).[2]	12 (also 11, 03, 04, and 20)	Wilcox	Minimize range compression for Lake Michigan-Huron (Goal: plan-to-PreProject ratios should be as close to 1.0 as possible)
LMH-03	Lake Michigan-Huron	Annual peak water level monotonically increases or decreases for any 7 years within a 10-year window.	Annual peak water level monotonically increases or decreases for 10 consecutive years.	14, 07 (also 03, 04)	Uzarski, Steinman	Maintain fish food supply
LMH-04	Lake Michigan-Huron	Water level increases by less than 0.30 meter between January and July for any 7 years in a 9-year window.	Water level increases by less than 0.30 meter between January and July for 9 consecutive years.	15, 07	Uzarski et al.	Maintain overall wetland fish abundance
LMH-05	Lake Michigan-Huron	Mean water level during growing season (Apr-Sep) is maintained at 177.65 meters or higher for any 3 years within a 5-year window.	Mean water level during growing season (Apr-Sep) is maintained at 177.65 meters or higher for a period of 5 consecutive years.	10	Albert	Prevent loss of meadow marsh habitat area
LMH-06	Lake Michigan-Huron	Mean growing season (Apr-Sep) water level drops below 175.0 meters for any 3 years within a 5-year window.	Mean growing season (Apr-Sep) water level drops below 175.0 meters for a period of 5 consecutive years.	10, 11	Albert	Prevent loss of bulrush habitat area
LMH-07	Lake Michigan-Huron	Mean growing season (Apr-Oct) water level is less than 176.2 meters for any 3 years within a 5-year window.	Mean growing season (Apr-Oct) water level is less than 176.0 meters for a period of 4 or more consecutive years.	08, 09	Chow-Fraser et al.	Maintain fish habitat/access in eastern Georgian Bay wetlands (current conditions)
LMH-08	Lake Michigan-Huron	Mean growing season (Apr-Oct) water level is less than 176.32 meters for any 3 years within a 5-year window.	Mean growing season (Apr-Oct) water level is less than 176.12 meters for a period of 4 or more consecutive years.	08, 09	Chow-Fraser et al.	Maintain fish habitat/access in eastern Georgian Bay wetlands (50-year forecast condition)

Table 3-1. Summary of IERM2 Coping Zone Criteria - Continued

Criterion Identifier	Lake Region	"Zone B" Condition	"Zone C" Condition or Range Compression Metric	PI Fact Sheet IDs	Proposed By	General Objective
LMH-09	Lake Michigan-Huron	Water level increases by more than 0.36 meter between March and June for any year.	Water level increases by more than 0.36 meter between March and June for 3 consecutive years.	15	Uzarski et al.	Maintain overall wetland fish diversity
LSC-01	Lake St. Clair	Mean water level for Mar-Oct maintained at or below 174.1 meters for any 3 years in a 5-year window.	Mean water level for Mar-Oct maintained at or below 174.1 meters for 5 consecutive years.	11	Albert	Prevent spread/dominance of invasive vegetation species (Phragmites, Typha)
LSC-02	Lake St. Clair	Mean water level for Mar-Oct maintained at or below 174.3 meters for any 3 years in a 5-year window.	Mean water level for Mar-Oct maintained at or below 174.3 meters for 5 consecutive years.	16	Mackey	Prevent significant loss of fish spawning habitat
LSC-03	Lake St. Clair	Mean water level for Mar-Oct maintained above 176.5 meters for any 3 years in a 5-year window.	Mean water level for Mar-Oct maintained above 176.5 meters for 5 consecutive years.	16	Mackey	Prevent significant loss of fish spawning habitat
ERI-01a	Lake Erie	Mean water level for Mar-Oct maintained below 173.91 meters for any 3 years in a 5-year window.	Mean water level for Mar-Oct maintained below 173.66 meters for 5 consecutive years.	17	Mortsch, Cabrera	Prevent significant loss of emergent vegetation habitat area in Long Point Bay
ERI-01b	Lake Erie	Mean water level for Mar-Oct maintained above 174.59 meters for any 3 years in a 5-year window.	Mean water level for Mar-Oct maintained above 175.2 meters for 5 consecutive years.	17	Mortsch, Cabrera	Prevent significant loss of emergent vegetation habitat area in Long Point Bay
ERI-02	Lake Erie	Variance in Mar-Oct mean water levels for 30-year rolling period is less than or equal to 0.045 m2.	Variance in Mar-Oct mean water levels for 30-year rolling period is less than or equal to 0.0095 m2.	17	Mortsch, Cabrera	Prevent significant loss of emergent vegetation habitat area in Long Point Bay
ERI-03a	Lake Erie	Mean growing season (Mar-Oct) water level is between 172.8 and 173.55 meters for 3 out of 5 years, or less than 172.8 meters in any given year; or the maximum difference in water levels for consecutive months is greater than 0.33 meter in any given year.	Mean growing season (Mar-Oct) water level is less than 172.8 meters for 5 consecutive years.	18	Doka, Gertzen	Prevent significant loss of submerged vegetation habitat area in Long Point Bay

Table 3-1. Summary of IERM2 Coping Zone Criteria - Continued

Criterion Identifier	Lake Region	"Zone B" Condition	"Zone C" Condition or Range Compression Metric	PI Fact Sheet IDs	Proposed By	General Objective
ERI-03b	Lake Erie	If the 30-year (rolling) variance in Mar-Oct water levels is < 0.01 m: mean growing season (Mar-Oct) water level is 174.2-174.6 meters for 3 out of 5 years or greater than 174.6 meter for a given year. If the 30-year rolling variance in Mar-Oct water levels >= 0.01 m: mean growing season (Mar-Oct) water level is 174.63-175.03 meters for 3 out of 5 years or greater than 175.03 meter for a given year.	If the 30-year (rolling) variance in Mar-Oct water levels is < 0.01 m: mean growing season (Mar-Oct) water level is greater than 174.6 m for 5 consecutive years. If the 30-year rolling variance in Mar-Oct water levels >= 0.01 m: mean growing season (Mar-Oct) water level is greater than 175.03 m for 5 consecutive years.	18	Doka, Gertzen	Prevent significant loss of submerged vegetation habitat area in Long Point Bay
ERI-04a	Lake Erie	Mean water level during the guild-specific spawning period is less than 172.8 meters in any given year, between 172.8 and 173.55 meters for 3 years in a 5-year window, or criterion "ERI-03a" is in "Zone B".	Mean water level during the guild-specific spawning period is less than 172.8 meters for 5 consecutive years, or criterion "ERI-03a" is in "Zone C".	19	Doka, Gertzen	Prevent significant loss of fish habitat area in Long Point Bay
ERI-04b	Lake Erie	If the 30-year (rolling) variance in Mar-Oct water levels is < 0.01 m: mean water level during the guild-specific spawning period is greater than 174.6 m in any given year, between 174.2 and 174.6 m for 3 years in a 5-year window, or criterion "ERI-03b" is in "Zone B". If the 30-year rolling variance in Mar-Oct water levels >= 0.01 m: mean water level during the guild-specific spawning period is greater than 175.03 m in any given year, between 174.63 and 175.03 m for 3 years in a 5-year window, or criterion "ERI-03b" is in "Zone B".	If the 30-year (rolling) variance in Mar-Oct water levels is < 0.01 m: mean water level during the guild-specific spawning period is greater than 174.6 m for 5 consecutive years. If the 30-year rolling variance in Mar-Oct water levels >= 0.01 m: mean water level during the guild-specific spawning period is greater than 175.03 m for 5 consecutive years. *If the ERI-03b condition is "Zone C" for a given year, then ERI-04b is also in "Zone C" for that year.*	19	Doka, Gertzen	Prevent significant loss of fish habitat area in Long Point Bay

[1] The "SUP-01" and "SUP-02" range compression criteria for Lake Superior are not linked to specific performance indicators; rather, these criteria are based on expert judgment regarding the water level range requirements for long-term maintenance of healthy and diverse wetland vegetation.

[2] These conditions are only evaluated when Pre-Project water levels indicate that supplies are sufficiently low following a peak water level event.

3.2 GENERAL ASSESSMENT APPROACH

The current IERM2 Coping Zone analysis is designed to identify specific water level, flow, or gate conditions that would be expected to trigger a “Zone B” or “Zone C” occurrence for a given year represented in a hydrologic/hydraulic scenario. The narrative description for each rule in Table 3-1 indicates the specific condition that would trigger a “Zone C” or “Zone B” assignment for a particular year in the evaluation of a scenario. If the hydrologic/hydraulic conditions are not categorized as “Zone C” or “Zone B” for a given year, then “Zone A” is assigned as a default. Therefore, the IERM2 Coping Zone analysis generates a “Zone A”, “Zone B”, or “Zone C” rating for each criterion for each year, and the sum of all of the A/B/C occurrences for a given criterion evaluation will always be equal to the total number of years (i.e., 109) represented in a hydrologic/hydraulic scenario. Note that this zone-based approach applies only to the 29 criteria that do not address range compression in Lake Superior and Lake Michigan-Huron.

It is important to note that a limitation of the current set of criteria and analysis is that the period of ecosystem recovery that would follow a “Zone C” event is not represented explicitly in the evaluation. For example, a “Zone C” occurrence may be predicted for a single year and then a “Zone B” or “Zone A” may be assigned for the following year if hydraulic conditions are restored such that the “Zone C” rule is no longer met. Ideally, the Coping Zone criteria would be expanded to include specific information on how many years a particular ecosystem component (e.g., vegetation or fish population) would be expected to remain in a significantly degraded condition following the initial decline into a “Zone C” condition. However, the research needed to support this level of assessment for the Upper Great Lakes is not currently available. It is highly recommended that this information gap in the current analysis be addressed through future ecosystem studies conducted as part of IUGLS Adaptive Management and/or other Great Lakes research efforts.

As alluded to previously, the zone-based approach is not employed for the four CZ criteria that address water level range compression in Lake Superior (SUP-01, SUP-02) and Lake Michigan-Huron (LMH-01, LMH-02). Continuous metrics were developed for these criteria to provide more detailed and directly useful information for plan formulation and evaluation purposes. These metrics are important because it has been demonstrated that water level range compression can significantly degrade wetland habitat health and diversity, such as has been the case for Lake Ontario (Wilcox and Xie 2007, 2008). As indicated in Table 3-1, criteria SUP-01 and LMH-01 evaluate how well a given hydrologic/hydraulic scenario reproduces periodic peak water level conditions for the corresponding Pre-Project ‘benchmark’ scenario. For these metrics, a “peak year” is identified as a year where the maximum monthly water level is greater than 37 cm (for Superior) or 65 cm (for Michigan-Huron) above the long-term (i.e., 109-year) mean water level. For example, for the historical NBS case, a total of 7 years are identified as “peak years” for Lake Superior: 1916, 1928, 1939, 1951, 1968, 1972, and 1986.

The SUP-02 and LMH-02 criteria are complementary to SUP-01 and LMH-01. These criteria are designed to evaluate how well a given hydrologic/hydraulic scenario reproduces post-peak drawdown conditions as defined by the corresponding Pre-Project 'benchmark' scenario. For this metric, a "post-peak drawdown event" is identified as a 5-year period following a "peak year" (as defined above) where the monthly maximum water level drops at least 0.45 meter (for Superior) or 0.75 meter (for Michigan-Huron) below the preceding peak for the Pre-Project scenario for at least one year. For example, for the historical NBS case, a Pre-Project drawdown of greater than 0.45 meter occurred following four Lake Superior "peak years": 1916, 1928, 1951 and 1986.

While the current analysis cannot provide a comprehensive evaluation of the recovery of the ecosystem once significant degradation has been predicted to occur, the IERM2 Coping Zone analysis provides a useful tool for IUGLS plan formulation and decision-making. The current analysis will evaluate the number of years where hydrologic/hydraulic conditions would be expected to trigger "Zone C" or "Zone B" occurrences, as well as provide metrics indicating how closely a given scenario reproduces the natural water level ranges as indicated by the Pre-Project scenario. This information can be used directly by plan formulators to evaluate and vet relative differences between candidate regulation plans for Lake Superior. Furthermore, the Study Board can evaluate the relative number of "Zone C" and "Zone B" occurrences and range compression metrics for candidate plans to assess tradeoffs between ecosystem benefits (or disbenefits) and modeled outcomes for economic and social sectors. In addition to providing specific guidance on evaluating alternative regulation plans for Lake Superior, the IERM2 Coping Zone analysis can be used to assess the potential ecosystem impacts for any number of plausible future NBS conditions (e.g., those that might result from climate change).

As discussed above, a total of 33 Coping Zone criteria have been developed and implemented to assess the likely ecosystem impacts associated with any given hydrologic/hydraulic scenario. An important question with respect to the evaluation of the Coping Zone criteria is whether conflicts between individual criteria are anticipated, and, if so, how those conflicts should be addressed. As discussed above, the Coping Zone approach is designed to identify conditions where significant degradation is expected to occur for one or more components of the ecosystem. The "Zone C" conditions and range compression metrics defined for the Coping Zone criteria generally reflect one of the following circumstances for a particular region of the Upper Great Lakes:

1. Prolonged high water level or flow conditions;
2. Prolonged low water level or flow conditions;
3. Too much or too little water availability in the St. Marys rapids;
4. Alteration of typical seasonal patterns in water level or flow;
5. Reduction in the inter-annual variability of the summertime peak water level; and

6. Compression of long-term range/variability in water levels (i.e., difference between periodic peak levels and water levels during low supply periods).

For the most part, these circumstances are not encountered at the same time; for example, prolonged high water level conditions for one part of the system are unlikely to occur at the same time as prolonged low water level conditions for another region. Conflicts occurring as a result of extreme conditions occurring simultaneously in Lake Superior and the downstream lake systems are theoretically possible. However, Lake Superior water level regulation has been shown to have only a very minor impact on water levels in Lake Michigan-Huron (i.e., less than 10 cm) and even less effect on Lake Erie water levels. This suggests that decisions made regarding Lake Superior regulation are unlikely to create conflict in the Coping Zone evaluation for Lakes Superior, Michigan-Huron, and Erie.

3.3 CRITERIA RATIONALE, UNCERTAINTY, & SENSITIVITY

An effective analysis of results generated by the IERM2 Coping Zone assessment requires a strong understanding of the following aspects of each individual criterion: 1) the rationale for developing the prescribed thresholds and durations, 2) inherent uncertainties and limitations associated with the criterion, and 3) the sensitivity of the criterion to alternative regulation plans and alternative net basin supply (NBS) scenarios. Table 3-2 provides a complete listing of the Coping Zone criteria including a concise summary of the rationale, uncertainties/limitations, and sensitivity associated with each criterion (or set of interrelated criteria). The information provided in Table 3-2 is not intended to be comprehensive; rather, this table is designed to provide the reader with a summary of key points that can be used to inform an assessment of the IERM2 Coping Zone results generated for a given set of regulation plans and NBS scenarios. Comprehensive documentation of the rationale, uncertainties, limitations, and sensitivity associated with the various criteria can be found in the Fact Sheets provided in Appendix A.

Table 3-2. Coping Zone Criteria Rationale, Uncertainty, & Sensitivity

Criterion Identifier	Lake Region	General Objective	Rationale	Uncertainty & Limitations	Sensitivity
SUP-01	Lake Superior	Prevent/minimize range compression for Lake Superior	Range compression introduced by regulation has been identified as a major factor adversely affecting coastal wetland ecosystems – e.g., in Lake Ontario (Wilcox and Xie 2007, 2008)	It is unknown how much range compression is required to adversely impact wetland vegetation diversity and habitat quality. Therefore, the range compression metrics have been ultimately designed as "continuous" metrics that can be used to determine whether range compression is better or worse for one plan compared to another.	High sensitivity - these metrics demonstrate high sensitivity because regulation of Lake Superior levels tends to reduce extreme peak water levels, limit post-peak drawdown events, and prevent extreme low water levels in some cases.
SUP-02	Lake Superior				
SUP-03	Lake Superior	Maintain viability of wild rice population	Water levels below ~182.56 meters would reduce wild rice coverage by 75-80%, which could threaten long-term viability if this condition lasts longer than 3 years.	The level of uncertainty is relatively low because the relationship between wild rice and water depth has been previously established (Meeker 1999). A potential limitation of these criteria is that they represent a relatively small geographic region. However, it is important to note that wild rice in Chequamegon Bay and Kakagon Slough has cultural significance for local tribal populations.	Very low sensitivity under historical and alternative NBS scenarios – no "Zone C" occurrences are predicted for 17 regulation plans for the historical and 9 alternative NBS scenarios.
SUP-04	Lake Superior		Water levels above 184.0 meters could reduce wild rice surface area by 50%, which could threaten long-term viability if this condition lasts longer than 3 years.		Low sensitivity under historical and alternative NBS scenarios – e.g., no "Zone C" occurrences are predicted for 17 regulation plans for the historical and 8 of 9 NBS scenarios.
SUP-05	Lake Superior	Prevent significant decline in northern pike abundance in Black Bay and Sturgeon Bay	The prescribed declines in water level relative to preceding years would force northern pike to spawn over submerged vegetation instead of bulrush, resulting in much lower spawning success. Therefore, extended periods of low water are expected to have a harmful impact on northern pike in these embayments.	Northern pike have a long life span, and, even with the loss of several year classes, there are opportunities for this species to recover over time. The durations for the prescribed criteria (e.g., 5 to 7 years) are intended to be protective of this species.	Low sensitivity under historical NBS conditions, moderate sensitivity for alternative NBS scenarios – no "Zone C" occurrences are predicted for 17 regulation plans under consideration for the historical NBS case.
SUP-06	Lake Superior				
SMG-01	St. Marys River	Prevent ideal conditions for sea lamprey reproduction and escapement above the Compensating Works	Sea lamprey are an invasive predator of major concern in the Upper Great Lakes system, and maintaining more than 4 or more gates open at the Compensating Works maximizes the suitable area available for sea lamprey reproduction and upstream escapement.	Note that no "Zone C" occurrences will be reported for any plans or scenarios.	No sensitivity - this criterion has been reclassified to "Zone B" and therefore no "Zone C" occurrences will be reported for any plans or scenarios.

Table 3-2. Coping Zone Criteria Rationale, Uncertainty, & Sensitivity - Continued

Criterion Identifier	Lake Region	General Objective	Rationale	Uncertainty & Limitations	Sensitivity
SMG-02	St. Marys River	Maintain sufficient habitat for native fish reproduction	Any flows lower than those associated with a ½ gate open setting would strand fish and desiccate invertebrates in the St. Marys rapids, resulting in damage to the local fishery.	This criterion is based on expert judgment - a ½ gate opening is currently the minimum setting for the Compensating Works, and therefore impacts for lower flow conditions have not been directly observed.	Very low sensitivity – the Compensating Works are currently operated with ½ gate open at a minimum, and this 'rule' is expected to be maintained for any new regulation plan selected.
SMQ-01	St. Marys River	Maintain periodic suitable spawning habitat area for lake sturgeon	Lake sturgeon is listed as a threatened species in Michigan and Ontario. This species is habitat-limited, and there is a unique population of sturgeon in the St. Marys River. Female lake sturgeon do not start reproducing until they are mature (~20 years), and then they spawn every 4 to 7 years, which limits the number and frequency of opportunities for reproduction to occur.	The uncertainty and limitations associated with the criterion are relatively minor because the species is threatened and known to be habitat-limited in the St. Marys River. The life cycle of lake sturgeon is generally well understood and supports the duration of 5 years for a "Zone C" condition.	Moderate sensitivity under historical and alternative NBS scenarios – extended periods (e.g. 4-5 years) of flows below the 1,700 m^3/s threshold can occur for some regulation plans for the historical NBS scenario.
SMQ-02	St. Marys River	Maintain spawning habitat in Lake George channel via flushing flow conditions	Flushing flows in Lake George are critical to preventing loss of spawning habitat due to long-term buildup of sediment. The threshold flow is defined as the flow rate that will transport 1 mm sand particles in approximately 40% of Lake George transects during May-June.	The threshold flow magnitude is generally well-supported by available transect bathymetry data and velocity calculations. The uncertainty is greater for the prescribed flow duration (i.e., 2 months) and frequency (i.e., once in 7 years), which are derived from ecosystem objectives for the Colorado River. Site-specific studies of the St. Marys River would be needed to better understand the magnitude, timing, and frequency of flow required to effectively flush non-cohesive sediments in Lake George.	Low sensitivity under historical NBS conditions, high sensitivity for alternative NBS scenarios – no "Zone C" occurrences are predicted for 17 regulation plans under consideration for the historical NBS case, but significant differences in "Zone C" conditions occur for some alternative NBS scenarios.

Table 3-2. Coping Zone Criteria Rationale, Uncertainty, & Sensitivity - Continued

Criterion Identifier	Lake Region	General Objective	Rationale	Uncertainty & Limitations	Sensitivity
SMH-01	St. Marys River (L. Huron WL)	Prevent mortality of lake herring that might be caused by water level declines	A fall-to-spring drop of 1.25 meter in Lake Huron water level would result in a 40% loss in suitable spawning habitat for lake herring. Because lake herring are listed as threatened and have notoriously variable annual recruitment, this magnitude of habitat loss should be considered to be significant.	The uncertainty associated with this criterion is relatively low because it is based on site-specific bathymetry. A water depth of 1 meter is assumed to be the minimum depth required to support lake herring spawning; however, this corresponds to the minimum documented depth for spawning of this species.	Very low sensitivity under historical and alternative NBS scenarios – no "Zone C" occurrences are predicted for 17 regulation plans under consideration for the historical and 9 alternative NBS cases.
SMH-02	St. Marys River (L. Huron WL)	Avoid flooding of black tern nests	Black tern is a conservation priority species in multiple states and in Ontario, and it represents other marsh nesting bird species that are conservation priorities. A maximum change in Lake Huron water level of 30 cm during June-August was selected as the threshold to minimize loss of nesting habitat based on the "midpoint" between ideal conditions (no change) and completely unsuitable conditions (60 cm change).	This PI and associated criterion are considered to have relatively low uncertainty because they were developed based on multiple published studies, and because nest flooding has been documented as a specific cause of species decline. This criterion reasonably assumes that 1) nesting success has a major influence on black tern abundance, 2) nesting success declines with water level changes beyond the conditions typically experienced by the species, and 3) black terns select nesting sites based on water depth ranges in wetlands early in the nesting period.	Very low sensitivity under historical and alternative NBS scenarios – no "Zone C" occurrences are predicted for 17 regulation plans under consideration for the historical and 9 alternative NBS cases.
SMH-03	St. Marys River (L. Huron WL)	Maintain suitable conditions for submerged aquatic vegetation	Submerged aquatic vegetation (SAV) provides critical habitat and an important energy source driving the lower food web within the St. Marys River. Significant decreases in water level will tend to reduce the amount of area suitable for SAV growth. The threshold of 174.5 meters corresponds to a predicted 55% loss of SAV area relative to mean water level conditions in Lake Huron.	This PI and associated criterion are considered to have relatively low uncertainty because they were developed based on site-specific bathymetry and multiple published studies that use similar depth range values for SAV. However, a test of the relationship developed has not been conducted with actual measurements of SAV area. Key assumptions include: 1) suitable depth range for SAV growth (2 to 7 meters), and 2) water depth is more of a limiting factor determining SAV distribution than water velocity.	Very low sensitivity under historical and alternative NBS scenarios – no "Zone C" occurrences are predicted for 17 regulation plans under consideration for the historical and 9 alternative NBS cases.

Table 3-2. Coping Zone Criteria Rationale, Uncertainty, & Sensitivity - Continued

Criterion Identifier	Lake Region	General Objective	Rationale	Uncertainty & Limitations	Sensitivity
SMH-04	St. Marys River (L. Huron WL)	Maintain backwater habitat for fish spawning	Backwater habitats in the Great Lakes have been degraded primarily due to shoreline development, with 65% loss of wetland habitat already occurring. The water level threshold of 175.6 meters corresponds to a total backwater habitat loss of 30% in the St. Marys River *beyond* the losses already incurred.	The uncertainty associated with the calculations of backwater habitat area is generally low because they are based on detailed site-specific bathymetry. The 30% loss threshold is less certain, but represents a reasonable estimate of unacceptable losses in the context of wetland area already lost as a consequence of shoreline development.	**Low sensitivity under historical NBS conditions, high sensitivity for alternative NBS scenarios** – significant differences in "Zone C" conditions occur for some alternative NBS scenarios.
LMH-01	Lake Michigan-Huron	Prevent/minimize range compression for Lake Michigan-Huron	Range compression introduced by regulation has been identified as a major factor adversely affecting coastal wetland ecosystems – e.g., in Lake Ontario (Wilcox and Xie 2007, Wilcox and Xie 2008)	It is unknown how much range compression is required to adversely impact wetland vegetation diversity and habitat quality. Therefore, the range compression metrics have been ultimately designed as "continuous" metrics that can be used to determine whether range compression is better or worse for one plan compared to another.	**Low to moderate sensitivity** - these metrics generally demonstrate low sensitivity to choice of regulation plan because Lake Superior regulation typically has a minimal effect on Lake Michigan-Huron water levels. However, extreme regulation plans could potentially contribute to minor (yet undesirable) range compression in Michigan-Huron.
LMH-02	Lake Michigan-Huron				
LMH-03	Lake Michigan-Huron	Maintain fish food supply	Multi-year trends in mean annual water level are an important factor affecting the structure of macroinvertebrate communities. Typically, water levels oscillate between "rising" and "falling" on a 3-5 year cycle. A 10-year monotonic increase or decrease in mean water level would represent an extreme case that is likely to have significant adverse impacts on fish food supply. Therefore, this condition is assumed to correspond to a "Zone C" occurrence.	The uncertainty associated with this criterion is considered to be relatively low. The underlying connection between macroinvertebrate diversity and abundance is based on 6 years of data from 10 wetland sites in Lake Huron (Les Cheneaux Islands). Additional data are needed for other regions to confidently extend this metric to other regions.	**Low sensitivity under historical and alternative NBS scenarios** – e.g., no "Zone C" occurrences are predicted for 16 of 17 regulation plans under consideration for the historical and 9 alternative NBS scenarios.

Table 3-2. Coping Zone Criteria Rationale, Uncertainty, & Sensitivity - Continued

Criterion Identifier	Lake Region	General Objective	Rationale	Uncertainty & Limitations	Sensitivity
LMH-04	Lake Michigan-Huron	Maintain overall wetland fish abundance	The prescribed threshold of 9 consecutive years of insufficient water increase between January and July is based on the life history traits of common wetland fish species. Available data suggest that lack of water level increase for many consecutive years could have a significant and potentially long-term adverse impact on overall wetland fish abundance.	The level of uncertainty associated with this criterion is considered to be relatively high. The importance of sufficient water level increase between January and July is supported by statistical analyses; however, the specific link between water level increases and fish production is not fully understood at this time.	Very low sensitivity under historical NBS conditions, low sensitivity for alternative NBS scenarios – minimal "Zone C" occurrences are predicted for 17 regulation plans under consideration for the 9 alternative NBS scenarios.
LMH-05	Lake Michigan-Huron	Prevent loss of meadow marsh habitat area	Under extended periods of high water levels, meadow marsh vegetation will tend to migrate upslope. However, existing barriers such as highways, coastal roads, and shoreline homes prevent this from occurring to a large extent for many wetlands in northern Lake Michigan-Huron. The threshold of 177.65 meters has been developed to represent extended water level conditions that are expected to significantly reduce meadow marsh diversity and surface area due to the presence of these upland barriers.	These criteria were originally developed for Les Cheneaux Islands wetlands, but has been broadened to other Michigan-Huron wetlands, such as Saginaw Bay, based on limited sampling and anecdotal evidence. The level of uncertainty is relatively low for application of these criteria to Les Cheneaux Island wetlands, but the uncertainty is greater for extending these criteria to other coastal wetlands in Lake Michigan-Huron.	Very low sensitivity under historical and alternative NBS scenarios – no "Zone C" occurrences are predicted for 17 regulation plans under consideration for the historical and 9 alternative NBS scenarios.
LMH-06	Lake Michigan-Huron	Prevent loss of bulrush habitat area	A decline in water level to below 175.0 meters would result in severe loss of plant diversity in the emergent marsh (i.e., bulrush) zone for northern Lake Michigan-Huron wetlands in shallow protected bays. A similar threshold is appropriate for Saginaw Bay, although down slope migration of the emergent marsh is more likely for that system.		

Table 3-2. Coping Zone Criteria Rationale, Uncertainty, & Sensitivity - Continued

Criterion Identifier	Lake Region	General Objective	Rationale	Uncertainty & Limitations	Sensitivity
LMH-07	Lake Michigan-Huron	Maintain fish habitat/access in eastern Georgian Bay wetlands (current conditions, 50-year forecast conditions)	These criteria address current conditions and 50-year forecast conditions considering glacial isostatic adjustment (GIA), respectively. Anecdotal evidence suggests that there has already been a considerable loss in fish habitat due to extended low water levels in the early 2000s. Based on a large representative dataset of wetland sill depths, additional fish habitat losses would be approximately 15% per meter of water drop below 176 meters. It is anticipated that significant, irreversible damage to the fish and wildlife community in eastern Georgian Bay will occur for extended periods (e.g., 4 years) of water levels below 176 meters.	The level of uncertainty for these criteria is considered to be very low. Extensive sampling of more than 100 wetlands was conducted to develop a representative dataset of wetland sill elevations in eastern Georgian Bay. Furthermore, the low water level conditions recently experienced in the early 2000s has provided evidence of the adverse impact of declining water level conditions on fish habitat in Georgian Bay wetlands.	High sensitivity under historical and alternative NBS conditions – this criterion is highly sensitive to extreme low water level conditions encountered in the historical and alternative NBS scenarios. However, this criterion is only moderately sensitive to choice of regulation plan due to the relatively small effect of Lake Superior regulation on water levels in Lake Michigan-Huron.
LMH-08	Lake Michigan-Huron				
LMH-09	Lake Michigan-Huron	Maintain overall wetland fish diversity	The prescribed threshold of 3 consecutive years of excessive water increase between March and June is based on the life history traits of common wetland fish species. Available data suggest that rapid water level increases occurring for several consecutive years may lead to dominance by a limited number of species. If dominance is achieved by a limited number of species, the system will not be able to recover easily even if conditions return to normal.	The level of uncertainty associated with this criterion is considered to be relatively high. The importance of avoiding very rapid water level increases between March and June is supported by statistical analyses; however, the specific link between water level increases and fish diversity is not fully understood at this time.	Very low sensitivity under historical and alternative NBS scenarios – no "Zone C" occurrences are predicted for 17 regulation plans under consideration for the historical and 9 alternative NBS scenarios.

Table 3-2. Coping Zone Criteria Rationale, Uncertainty, & Sensitivity - Continued

<table>
<tr><th>Criterion Identifier</th><th>Lake Region</th><th>General Objective</th><th>Rationale</th><th>Uncertainty & Limitations</th><th>Sensitivity</th></tr>
<tr><td>LSC-01</td><td>Lake St. Clair</td><td>Prevent spread/dominance of invasive vegetation species (e.g., Phragmites)</td><td>Previous studies for Dickinson Island marsh in the St. Clair River delta demonstrated significant replacement of native vegetation by invasive species (e.g., Phragmites) during prolonged low water level conditions occurring between 1988 and 2005. Significant replacement of native vegetation/habitat is expected to occur at the threshold of 174.1 (for a duration of 5 years), and recovery will be unlikely or at least very slow and difficult after water levels return to normal.</td><td>The level of uncertainty associated with this criterion is considered to be low because previous studies have documented replacement of native emergent vegetation by Phragmites during an extended period of low water levels. It should also be noted that the low water threshold of 174.1 meters is very similar to the threshold defined for criterion LSC-03.</td><td>Very low sensitivity under historical and alternative NBS scenarios – no “Zone C” occurrences are predicted for 17 regulation plans under consideration for the historical and 9 alternative NBS scenarios.</td></tr>
<tr><td>LSC-02</td><td>Lake St. Clair</td><td rowspan="2">Prevent significant loss of fish spawning habitat</td><td rowspan="2">The coastal wetlands of Lake St. Clair provide spawning and nursery habitat for numerous fish species, and they play a major role in supporting regional fish populations in Lake Erie and Lake Michigan-Huron. Based on site-specific bathymetry data, the prescribed low and high water level thresholds correspond to a 40% loss in fish spawning and nursery habitat. Discussions with fisheries experts indicate that a 40% loss in spawning habitat for a period of 5 years (or longer) would significantly impair the Lake St. Clair fish community.</td><td rowspan="2">The level of uncertainty associated with this criterion is considered to be low because estimates of habitat loss are based on bathymetry data available for Lake St. Clair, as well as previous studies conducted by Goodyear et al. (1982).</td><td rowspan="2">Low sensitivity under historical and alternative NBS scenarios – no “Zone C” occurrences are predicted for 17 regulation plans under consideration, with the exception of very limited “Zone C” conditions for LSC-02 for a high supply NBS scenario for Lake Michigan-Huron.</td></tr>
<tr><td>LSC-03</td><td>Lake St. Clair</td></tr>
</table>

Table 3-2. Coping Zone Criteria Rationale, Uncertainty, & Sensitivity - Continued

Criterion Identifier	Lake Region	General Objective	Rationale	Uncertainty & Limitations	Sensitivity
ERI-01a	Lake Erie	Prevent significant loss of emergent vegetation habitat area in Long Point Bay	This set of criteria identify short- and long-term water level conditions in Lake Erie that are expected to contribute to significant (> 15%) losses in emergent wetland area, a loss in connectivity between the Inner Bay and Lake Erie (preventing fish migration), and an increase in fetch due to flooding across Long Point (affecting vegetation growth).	The level of uncertainty associated with these criteria is low to moderate. The “Zone C” thresholds and durations are derived from the application of a rules-based model of emergent wetland response to flooding and drying history. However, the rules-based model has been demonstrated to be reasonably accurate for prediction of emergent vegetation coverage.	**Very low sensitivity under historical or alternative NBS conditions** – no “Zone C” occurrences are predicted for 17 regulation plans under consideration for the historical or 11 alternative NBS scenarios with one exception: two “Zone C” occurrences are reported for ERI-01a for nearly all plans for a Michigan-Huron low supply scenario.
ERI-01b	Lake Erie				
ERI-02	Lake Erie				
ERI-03a	Lake Erie	Prevent significant loss of submerged vegetation (SAV) habitat area in Long Point Bay	“Zone C” conditions associated with the lower water level threshold were assigned to represent conditions where area suitable for SAV growth drops below 50% of the maximum area. “Zone C” conditions associated with the high water level threshold represent conditions where significant areas of SAV growth become exposed to wind/wave action as a result of flooding across Long Point spit.	The level of uncertainty associated with these criteria is low to moderate. The “Zone C” thresholds and durations are derived from the application of a rules-based model of SAV based on water depth, fetch distance, substrate, etc. However, the model has been demonstrated to provide reasonably good accuracy for prediction of SAV coverage in response to these variables.	**No sensitivity under historical or alternative NBS conditions** – no “Zone C” occurrences are predicted for 17 regulation plans under consideration for the historical or alternative NBS scenarios.
ERI-03b	Lake Erie				
ERI-04a	Lake Erie	Prevent significant loss of fish habitat area in Long Point Bay	Coping Zone classifications for fish habitat are derived from the condition of emergent/submergent vegetation (e.g., “Zone C”), as well as available water depth within the vegetation zones.	The level of uncertainty associated with these criteria is considered to be moderate. The thresholds and durations associated with “Zone C” conditions are derived from models of fish habitat supply.	**No sensitivity under historical or alternative NBS conditions** – no “Zone C” occurrences are predicted for 17 regulation plans under consideration for the historical or alternative NBS scenarios.
ERI-04b	Lake Erie				

3.4 COPING ZONE CALCULATOR

The rules developed for the Coping Zone criteria can be evaluated solely based on monthly inputs for lake water levels and flows and gate openings in the St. Marys River. Although the Coping Zone criteria are consistent with the suite of performance indicators and sub-models represented in the full IERM2 model, the rules themselves do not require as input any detailed performance indicator output from the full model. The rules for the Coping Zones were implemented in the IERM2 model, so that the model provides a complete tool for analyzing the suite of performance indicators and Coping Zone criteria. However, it was recognized that there would also be great benefit to developing a standalone “calculator” that would provide plan formulators, the Study Board, and other members of the IUGLS with a tool to efficiently run and evaluate the IERM2 Coping Zone analysis. This tool could serve as the linkage between the full IERM2 model and the Shared Vision Model (SVM), which is being used as the primary Study tool for plan evaluation and decision-making.

In order to best meet the general needs of the IUGLS, and to be consistent with the needs and format of the SVM evaluation, a “Coping Zone Calculator” was developed in a Microsoft Excel spreadsheet (Figure 3-2). The calculator is designed to accept hydrologic/hydraulic scenario plan sheets as input based on the same format used in the SVM. Rules for each Coping Zone criterion are implemented in a series of Visual Basic for Applications (VBA) macros, and a scenario can be fully evaluated for all criteria with the click of a button. Although the rules are encoded in VBA, they can be readily verified with manual checks and hand calculations to ensure that the correct results are being produced. Consistent with the approach outlined above, the rules are applied such that each year is assigned a “A”, “B”, or “C” for each zone-based criterion and a numeric result for each range compression metric. Results are reported to a scenario-specific worksheet such as that shown in Figure 3-2, with the Coping Zone criteria listed across the columns and the evaluation years listed as rows. The results are also summarized in terms of the number of occurrences of zones “A”, “B”, and “C” and mean range compression metric scores across the 109-year simulation period. Because these results are always reported and summarized in a consistent format, the results can be efficiently compared across different scenarios. The following section describes some recommended approaches for comparing and visualizing results generated by the Coping Zone Calculator.

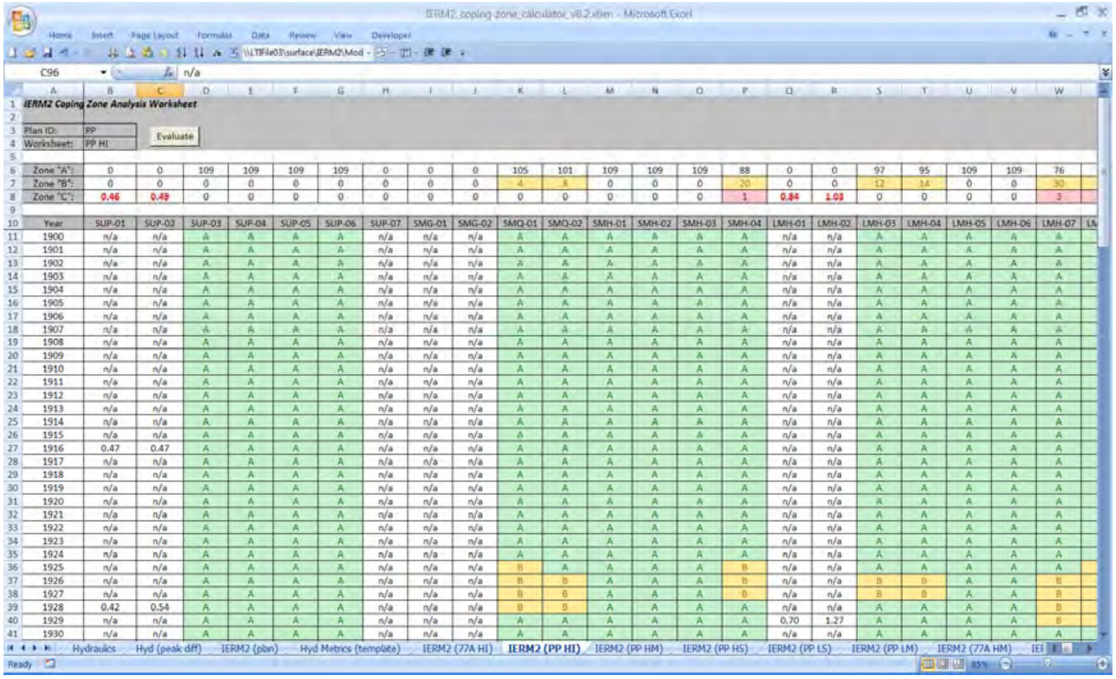


Figure 3-2. Example Worksheet for IERM2 Coping Zone Calculator

Following the initial development and testing phase, the Coping Zone Calculator was fully integrated into the SVM framework. Subsequent additions and updates have been made to the standalone version of the calculator, and these revisions have been fed forward and incorporated into the SVM and the IERM2 model code at appropriate intervals in order to maintain consistency between the different versions of the calculator.

3.5 EVALUATING SCENARIO RESULTS

Although the output generated by the Coping Zone analysis is relatively simple (i.e., “A”, “B”, or “C” ratings or metric ratios for each scenario year), there is a need for a systematic approach to comparing the results of the analysis across multiple hydrologic/hydraulic scenarios. The most straightforward approach is to compare the number of predicted “Zone C” and/or “Zone B” occurrences for a selected ‘alternative’ plan against a ‘baseline’ plan. It is recommended that the primary focus of these relative comparisons be “Zone C” occurrences for two reasons: 1) “Zone B” is of much less concern with respect to long-term degradation of the ecosystem, and 2) many of the “Zone B” definitions are somewhat arbitrarily developed based on a less strict version of the rules defined for “Zone C” (see discussion in Section 3.1). In general, “Zone B” conditions are not expected to be a cause of great concern given the resiliency demonstrated by coastal wetland ecosystems in response to historical water level fluctuations in the Upper Great Lakes.

The recommended approach for evaluating the range compression metrics is to calculate the plan-to-PreProject ratio for each raw metric for each plan. Ideally, ratios should be calculated and evaluated for each individual “peak year” or “post-peak drawdown event"; however, an average ratio calculated across all peak/drawdown events within a 109-year simulation period can be used to provide a summary of how well a given plan reproduces natural water level ranges (as indicated by Pre-Project). The closer a plan-to-PreProject ratio is to a value of 1.0, the better that regulation plan maintains the system's naturally occurring high water level and post-peak drawdown conditions.

With respect to summarizing the "Zone C" results for two plans, the 'alternative' plan can be simply rated by the following:

- **"Better" –** if it has less "Zone C" occurrences than the 'baseline' plan;
- **"Same" –** if it has the same number of "Zone C" occurrences as the 'baseline' plan; and
- **"Worse" –** if it has more "Zone C" occurrences than the 'baseline' plan.

These ratings should be applied to each individual Coping Zone criterion, and the individual criteria should be examined to help understand why and when impacts are occurring. Based on the detailed (i.e., time series) reporting and the summaries obtained from the analysis, the performance of one plan relative to another with respect to ecosystem impacts can be assessed across the full suite of zone-based Coping Zone criteria.

A modified version of the IERM2 target diagram was developed to visualize Coping Zone criteria evaluation results. The Coping Zone target diagram, which can be accessed by selecting the "Coping Zones" plot type in the IERM2 interface, allows the user to plot the results of the analysis for the suite of criteria for user-specified 'baseline' and 'alternative' hydrologic/hydraulic scenarios (Figure 3-3). Consistent with the approach proposed above, the criteria are rated based on the number of "Zone C" occurrences that are calculated for the "alternative" scenario relative to the "baseline" scenario:

- Points that are plotted inside the green circle indicate that there are fewer "Zone C" occurrences (or a higher score for a range compression metric) for the 'alternative' scenario relative to the 'baseline' scenario (rating of "Better");
- Points that are plotted between the two yellow concentric circles indicate that the number of "Zone C" occurrences (or the range compression metric) is identical for the two scenarios (i.e., rating of "Same"); and
- Points that are plotted between the two red concentric circles indicate that there are a greater number of "Zone C" occurrences (or a lower score for a range compression metric) for the 'alternative' scenario (rating of "Worse").

Although the target diagram shown in Figure 3-3 is specific to the IERM2 model, tabular or graphical summaries of the same information are being developed in the Shared Vision Model to support the relative comparison of alternative regulation plans for a range of basin supply scenarios.

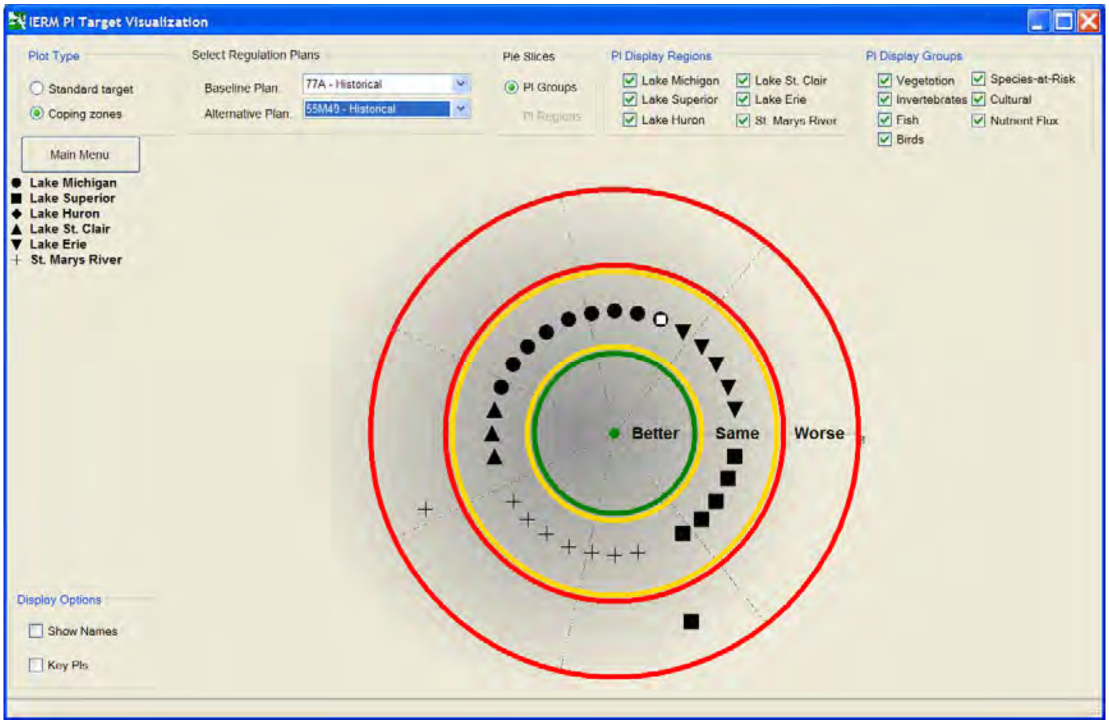


Figure 3-3. IERM2 Target Diagram for Coping Zones

4. IERM2 PRELIMINARY APPLICATION

The process of developing and evaluating alternative regulation plans and plausible future net basin supply scenarios is ongoing as of the writing of this report (June 2011). Therefore, it was not possible to produce a final comprehensive evaluation of regulation plans and basin supply conditions with the IERM2 model for this report. In lieu of a complete application of the modeling framework, a preliminary application was conducted for the purpose of demonstrating the utility of the IERM2 Coping Zone analysis and likely outcomes for key hydrologic/hydraulic scenarios. This chapter presents and discusses the results of the IERM2 Coping Zone analysis for the following scenarios:

- Pre-Project and Plan 77A, as applied to historical supply conditions (for the 1900-2008 period);
- Fifteen alternative Lake Superior regulation plans, as applied to historical supply conditions; and
- Pre-Project, Plan 77A, and fifteen alternative plans applied to 9 stochastic supply scenarios.

The results and analysis presented in this chapter can be considered as representative of outcomes for the IERM2 Coping Zone analysis for the current set of regulation plans and net basin supply scenarios. However, the findings based on the current suite of hydrologic/hydraulic scenarios should be considered as preliminary given that regulation plans and supply scenarios were still under development at the time of the writing of this report.

4.1 EVALUATION OF PRE-PROJECT (HISTORICAL SUPPLIES)

The IERM2 Coping Zone Calculator was run for two Pre-Project "plans" as applied to historical (1900-2008) net basin supply conditions. Two versions of Pre-Project were evaluated: 1) *with* the Long Lac and Ogoki (LLO) diversions, and 2) *without* the LLO diversions. The Pre-Project case with diversions represents the Upper Great Lakes system as it would have been historically if regulation at Sault Ste. Marie did not occur. The case without diversions represents a completely natural (i.e., no human impact) water level condition for Lake Superior; however, water levels for the lake systems below Lake Superior (Michigan-Huron, Lake St. Clair, and Erie) are not completely natural because the Chicago Area Waterways (CAWS) diversions is still represented in this case. Therefore, neither Pre-Project case represents true "natural" water level conditions for Lake Michigan-Huron and the downstream lakes and connecting channels.

"Zone C" results are summarized in Table 4-1 for both Pre-Project cases. There are no "Zone C" occurrences reported for Lake Superior, Lake St. Clair, or Lake Erie for either Pre-Project scenario. For the Pre-Project case with diversions, there are minimal occurrences of "Zone C" for the St. Marys River backwater fish spawning habitat criterion (SMH-04) and for the low water criteria developed for Georgian Bay wetlands (LMH-07, LMH-08). For criterion SMH-04, “Zone C” conditions are reported for just a single year (1964) where drought conditions reduced the Lake Huron annual average water level just below 176.0 meters. “Zone C” occurrences for the LMH-08 criterion are not directly relevant for the 1900-2008 historical period because this criterion represents circumstances following 50 years of glacial isostatic adjustment (GIA) relative to the present-day status of the wetlands (see Section 3.1 for related discussion). The “Zone C” occurrences for LMH-07, which represents the “present-day” Georgian Bay criterion, occur primarily during the severe drought period associated with the 1930s (as well as year 1966). It is important to note that due to GIA the land surface and wetland outlets in the 1930s would have been approximately 20 cm lower relative to the Lake Huron outlet, as compared to present-day conditions. Therefore, low water level conditions experienced during the actual 1930s drought period would not have resulted in a “Zone C” condition at that time. Given this context, the results obtained for the Pre-Project case with no diversions are consistent with the expectations of minimal “Zone C” occurrences for the 1900-2008 historical period.

The results for the pre-project “no LLO diversion” case are generally similar to those for the “with LLO diversions case”. Again, there are no “Zone C” occurrences for Lake Superior, Lake St. Clair, or Lake Erie. Criteria SMH-04, LMH-07, and LMH-08 all have “Zone C” occurrences, as they do for the “with LLO diversion” case, and there is also one “Zone C” occurrence reported for St. Marys criterion SMQ-02. The caveats discussed above for criteria LMH-07 and LMH-08 apply for this scenario as well. The removal of the LLO diversion inputs effectively lowers Lake Michigan-Huron mean monthly water levels by an average of 11 cm, which is sufficient to trigger some additional “Zone C” occurrences for SMH-04, LMH-07, and LMH-08. However, it is important to note that the LLO inflow diversions have historically offset the impact of the Chicago outflow diversion on Lake Michigan-Huron water levels. The Chicago diversion results in a long-term decrease of 6 cm in Lake Michigan-Huron water levels (IJC 1993), which means that removing only the LLO diversions results in Michigan-Huron water levels being 5 cm lower than would occur for a “no diversions” scenario (i.e., the true natural condition). Although a true natural water level scenario for Michigan-Huron has not been run through the Coping Zone Calculator, an adjustment of +5 cm would be expected to eliminate a number of the additional “Zone C” occurrences that are reported in Table 1 for the “no LLO diversion” case.

It should be noted that the two St. Marys River criteria (SMG-01, SMG-02) that are based on gate settings for the Compensating Works cannot be evaluated for scenarios based on “Pre-Project” because gate information is not generated for these scenarios. When gate information is not available, the Coping Zone Calculator reports “n/a” and results are not tabulated for criteria SMG-01 and SMG-02.

Table 4-1. Coping Zone Analysis for Pre-Project Cases Based on Historical Net Basin Supplies (1900-2008)

Region	Pre-Project (**with** LLO diversions)		Pre-Project (**without** LLO diversions)	
	Criteria with "Zone C"s	Count of "Zone C" Years	Criteria with "Zone C"s	Count of "Zone C" Years
Lake Superior	(none)		(none)	
St. Marys River	SMH-04	1	SMQ-02 SMH-04	1 5
Michigan-Huron / Georgian Bay	LMH-07 LMH-08	3 6	LMH-07 LMH-08	5 19
Lake St. Clair	(none)		(none)	
Lake Erie	(none)		(none)	

4.2 EVALUATION OF PLAN 77A (HISTORICAL SUPPLIES)

The IERM2 Coping Zone Calculator was run for the "Plan 77A" regulation plan as applied to historical (1900-2008) net basin supply conditions. The "Zone C" results for Plan 77A are summarized in Table 4-2. There are no "Zone C" occurrences reported for Lake Superior, Lake St. Clair, or Lake Erie for Plan 77A. Criteria SMH-04, LMH-07, and LMH-08 have the same number of "Zone C" occurrences as for the Pre-Project (no diversion) case, and these results were discussed in Section 4.1. For the St. Marys River, criterion SMQ-01 has one additional "Zone C" occurrence relative to the Pre-Project case. Criterion SMQ-01 identifies "Zone C" as conditions where flow in the St. Marys River during the month of June is insufficient (< 1,700 m^3/s) to promote lake sturgeon spawning in the River for 5 consecutive years. For Plan 77A, flows of less than 1,700 m^3/s occur during the 5-year period of 1922-1926. By comparison, the Pre-Project case generates flows below this threshold for only a 4-year period (1923-1926).

Table 4-2. Coping Zone Analysis for Plan 77A Based on Historical Net Basin Supplies (1900-2008)

Region	Criteria with "Zone C"s	Count of "Zone C" Years	Change in "Zone C" Years Relative to Pre-Project (*with diversions*)
Lake Superior	(none)		
St. Marys River	SMQ-01	1	1 additional "Zone C"
	SMH-04	1	(no change)
Michigan-Huron / Georgian Bay	LMH-07	3	(no change)
	LMH-08	6	(no change)
Lake St. Clair	(none)		
Lake Erie	(none)		

As discussed earlier in this section, the range compression metrics for Lake Superior (SUP-01, SUP-02) and Lake Michigan-Huron (LMH-01, LMH-02) can be conveniently expressed as ratios by using the Pre-Project scenario as a benchmark for natural water level range conditions. The range compression metrics generate results for only a subset of years within a 109-year simulation period – i.e., when peak water level conditions and subsequent drawdown events are identified for the Pre-Project case. Ratios for each metric are calculated simply by dividing the raw metric score for a given plan and NBS scenario by the Pre-Project metric score for that same NBS scenario. Figures 4-1 and 4-2 show the Plan 77A ratios for the SUP-01 and SUP-02 metrics, respectively, for individual "peak" years and post-peak time periods where significant drawdown events occur based on the Pre-Project scenario. Figure 4-3 compares the mean ratios across the 109-year period for Plan 77A for all four range compression metrics. These results suggest that relative to the natural condition, Plan 77A has reduced the magnitude of Lake Superior peak water levels and post-peak drawdown events on average by approximately 20% and 30%, respectively. By comparison, the impact of Plan 77A on Lake Michigan-Huron peak water levels and post-peak drawdown events is minimal. This is expected because the regulation of Lake Superior generally has only a very small effect on long-term water level fluctuations in Lake Michigan-Huron.

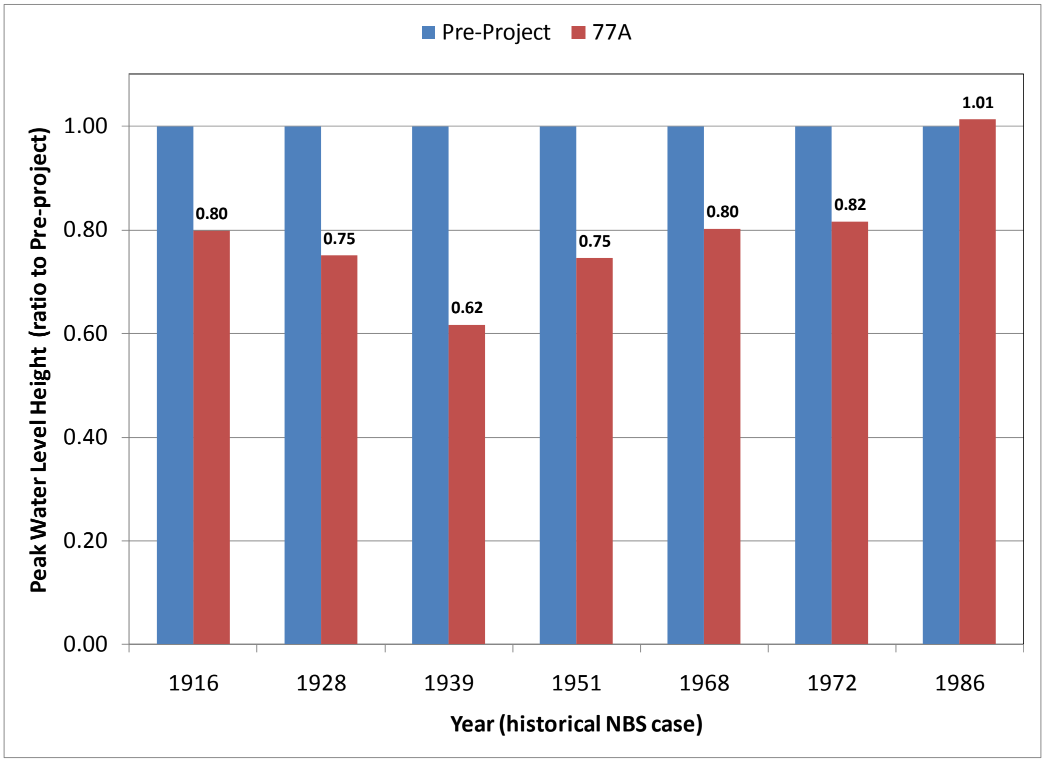


Figure 4-1. Comparison of SUP-01 Criterion Metric Results for Plan 77A and Pre-Project (Historical Net Basin Supply Scenario)

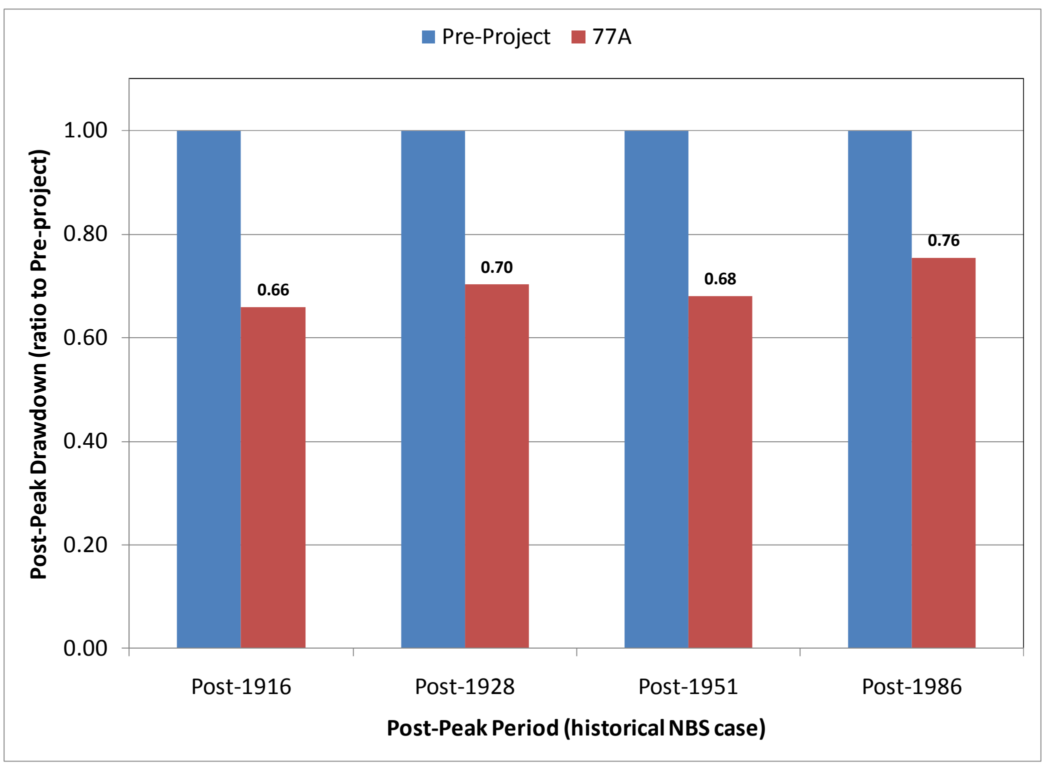


Figure 4-2. Comparison of SUP-02 Criterion Metric Results for Plan 77A and Pre-Project (Historical Net Basin Supply Scenario)

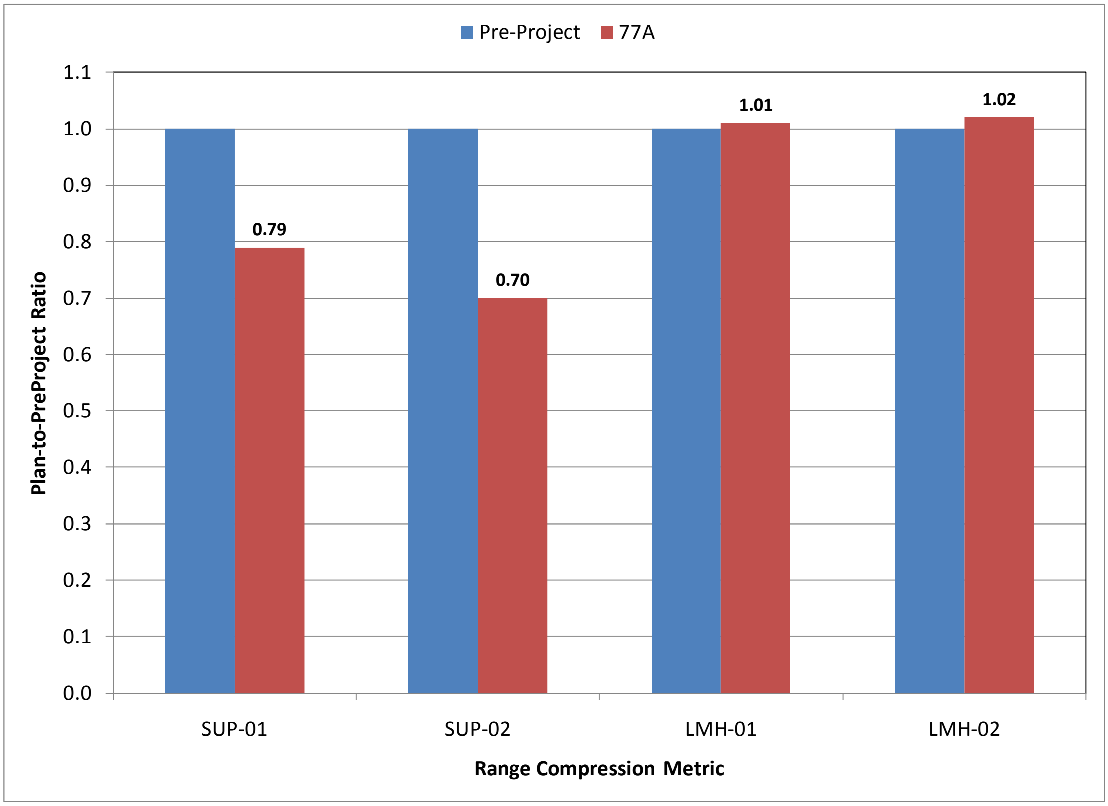


Figure 4-3. Comparison of Range Compression Metric Results for Plan 77A and Pre-Project

4.3 EVALUATION OF ALTERNATIVE PLANS (HISTORICAL SUPPLIES)

With respect to summarizing the "Zone C" results for two plans, an 'alternative' plan can be evaluated against a 'baseline' plan (e.g., 77A) by tabulating 1) the increase/decrease in "Zone C" occurrences for each of the 29 zone-based criterion, and 2) the plan-to-PreProject ratios for the four range compression metrics. A preliminary Coping Zone analysis was conducted for a suite of alternative regulation plans that have been developed to date for the IUGLS. In addition to the Plan 77A historical scenario, the Coping Zone Calculator was run for the following regulation plans available in the SVM as of early June 2011 (note that all plans were applied to the historical supply conditions for 1900-2008):

- "Pre-Project" (PP),
- "77B",
- "122", "123", "124", "125", "126", "127", "128", "129", "130",
- "55M49",
- "Nat60",
- "PFN3", and

- "Bal25".

The annual results of the Coping Zone analyses for all of these alternative plans are too detailed to report here. However, as described above, the results for the 29 zone-based criteria can be readily summarized by comparing the number of "Zone C" occurrences for each alternative plan against the number of "Zone C" occurrences reported for Plan 77A (consistent with the approach recommended above). Table 4-3 provides a summary of these comparisons against Plan 77A. It should be noted that only three of the Coping Zone criteria (SMQ-01, LMH-07, LMH-08) shown in this table are sensitive to the choice of regulation plan (i.e., have a different number of "Zone C" occurrences for any plan relative to 77A) for the historical NBS scenario.

Table 4-3. Comparison of "Zone C" Occurrences for Regulation Plans Relative to Plan 77A (based on historical net basin supplies)[1]

Criteria ID [2]	PP	77B	122, 124-128	129	130, 123	55M49	Nat60	PFN3	Bal25
SUP-03, SUP-04, SUP-05, SUP-06	0	0	0	0	0	0	0	0	0
SMG-02	0	0	0	0	0	0	0	0	0
SMQ-01	+1	0	0	+1	0	0	0	+1	+1
SMQ-02	0	0	0	0	0	0	0	0	0
SMH-01, SMH-02, SMH-03, SMH-04	0	0	0	0	0	0	0	0	0
LMH-01, LMH-02, LMH-03, LMH-04, LMH-05, LMH-06	0	0	0	0	0	0	0	0	0
LMH-07	0	0	+1	+1	+1	0	0	+1	+1
LMH-08	0	0	0	+1	+1	0	0	+1	-1
LMH-09	0	0	0	0	0	0	0	0	0
LSC-01, LSC-02, LSC-03	0	0	0	0	0	0	0	0	0
ERI-01a, ERI-01b, ERI-02, ERI-03a, ERI-03b, ERI-04a, ERI-04b	0	0	0	0	0	0	0	0	0

[1] Negative values shown in red indicate the number of additional "Zone C" occurrences that are reported for a given plan relative to Plan 77A. Positive values shown in green indicate how many less "Zone C" occurrences are reported for a given plan relative to Plan 77A. Empty cells indicate no change in "Zone C" conditions for a criterion relative to Plan 77A.

[2] Coping Zone criteria that are sensitive to choice of regulation plan (for historical supplies) are shown in bold.

Plan-to-PreProject ratio results for the four range compression criteria are summarized in Table 4-4. These results represent the average of all ratios generated for the 109-year hydrologic/hydraulic simulation associated with each regulation plan for the historical NBS scenario. Green and red cells in Table 4-4 are used to highlight the more significant differences for alternative plans relative to Plan 77A as follows:

- Green cells indicate average ratios that are more than 5% *closer to* the Pre-Project benchmark ratio (of 1.0) relative to Plan 77A; and
- Red cells indicate average ratios that are more than 5% *further away from* the Pre-Project benchmark ratio (of 1.0) relative to Plan 77A.

Table 4-4. Comparison of Range Compression Metric Ratios for Regulation Plans (based on historical net basin supplies)[1]

Criteria ID	77A	PP	77B	122, 124-128	129	130	55M49	Nat60	PFN3	Bal25
SUP-01	0.79	1.00	0.89	~ 0.81	0.80	0.79	0.77	0.85	0.67	0.90
SUP-02	0.70	1.00	0.85	0.77	0.76	0.75	0.70	0.80	0.57	0.93
LMH-01	1.01	1.00	1.01	0.98	0.98	0.98	1.08	0.99	1.01	0.99
LMH-02	1.02	1.00	1.02	0.95	0.96	0.98	1.14	0.99	1.00	0.99

[1] Values highlighted in green indicate ratios that are more than 5% closer to the Pre-Project (PP) benchmark (ratio = 1.0) relative to Plan 77A ratio. Values highlighted in red indicate ratios that are more than 5% further away from the PP benchmark relative to the Plan 77A ratio.

Based on the summary results in Tables 4-3 and 4-4, the performance of the regulation plans with respect to the IERM2 Coping Zone criteria and range compression metrics can be summarized as follows:

- Only three Coping Zone "zone-based" criteria currently demonstrate sensitivity to the choice of regulation plan for the historical NBS scenario: lake sturgeon spawning in the St. Marys River (SMQ-01), and the two criteria related to eastern Georgian Bay wetland connectivity and vegetation (LMH-07, LMH-08).
- In general, alternative plans to Plan 77A either generate fewer "Zone C" occurrences or demonstrate no difference in the number of "Zone C" occurrences. (The only exception is plan "Bal25", which incurs one additional "Zone C" occurrence for criterion LMH-08.)
- In terms of minimizing compression of the water level range in Lake Superior, several alternative plans appear to perform better than Plan 77A. Specifically, plans 77B, Nat60, and Bal25 all have SUP-01 and SUP-02 ratios that are more than 5% closer to Pre-Project than Plan 77A. Plan "Bal25" in particular significantly improves the SUP-02 metric. Plan "PFN3" is the only plan shown in Table 4-4 that appears to compress the Lake Superior water level range more than Plan 77A. This characteristic makes plan "PFN3" undesirable from an ecological perspective despite the fact that it decreases the number of "Zone C" occurrences for several of the zone-based criteria.
- In general, Plan 77A and alternative plans have little impact on Lake Michigan-Huron water level ranges relative to the Pre-Project benchmark.

However, plan "55M49" actually increases the magnitude of both periodic peak water levels and post-peak drawdown events, an effect that may also be undesirable for the ecosystem.

In summary, the results for the historical NBS scenario suggest that there are limited differences between alternative regulation plans in terms of "Zone C" conditions. However, some alternative plans demonstrate a relatively significant increase in the Lake Superior water level range (i.e., towards a more natural condition) relative to Plan 77A.

4.4 EVALUATION OF ALTERNATIVE SUPPLY CONDITIONS

As discussed in previous chapters, an important objective of the overall IERM2 model, and the Coping Zone Calculator in particular, is to support an analysis of alternative net basin supply (NBS) conditions. Alternative NBS conditions are being developed through the Study through multiple approaches, including:

1. Stochastic simulations that generate long time series (e.g., 50,000 years) of synthetic monthly water level and flow conditions based on what has been observed during the historical period of record (i.e., 1900-2008); and
2. Climate change simulations that predict water level and flow conditions that may occur in the short-term or long-term as a result of climate change. These simulations are derived from the results of Regional Climate Models (RCMs) that are linked to Global Climate Models (GCMs) (MacKay et al. 2008, Lofgren 2004).

At that time this report was developed, 12 NBS scenarios (i.e., 109-year sequences of monthly net basin supplies) had been imported into the SVM and evaluated for 15 candidate regulation plans in addition to Pre-Project and Plan 77A. That set of NBS scenarios includes the following:

- "HI" – historical (actual monthly net basin supplies for 1900-2008);
- "LS" – stochastic period with the lowest overall NBS for Lake Superior;
- "HS" – stochastic period with the highest overall NBS for Lake Superior;
- "LM" – stochastic period with the lowest overall NBS for Lake Michigan-Huron;
- "HM" – stochastic period with the highest overall NBS for Lake Michigan-Huron;
- "DS" – "dry" stochastic period;
- "WS" – "wet" stochastic period;
- "LR" – "low range" stochastic period;
- "AT" – climate change scenario "aet" (simulation run with Canadian Regional Climate Model); and

- "AV" – climate change scenario "aev" (simulation run with Canadian Regional Climate Model).

The ten NBS scenarios listed above were used to run a complete suite of simulations for each of the regulation plans listed in Section 4.3. (Note that two NBS scenarios ("T1" and "T2") are excluded from the above list because they generate erroneous water level simulation results for Lake Superior.)

To provide an illustrative comparison, Coping Zone analysis results for alternative regulation plans "55M49" and "77B" are summarized in Table 4-5, with detailed results provided in Table 4-6 and Table 4-7, respectively. The results in these tables are specific to each individual Coping Zone criterion (shown in rows) and alternative NBS scenario (shown in columns). The first four rows of each table report the difference in the range compression ratios for each candidate plan relative to Plan 77A. Green highlighting is used to indicate range compression ratios that are more than 5% *closer to* Pre-Project as compared to the Plan 77A ratio. Likewise, red highlighting is used to indicate range compression ratios that are more than 5% *further away* from Pre-Project as compared to Plan 77A. Note that in some cases for Lake Michigan-Huron, a regulation plan may produce a larger range than would occur naturally, as defined by Pre-Project. The remainder of the rows in Tables 4-6 and 4-7 provide the results for the 29 zone-based criteria. Negative values shown in red indicate that there are *more* "Zone C" occurrences for the alternative regulation plan relative to Plan 77A, and negative values shown in green indicate that there are *fewer* "Zone C" occurrences for the alternative regulation plan relative to Plan 77A.

Table 4-5. Summary Comparison for Plans "55M49" and "77B" to Plan 77A

Criteria Category	Plan "55M49"	Plan "77B"
Lake Superior range compression	Significantly worse than 77A for most alternative NBS scenarios	Significantly better than 77A for all alternative NBS scenarios
Lake Superior "Zone C"s	One fewer "C" for SUP-05; no change otherwise	No change from 77A
St. Marys River "Zone C"s	More "C"s for criteria SMQ-01, SMQ-02, SMH-04 (for most alternative NBS scenarios)	Similar to 77A overall, but fewer "C"s for SMQ-01, SMH-04 for some NBS scenarios
Michigan-Huron "Zone C"s	Mixed results for "C"s in Georgian Bay (LMH-07, LMH-08)	Mixed results for "C"s in Georgian Bay (LMH-07, LMH-08)
Lake St. Clair "Zone C"s	No change from 77A	No change from 77A
Lake Erie "Zone C"s	No change from 77A	No change from 77A

Regulation plans "55M49" and "77B" appear to behave similarly for the historical NBS case for zone-based criteria, although plan "77B" performs significantly better on the Lake Superior range compression metrics than "55M49". However, evaluating the two plans across the nine alternative NBS scenarios shown in Tables 4-6 and 4-7 suggests that the two plans perform quite differently for some of the Coping Zone criteria. As indicated in Table 4-5, "77B" performs better than "55M49" in terms of reducing Lake Superior range compression across alternative NBS scenarios, similar to the historical NBS case. However, the results for the nine alternative NBS scenarios also indicate that “55M49” is likely to increase “Zone C” occurrences for several St. Marys River criteria relative to 77A, while “77B” performs similarly to Plan 77A for the St. Marys River criteria, with some potential improvements. The Coping Zone criteria for Lake St. Clair and Lake Erie do not demonstrate sensitivity to choice of regulation plan in this case. Of the Lake Michigan-Huron criteria, only the eastern Georgian Bay criteria demonstrate sensitivity, with mixed results obtained for both “77B” and “55M49” and the outcome dependent on the specific NBS scenario.

The results reported in Tables 4-5, 4-6, and 4-7 and the above analysis provide a demonstration of how the results of the IERM2 Coping Zone Calculator can be used to evaluate the relative benefits and drawbacks of alternative regulation plans when compared against Plan 77A (or another baseline plan, such as Pre-Project) across one or more NBS scenarios. The results and findings presented in this section for plans “55M49” and “77B” should be considered preliminary at this point pending final verification of the Coping Zone Calculator results. However, the comparison between these two plans highlights the importance of evaluating the robustness of candidate regulation plans across multiple NBS scenarios, as opposed to focusing on only the historical NBS scenario. In this particular case, plan “55M49” appears to perform equally well to Plan 77A and “77B” for zone-based criteria when applied to the historical NBS case; however, differences emerge when comparing the three plans across a set of plausible alternative NBS scenarios.

Table 4-6. Regulation Plan "55M49" Coping Zone Analysis for Alternative Net Basin Supply Scenarios [1]

Coping Zone ID [2]	HI	LS	HS	LM	HM	DS	WS	LR	AT	AV
SUP-01	-0.02	-0.11	-0.11	-0.13	-0.01	-0.11	-0.11	-0.06	0.00	-0.07
SUP-02	0.00	-0.03	-0.11	-0.02	-0.08	-0.17	-0.10	-0.05	0.06	0.01
LMH-01	0.06	0.03	0.03	0.04	0.05	0.03	0.05	0.05	0.03	0.03
LMH-02	0.11	0.09	0.01	0.13	0.07	n/a	0.10	n/a	n/a	0.09
SUP-03	0	0	0	0	0	0	0	0	0	0
SUP-04	0	0	0	0	0	0	0	0	0	0
SUP-05	0	0	+1	0	0	0	0	0	0	0
SUP-06	0	0	0	0	0	0	0	0	0	0
SMG-01	0	0	0	0	0	0	0	0	0	0
SMG-02	0	0	0	0	0	0	0	0	0	0
SMQ-01	0	0	0	-2	-7	-12	0	0	0	-2
SMQ-02	0	-6	-3	-6	-1	-1	-1	-2	0	0
SMH-01	0	0	0	0	0	0	0	0	0	0
SMH-02	0	0	0	0	0	0	0	0	0	0
SMH-03	0	0	0	0	0	0	0	0	0	0
SMH-04	0	-2	0	0	-3	-1	0	0	0	-1
LMH-03	0	0	0	0	0	0	0	0	0	0
LMH-04	0	0	0	0	0	0	0	0	0	0
LMH-05	0	0	0	0	0	0	0	0	0	0
LMH-06	0	0	0	0	0	0	0	0	0	0
LMH-07	0	+1	0	0	0	+1	-1	0	-1	0
LMH-08	0	-1	0	0	-3	0	0	-3	0	0
LMH-09	0	0	0	0	0	0	0	0	0	0
LSC-01	0	0	0	0	0	0	0	0	0	0
LSC-02	0	0	0	0	0	0	0	0	0	0
LSC-03	0	0	0	0	0	0	0	0	0	0
ERI-01a	0	0	0	0	0	0	0	0	0	0
ERI-01b	0	0	0	0	0	0	0	0	0	0
ERI-02	0	0	0	0	0	0	0	0	0	0
ERI-03a	0	0	0	0	0	0	0	0	0	0
ERI-03b	0	0	0	0	0	0	0	0	0	0
ERI-04a	0	0	0	0	0	0	0	0	0	0
ERI-04b	0	0	0	0	0	0	0	0	0	0

[1] Negative values shown in red indicate the number of additional "Zone C" occurrences that are reported for Plan "55M49", or range compression ratios that are 5% lower, relative to Plan 77. Positive values shown in green indicate how many less "Zone C" occurrences are reported for Plan "55M49", or range compression ratios that are 5% closer to Pre-Project than the Plan 77A ratio. Values of zero for zone-based criteria indicate no change in "Zone C" occurrences relative to Plan 77A.

[2] Range compression metrics are shown in bold in the first four rows, with the zone-based criteria listed below those rows. Values of "n/a" indicate that the metric is not calculated for a given NBS scenario.

Table 4-7. Regulation Plan "77B" Coping Zone Analysis for Alternative Net Basin Supply Scenarios [1]

Coping Zone ID [2]	HI	LS	HS	LM	HM	DS	WS	LR	AT	AV
SUP-01	0.10	0.08	0.11	0.07	0.10	0.06	0.09	0.09	0.10	0.07
SUP-02	0.15	0.05	0.10	0.09	0.10	0.09	0.10	0.09	0.12	0.07
LMH-01	0.00	-0.01	-0.02	-0.01	0.00	0.00	-0.01	0.01	-0.01	-0.01
LMH-02	-0.01	-0.02	-0.06	-0.02	-0.01	n/a	-0.02	n/a	n/a	0.01
SUP-03	0	0	0	0	0	0	0	0	0	0
SUP-04	0	0	0	0	0	0	0	0	0	0
SUP-05	0	0	0	0	0	0	0	0	0	0
SUP-06	0	0	0	0	0	0	0	0	0	0
SMG-01	0	0	0	0	0	0	0	0	0	0
SMG-02	0	0	0	0	0	0	0	0	0	0
SMQ-01	0	0	0	0	0	0	0	0	0	0
SMQ-02	0	0	0	0	+2	0	0	0	0	0
SMH-01	0	0	0	0	0	0	0	0	0	0
SMH-02	0	0	0	0	0	0	0	0	0	0
SMH-03	0	0	0	0	0	0	0	0	0	0
SMH-04	0	0	+1	0	+3	0	0	0	0	0
LMH-03	0	0	0	0	0	0	0	0	0	0
LMH-04	0	0	0	0	0	0	0	0	0	0
LMH-05	0	0	0	0	0	0	0	0	0	0
LMH-06	0	0	0	0	0	0	0	0	0	0
LMH-07	0	+1	0	0	0	-4	0	0	0	0
LMH-08	0	0	0	0	0	0	0	0	0	-1
LMH-09	0	0	0	0	0	0	0	0	0	0
LSC-01	0	0	0	0	0	0	0	0	0	0
LSC-02	0	0	0	0	0	0	0	0	0	0
LSC-03	0	0	0	0	0	0	0	0	0	0
ERI-01a	0	0	0	0	0	0	0	0	0	0
ERI-01b	0	0	0	0	0	0	0	0	0	0
ERI-02	0	0	0	0	0	0	0	0	0	0
ERI-03a	0	0	0	0	0	0	0	0	0	0
ERI-03b	0	0	0	0	0	0	0	0	0	0
ERI-04a	0	0	0	0	0	0	0	0	0	0
ERI-04b	0	0	0	0	0	0	0	0	0	0

[1] Negative values shown in red indicate the number of additional "Zone C" occurrences that are reported for Plan "77B", or range compression ratios that are 5% lower, relative to Plan 77. Positive values shown in green indicate how many less "Zone C" occurrences are reported for Plan "77B", or range compression ratios that are 5% closer to Pre-Project than the Plan 77A ratio. Values of zero for zone-based criteria indicate no change in "Zone C" occurrences relative to Plan 77A.

[2] Range compression metrics are shown in bold in the first four rows, with the zone-based criteria listed below those rows. Values of "n/a" indicate that the metric is not calculated for a given NBS scenario.

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5. NEXT STEPS FOR IERM2 FRAMEWORK

Because the Planning Formulation and Evaluation Group (PFEG), the Adaptive Management Working Group (AMWG), and the Study Board will continue to develop and evaluate regulation plan/basin supply scenarios over the next several months, LimnoTech will continue to act as a liaison between these groups and the ETWG by continuing to run new scenarios as they are developed through the IERM2 model and share the results with the ETWG and Site Coordinators. Based on the results for new scenarios, the Site Coordinators and other ecological scientists within ETWG can evaluate and interpret the results, and then provide comments and questions to the PFEG, the AWMG, and the Study Board as necessary and appropriate.

The version of the Coping Zone Calculator presented in this report has been integrated into the SVM as the environmental response component of that decision support tool. As new scenarios are developed and results are reviewed, there may be required revisions to the Calculator (either being recommended by the Shared Vision Action Team or by ETWG). If necessary, LimnoTech will make the appropriate revisions and work with members of the Shared Vision Action Team to integrate those revisions into the SVM.

Moving forward through the remainder of the Study and beyond, it is envisioned that the IERM2 framework can be used as an effective tool to help inform and facilitate Adaptive Management of water level regulation for the Upper Great Lakes system. The role of the IERM2 framework in supporting the Adaptive Management process and specific recommendations for monitoring based on current IERM2 results are discussed in Chapter 6.

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6. ADAPTIVE MANAGEMENT RECOMMENDATIONS

In addition to its primary role of quantifying the relationships between alterations of water level and flow regime (either natural or human regulated) and key indicators of the ecological response of nearshore ecosystems in the Upper Great Lakes, the IERM2 provides a framework for integrating the available data and knowledge of the ETWG and ecological site researchers into a representation of what is known (and unknown) about the effects of hydrologic regimes on nearshore ecosystems. Thus, the IERM2 model development and application process can be used to inform the Adaptive Management (AM) process for the Upper Great Lakes developed by the Adaptive Management Workgroup (AMWG 2010). AM is an important feature of effectively managing Upper Great Lakes coastal ecosystems because:

1. There is considerable uncertainty concerning the nature and extent of future changes in water level and flow regime (e.g., resulting from climate change);
2. There is uncertainty about future socio-economic conditions that may affect future environmental service demands on the Great Lakes; and
3. Insufficient ecological data and theory exist to fully understand and predict ecosystem changes resulting from future alterations in water level and flow regime (i.e., magnitude, timing, and duration).

The IERM2 framework can support the IUGLS AM process with respect to ecological responses in two ways. First, it can provide a prediction of how coastal ecosystems will respond to the selected regulation plan applied to a forecasted long-term basin supply scenario. This model prediction will identify the most sensitive ecological areas and components relative to potential adverse impacts, thus guiding the post-implementation monitoring that will feed into the next iteration of the AM process. Second, and perhaps more importantly, the results and relative uncertainty analysis obtained from the current model, which is summarized in Table 3-2 of this report, can be used to focus the limited resources available for monitoring on specific components of the ecosystem and hydrologic/hydraulic conditions where adverse impacts are likely to be most significant and detectable and most uncertain. In both processes additional monitoring data can in turn be used to revise and update the ecological responses represented in the IERM2 framework to provide improved predictive capability. In this way, the model can be updated and improved in an iterative fashion as part of the overall AM process.

In an effort to initially support the AM process described above, ETWG and the Site Coordinators have worked with LimnoTech to review and evaluate the data used to develop the current version of the IERM2 model and its application output. The review and evaluation process considered identifying those ecological components that are most sensitive to water level regime conditions, those that are most representative of ecosystem change, and those that are potentially most vulnerable to changing water level regimes. Then among those components that meet these criteria, the relative uncertainties in predicted responses were also evaluated. As indicated in Table 3-2, the coastal ecosystem components and associated water level objectives that meet the sensitivity and uncertainty criteria are:

- Avoid range compression in Lake Superior as a means of maintaining coastal wetland vegetation integrity and diversity – the quantitative relationship between magnitude of range compression and impact on wetland vegetation diversity is uncertain;
- Periodically (at least once every 5 years) maintain sufficient flow (> 1700 m^3/s) in the St. Marys River during June to provide suitable spawning habitat conditions for lake sturgeon – uncertainty relative to this component is relatively low;
- Maintain sufficient fish spawning habitat (not more than 30% loss of current habitat area) in St. Marys River backwater region of Lake Huron – the fish recruitment impact of a 30% loss in habitat is uncertain; and
- Maintain fish habitat (i.e., vegetation conditions) and access (i.e., connectivity) in eastern Georgian Bay wetlands by maintaining sufficient water exchange with the main bay – uncertainty is relatively low regarding the adverse impact concern, but ongoing monitoring of the response is warranted.

Given the ecological importance of coastal wetlands in the Great Lakes and the understood conceptual importance of wetland vegetation to the structure and functioning of the entire ecosystem, ETWG developed the physical and biological data acquisition and monitoring recommendations presented below to best support the Study's Adaptive Management process.

Acquisition and use of better hydrologic data are essential to support the Adaptive Management process for Great Lakes water levels and flows. Specifically, we recommend the following:

- Improved measurement of Great Lakes hydrologic components, including evaporation, lake surface precipitation, lake water levels, 3D water temperature, and major tributary flows will greatly facilitate better model forecasts of net basin supplies and associated water levels and connecting channel/St. Lawrence River flows; and
- Development of a data management and communication (DMAC) system within the Great Lakes to provide coastal and floodplain managers access to model forecasts in a timely and usable way, so that this information can inform water regulation planning.

Because wetland vegetation is very sensitive to water level regime and because most wetland faunal components respond to the vegetation changes at some level, the ETWG has reached a consensus that wetland vegetation type and spatial extent is a key ecological performance indicator to monitor relative to water level regime stressors. That being the case, it would be desirable to obtain good quality infrared air photos on a five year rotating cycle, including coverage of the entire Great Lakes shoreline. This work could be coordinated with the five-lake Cooperative Science and Monitoring Initiative (CSMI) so that each lake is flown during its CSMI intensive field year. The photointerpretation and ground-truthing of these remote sensing data could be accomplished by comparison with the data collected at a series of “sentinel” coastal wetland sites (see discussion below). This process would be the best way to relate significant trends in net basin supply and regulation response with important vegetation changes occurring as a result of these trends.

With regard to the ecological impacts of changing water levels and flows, it would be quite valuable to identify several master shoreline ecosystem sites that represent good geographic and ecological coverage of the entire Great Lakes coastline. These sites would be used as “sentinel” sites for informing the system response to changes in water level regime, either from natural variability or from variability resulting from regulation and/or climate trends. Regular monitoring of these sites for both hydrologic and biologic condition would provide an excellent long-term data set of the temporal and spatial relationships between water level regime and coastal ecosystem structure and function. These long-term sentinel data sets can be used for improving ecological response forecasting models as well as evaluating the success of management actions that have been implemented. The types of data collection, including frequency of collection, at each sentinel site should include but not necessarily be limited to the following:

- High resolution coastal bathymetry and shoreline topography – every five years;
- Site sediment substrate and shoreline geomorphology characterization – every five years;
- Land use/land cover in a region of influence around the site – every five to ten years;
- Gaged water level measurements – recorded continuously;
- Types and spatial extent of both emergent and submergent vegetation in the water as well as types and spatial extent of vegetation above the water line in a region of influence around the site – annually in mid- to late-summer;
- Benthic macroinvertebrate, fish, bird, and amphibian taxonomic composition and biomass – annually in mid- to late-summer; and
- Selected water quality (total suspended solids, total organic carbon, water transparency/light penetration, nutrients) and benthic and water column metabolism (photosynthesis/respiration) – seasonally, if possible, but annually at a minimum.

The development of the above sentinel coastal wetland ecosystem program should be coordinated with the ongoing Great Lakes coastal wetland inventory program being directed by Dr. Don Uzarski, Central Michigan University. This program plans to monitor the majority of Great Lakes coastal wetlands across the basin over a five-year period. The monitoring program will assess fish, invertebrate, bird, amphibian, and plant communities, along with water quality variables, using consistent, uniform protocols developed by the GLCWC (2008). The outcome of this project will be a robust and sustainable long-term monitoring program producing scientifically-defensible wetland condition assessments. We therefore recommend that this program be used for selection of the IUGLS adaptive management "sentinel" sites, for the development of initial baseline conditions for those sites, and for establishing the ongoing monitoring protocol for those sites.

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APPENDIX A

PERFORMANCE INDICATOR FACT SHEETS

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Fact Sheet ID: 01

Performance Indicator (PI) Name/Short Description: Wild rice surface area in Kakagon Slough (Chequamegon Bay, Lake Superior)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Dr. Jim Meeker, Northland College

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is the surface area of wild rice in the Kakagon Sloughs, Lake Superior, Wisconsin. Percent cover of wild-rice in the Kakagon Sloughs relative to other taxa was observed over four years of extreme water level change in Lake Superior from 1986 to 1989. Taxa were categorized as one of eight life forms (or structural forms or guilds), including wild-rice (*Zizania*, only one taxa), emergent, floating, flexuous stemmed, submergent, annuals, graminoids, and shrubs.

Ecological Importance/Niche: Northern wild-rice (*Zizania palustris* L. var. *palustris*) is a native North American grain that was once abundant across the "wild-rice" district of northeastern Minnesota, northern Wisconsin, and southern Ontario. The Kakagon Slough wetlands are unique among Lake Superior's wetlands due to dominance by wild-rice. The Kakagon Sloughs are located along the southern shore of Lake Superior in northern Wisconsin and are recognized as a National Natural Landmark.

Extensive wild-rice marshes likely existed in other locations on the Great Lakes, such as the lower end of Green Bay, other locations in Lake Superior, and the mouth of the St. Louis River (near the present day cities of Duluth-Superior). Unfortunately, most of the major wetland complexes near larger cities were drained, filled or otherwise extremely degraded.

The stewards of the productive Kakagon Slough wetland complex are the Bad River Band of Lake Superior Chippewa, who for centuries have harvested wild-rice from these waters. The data reported are, in part, a response to Bad River's concern for the long-term health of this wetland, as well as the recognized gap in information on the ecology of northern wild-rice in a riverine habitat.

Temporal Validity: The peak annual Lake Superior water levels (based on the monthly mean water level time series) are used to compute the total surface area coverage of wild rice as a function of water depth in Kakagon Slough for each simulation year. The estimated surface area coverage is considered to be representative of wild rice coverage for the growing season.

Spatial Validity: Vegetative sampling took place each year along 11 re-locatable transects perpendicular to shoreline (located by metal posts on the shoreline). Paired 0.5 m x 0.5 m quadrats were utilized and sampled at about one meter intervals along the transects. A total of 1,108 quadrats were sampled over four years, varying from about 250 to 330 each year, depending on what portion of the transects were vegetated. Individual quadrats were not re-locatable, but approximate areas were located by stretching a taut line out from shore each year at a known azimuth (or horizontal angular distance from a reference direction) from the metal posts. Percent cover for all taxa in each quadrat was recorded by a single observer (Dr. Meeker).

Hydrology Link: The Kakagon Sloughs are a part of the Lake Superior lowland province, and are directly influenced by lake-wide water level changes. In addition, this wetland experiences considerable short-term water level fluctuations due to the seiche activity associated with Chequamagon Bay. As suggested in Meeker (1993, 1996), both the estuarial characteristics of the Kakagon Slough and the influence of fluctuating water levels on Lake Superior contribute to this wetland's productivity.

Data utilized for this wild-rice PI were used to assess the presumed competitive interactions among taxa by monitoring changes in percent cover of wild-rice and other macrophytes in response to water level fluctuations in Lake Superior over the span of four years. This period of study followed a water level drawdown of about 0.5 m between 1986 (a high water year) and 1988 (a low water year).

Data for this PI demonstrate that drawdown years, like 1988, are important in maintaining long-term wild-rice abundance by allowing this annual species to rapidly re-colonize areas that were too deep for most aquatic species during high water years. Similar findings were also reported for other taxa in Wilcox and Meeker (1995). Data suggest that regulation of water levels in the Lake Superior basin toward a more stabile water level regime would be very damaging for this productive wild-rice wetland.

Algorithm: The algorithm for the wild rice PI was developed to capture the major features of the wild rice data collected for 1986-89. A normal distribution curve describing percent cover as a function of depth was fit to the data, as shown in Figure 1. The peak of the normal distribution, which occurs at approximately 0.7 meter of water depth, was assumed to be 26% for a typical year. However, the distribution was adjusted to have a peak of roughly 40% for years where a cumulative decline of 45 cm or greater had been observed over a 2-year period. Therefore, the wild rice % cover function is adjusted upward specifically for “low water” years, while the default function (peak = 26%) is used for all other years. The peak monthly water level is used along with the transect bathymetry for Kakagon Slough to determine the water depth at various points along the transect, which is approximately 17 meters wide. These percent cover estimates and associated lateral distances (i.e., along the transect) are then multiplied by a longitudinal distance of 5 km to compute the total surface area of wild rice (in hectares) along Kakagon Slough on an annual basis.

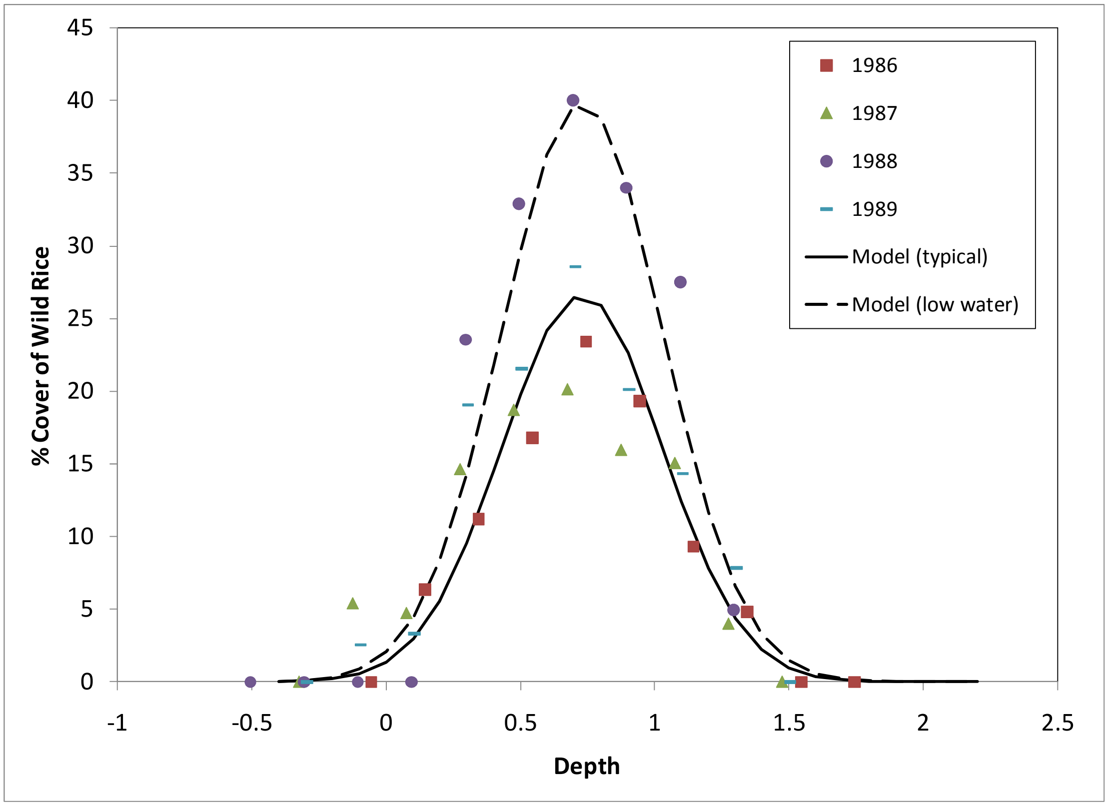

Figure 1. Wild Rice Cover as a Function of Water Depth

Coping Zone Criteria:

- **<u>SUP-03 Criterion</u>:**
  - <u>Zone B</u>: Peak summertime water level drops below 182.56 meters for one or more years in a 4-year period (proposed by LTI).
  - <u>Zone C</u>: Peak summertime water level drops below 182.56 meters for 3 or more consecutive years.
- **<u>SUP-04 Criterion</u>:**
  - <u>Zone B</u>: Peak summertime water level rises above 184.0 meters for one or more years in a 4-year period (proposed by LTI).
  - <u>Zone C</u>: Peak summertime water level rises above 184.0 meters for 3 or more consecutive years.

Calibration Data: Wild rice cover data collected in Kakagon Slough during the 1986-89 period.

Validation Data: None

Risk and Uncertainty Assessment: The uncertainty associated with this PI is considered to be relatively low, as the relationship between water depth and wild rice has been previously established (Meeker, 1993).

Confidence, Significance and Sensitivity:

Confidence: Water depth was measured at the time of sampling and later corrected for seiche by referring to the USGS continuous recording water level gauge (all water levels for a particular year were in reference to 1985 IGLD). For each year, the total number of quadrats, across all transects sampled, was ordered from shallow to deep elevation and sorted into 20 cm intervals.

Significance: Not available

Sensitivity: Not available

Documentation and References:

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Fact Sheet ID: 02

Performance Indicator (PI) Name/Short Description: Bulrush Marsh – surface area in Black Bay and Sturgeon Bay (Lake Superior)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Allan Harris and Robert Foster

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is the surface area of bulrush marsh at Black Bay and Sturgeon Bay, Ontario. Bulrush marsh is the most common emergent wetland community on the north shore of Lake Superior in Ontario. The dominant plant species are typically hardstem bulrush and softstem bulrush (*Schoenoplectus acutus* and *S. tabernaemontani*) along with spikerush (*Eleocharis smallii*). This wetland community has low species richness, low plant biomass, is tolerant of wave energy, and occurs at elevations that are inundated most of the year with water depths typically 40 to 110 cm (Harris et al. 1996). On Lake Superior, bulrush marsh generally occurs as a narrow fringe (2 to 20 m wide) on bays with sand, silt, or clay substrates.

Ecological Importance/Niche: Although their ecological functions are not well documented, marshes at Black Bay and Sturgeon Bay are probably important waterfowl and fish spawning and nursery habitat. Both are provincially significant wetlands (Harris and Foster 1998, 2002) and were assessed to have significant ecological functions based on their hydrological, biological, and social features, as well as other features (OMNR 1993). Black Bay formerly supported a commercial fishery for walleye and continues to support a yellow perch fishery (Colby and Foster 2001). Shoreline marshes are probably important nursery habitat for these species. Northern pike spawning occurs in bulrush marshes in both Sturgeon Bay and Black Bay (Harris and Foster personal observations 2010). Pike is of importance for recreational angling and an important predator. Black Bay is a regionally significant migratory stopover for waterfowl and shorebirds (Harris and Foster 2002).

Temporal Validity: Examination of a series of aerial photos from 1947 to 2010 suggests that the bulrush marsh community at Black Bay has persisted in approximately the same location for at least several decades.

Spatial Validity: Bulrush marsh communities are found in lake and river systems throughout northwestern Ontario. The two study areas, Black Bay and Sturgeon Bay, represent different physical environments. Black Bay is a large, shallow bay with fringing wetland surrounding about 40% of the shoreline (Harris and Foster 2000). The study area is representative of much of the shoreline (shallow, sandy substrate, with bulrush). Sturgeon Bay is more typical of bedrock controlled shorelines, with less extensive, intermittent bulrush marsh.

Hydrology Link: The relationship between water levels and emergent wetlands is well documented (e.g., Keddy 2000; Mortsch et al. 2006; Ciborowski et al. 2008). On Black Bay and

Sturgeon Bay, bulrush marsh occurs at elevations typically inundated by Lake Superior waters, but exposed at irregular intervals (Figure 1).

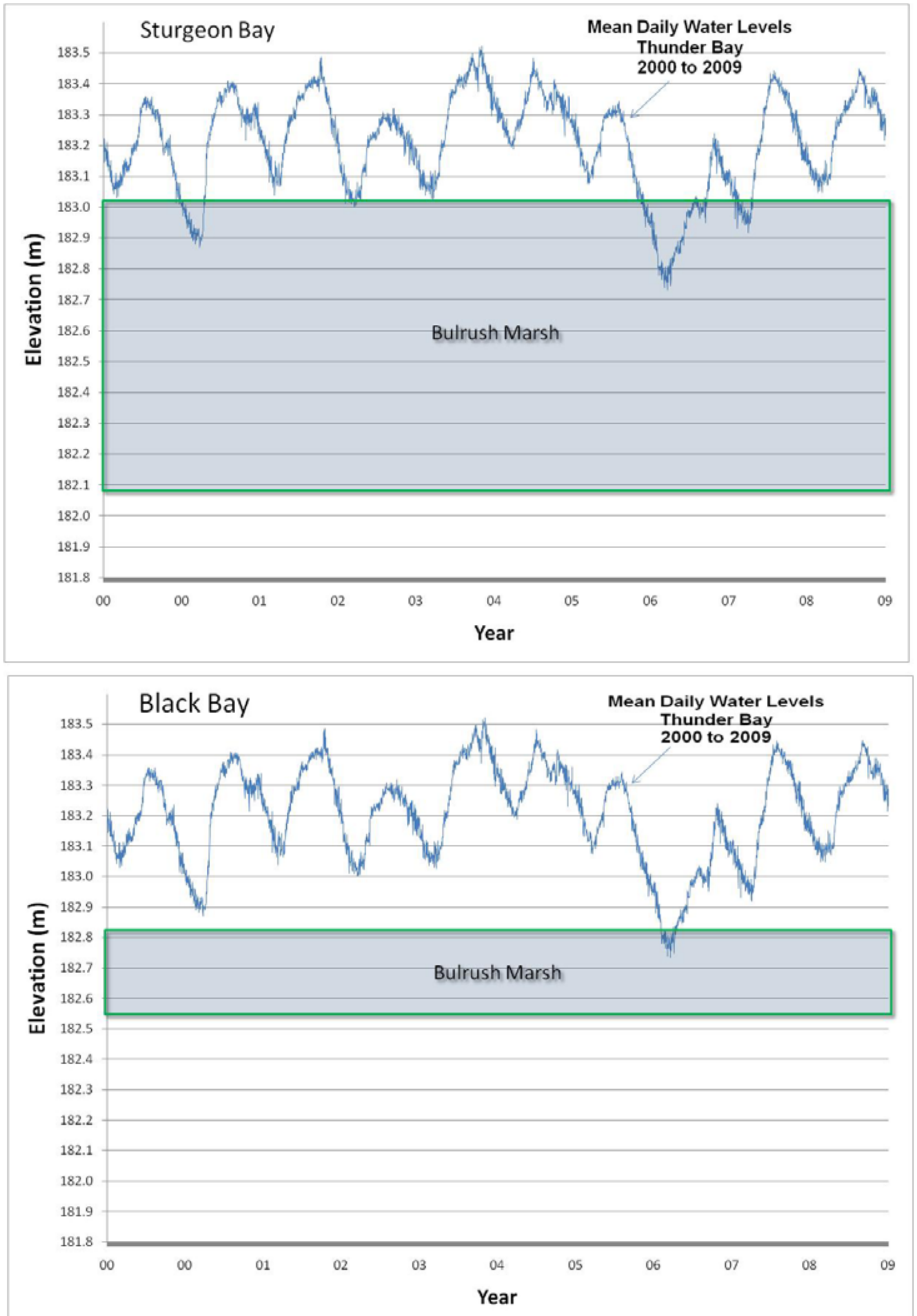

Figure 1. Elevation of bulrush marsh relative to Lake Superior water levels 2000 to 2009. Shaded box represents the elevation range of bulrush marsh (10th to 90th percentiles).

Algorithm: The PI was developed based on fieldwork conducted in 2010 using the following approach:

1. Bulrush marsh communities were mapped;
2. Elevation ranges for bulrush marsh communities were measured;
3. Bathymetry for the study areas was measured; and
4. Future area of bulrush marsh was predicted, assuming bulrush marsh will move down slope to occupy the same depth range as water levels decline.

Lakebed elevation of the bulrush marsh community was measured at Black Bay and Sturgeon Bay. (Bulrush marsh was essentially absent at Cloud Bay, and no model was developed for this site although bathymetry data were collected.) Elevation range of the bulrush marsh was determined from mapped polygons and field observations. The 10th and 90th percentiles of the bathymetry points were used to eliminate outliers (Table 1). Bathymetry data were collected for all of Sturgeon Bay and a representative area of Black Bay.

Table 1. Lakebed elevation ranges for bulrush communities at Black Bay and Sturgeon Bay, Lake Superior.

	Max Elevation (m)	**Min Elevation (m)**	**Elevation Range (m)**	**10th Percentile (m)**	**90th Percentile (m)**
Black Bay	183.199	182.393	0.876	182.534	182.812
Sturgeon Bay	183.100	181.939	1.16	182.092	183.039

Bathymetry points were converted to a triangular irregular network (TIN, a vector based representation of the physical land surface or sea bottom), which was then converted to a raster, and surface area was tabulated for each 1 cm elevation bin. Habitat area within the bulrush marsh depth range was calculated and charted under a range of declining water levels (

Figure *2*).

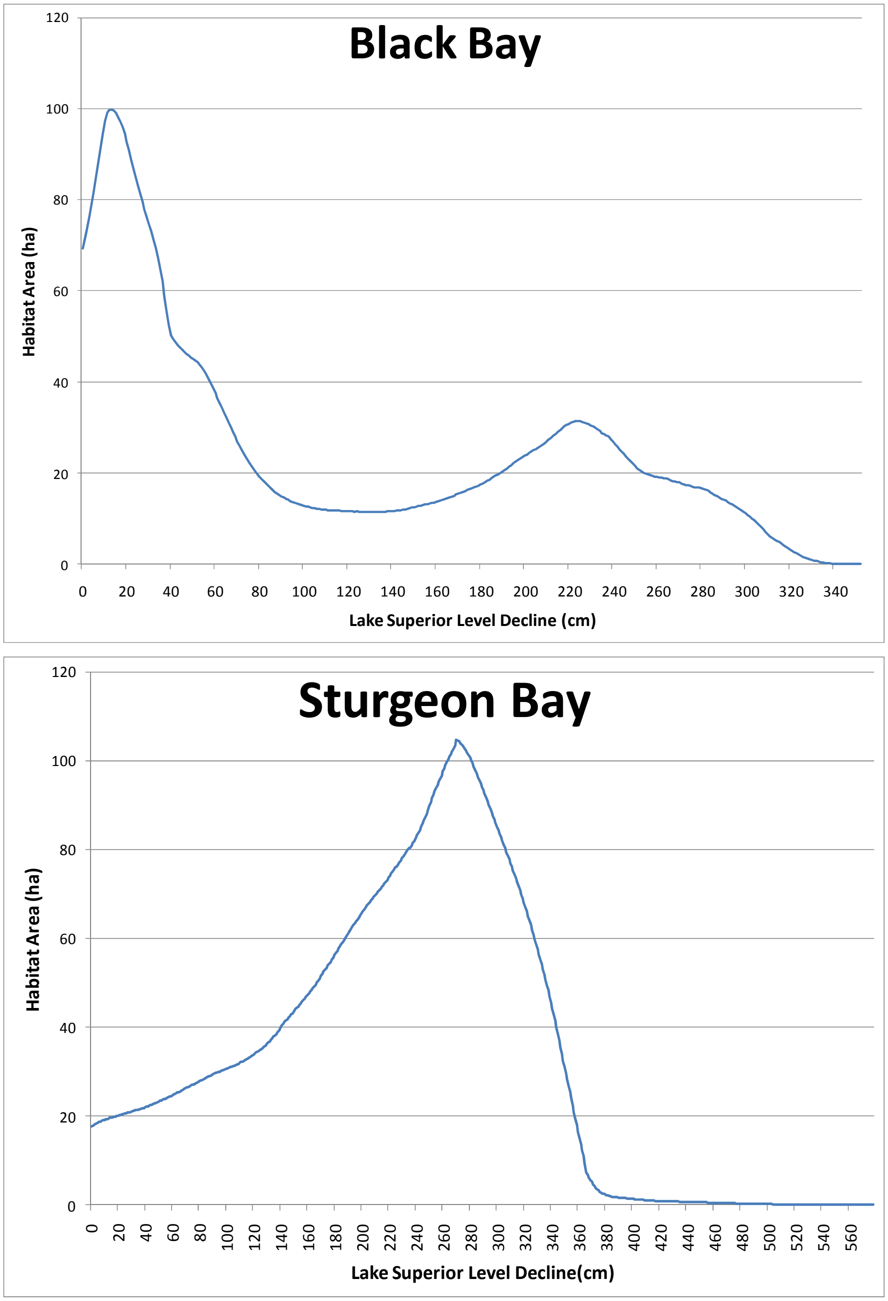

Figure 2. Forecast habitat area for bulrush marsh at varying levels of Lake Superior water level decline. (The zero point on the x-axis is the present habitat area of bulrush marsh.)

Coping Zone Criteria:

- **<u>SUP-05 Criterion (for Black Bay)</u>:**
  - <u>Zone B</u>: Mean spring (Apr-May) water level is more than 0.67 meter below the mean level for the preceding 10-year period for any 5 years within a 7-year window.

- Zone C: Mean spring (Apr-May) water level is more than 0.67 meter below the mean level for the preceding 10-year period for 7 or more consecutive years.

- **SUP-05 Criterion (for Sturgeon Bay):**
  - Zone B: Mean spring (Apr-May) water level is more than 1.12 meter below the mean level for the preceding 10-year period for any 5 years within a 7-year window.

  - Zone C: Mean spring (Apr-May) water level is more than 1.12 meter below the mean level for the preceding 10-year period for 7 or more consecutive years.

Coping zone criteria for northern pike spawning behaviour and habitat reflects a conservative and protective low water duration of five years for lower Zone B and seven years for Zone C in the IERM2 model. Within five years of low water levels it is anticipated impacts (lower Zone B) would occur, and after seven years those impacts will become significant (Zone C). Northern Pike have a long life span and even with the loss of several year classes, there are opportunities for them to recover over time. However, extended periods of low water will have a harmful impact on these fish.

Reproductive success will likely be reduced if pike are forced to spawn in deeper water, which would be the case if water levels decline prior to spawning such that pike are forced to spawn over submergents that are otherwise in deeper water the rest of the year. The deeper water is cooler with lower temperatures, resulting in delayed development and growth of eggs. By the time the larvae hatch, much of the available food supply that the larval fish would typically feed upon is significantly diminished. This type of spawning activity has been described as a "reproductive sink" and northern pike recruitment under these conditions is extremely low. If water levels are consistently low throughout the year (e.g., from water level regulation or global warming), then we expect pike to move down the gradient in response to water levels and spawn in shallow water, wherever it was. It might not be over the most suitable vegetation, however, if there is a time lag for vegetation migration.

Calibration Data: Not available

Validation Data: Not available

Risk and Uncertainty Assessment: Not available

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

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Ontario Ministry of Natural Resources (OMNR). 1993. Ontario Wetland Evaluation System Northern Manual. First Edition. Ontario Ministry of Natural. Resources (OMNR), Northwest Science & Technology, Timmins, Ontario. Technical Manual TM-001. 182 p. + Supplements.

Fact Sheet ID: 03

Performance Indicator (PI) Name/Short Description: Northern Wetland Macroinvertebrates – species richness (St. Louis River Estuary, Lake Superior and Green Bay, Lake Michigan)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: V. Brady and D. Breneman

Modeled by: LimnoTech (Redder, DePinto)

PI Metrics: Potential metrics for northern wetland macroinvertebrates (hereafter invertebrates) include invertebrate taxa richness; proportion of dragonflies and damselflies (proportion Odonata) within the community; and proportion of the community comprised of climbing invertebrates (proportion climbers). Invertebrate metrics are modeled based on extent of wetland vegetation types (emergent, submergent, and mixed vegetation) versus unvegetated areas. Because these potential metrics respond in a similar manner across the vegetation types, invertebrate taxa richness was selected as a representative macroinvertebrate abundance and diversity PI for wetland sites in both St. Louis River Estuary and Green Bay.

Ecological Importance/Niche: Coastal wetland macroinvertebrates (fly larvae, bugs and beetles, mayflies, caddisflies, dragonflies and damselflies, snails, mussels, worms, amphipods, crayfish, and many other invertebrates) are the intermediate link in the food chain for many Great Lakes forage fish and juvenile predatory fish. Wetland invertebrates convert plant and algal biomass into a food resource (their own bodies) for forage and juvenile predatory fish. A robust and diverse wetland invertebrate community will be better able to support a robust and diverse community of forage and, ultimately, predatory and game fish.

Dragonflies and damselflies are large invertebrate predators that are common in wetlands. As large and relatively long-lived predators, odonates represent some of the more sensitive invertebrates living in coastal wetlands. Climbing invertebrates rely on the vertical structure of plants to move up and down in the water column and conceal their movement as they hunt and forage, all the while not exposing their position to other predators. Many climbers also rely on the plants as a food resource (either the plants themselves, the epiphyton (algae) that grows on other plants or other invertebrates living on the vegetation). Together, these metrics represent the overall wetland invertebrate community (taxa richness metric), a group of relatively sensitive invertebrates (proportion Odonata), and a behavioral group (proportion climbers).

Temporal Validity: Metrics are based on samples collected from late July to early September. Data from samples collected earlier in the season may not produce the same results due to incomplete development of both the vegetation and maturity of the invertebrates. In addition, samples collected later in the season may not produce the same results due to senescence (biological aging) of the vegetative habitat and migration or over-wintering strategies of the invertebrates. Large interannual variability can occur among samples collected at the same location due to the high spatial variability of aquatic invertebrates. However, the general nature of these metrics should make them relatively robust despite this level of variability.

Spatial Validity: These metrics were generated from samples collected in coastal wetlands across the US side of the northern Great Lakes, from Duluth, Minnesota in the northwest, to the southern end of Green Bay, and across coastal wetlands along the northern half of Michigan's Lower Peninsula on both Lake Michigan and Lake Huron (Figure 1).

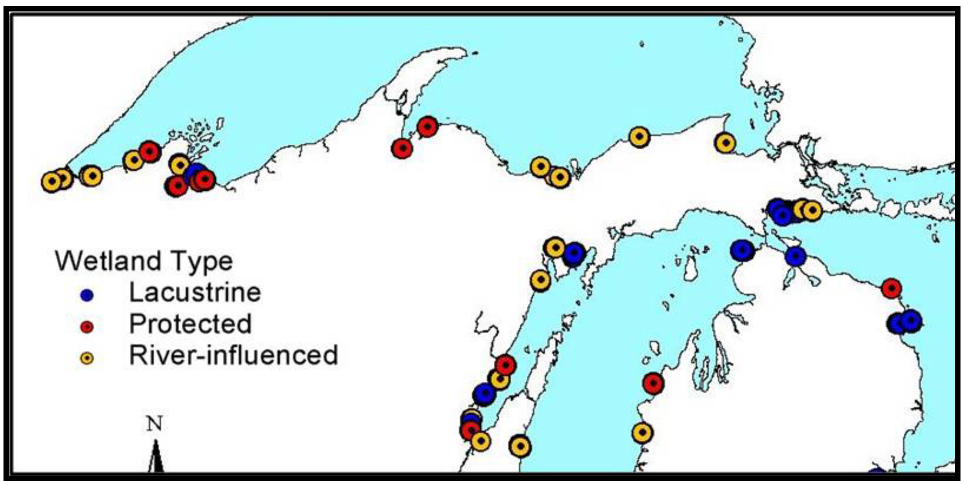

Figure 1. Location and type of wetlands sampled by the Great Lakes Environmental Indicators Project (GLEI). These data were re-analyzed to produce the northern wetland invertebrate indicators.

Hydrology Link: Many wetland invertebrates respond to water level fluctuations indirectly, as habitat structure and aquatic vegetation are made available with changing water levels. In other words, as long as water is present and of a reasonably appropriate depth, the more important component for many invertebrates is the presence, density, and type (or form) of macrophytic (rooted or floating aquatic plants) vegetation. The water level models predict the presence and type of vegetation, which in turn is useful in predicting invertebrate metrics.

Algorithms:

All potential PI relationships are based on Great Lakes Environmental Indicator (GLEI) project data collected in 2002-2003 across all five Great Lakes (Danz et al. 2005; Johnson et al. unpublished data; Niemi et al. 2009). Data analyzed for this effort are from 62 Great Lakes coastal wetland sites across the US side of the upper Great Lakes, covering all but the most southerly portion of Lake Michigan. Invertebrate data were collected using D-frame dip nets (operative mesh size 0.5 mm). Samples were collected along a minimum of two transects per wetland, with one sample on each transect in shallow water (typically 20-50 cm) and one in deeper water (50-100 cm). Large or complex sites had three transects. Samples were often completely processed; no less than ¼ of any given sample was processed. Invertebrates were identified to lowest practical taxonomic unit, which is typically at the genus level for insect taxa. The one exception is the taxa, Chironomidae (Diptera), which were left at family level. All data were converted to proportions. Samples were averaged within sites by depth zone (shallow or deep), with two to three samples per zone, depending on site. Invertebrate data were then converted to metrics based on taxa counts, functional feeding groups, behaviors, tolerance to stress, and higher-order taxonomic groups. Data were ANOVA-tested among locations grouped by dominant vegetation type. The results of this analysis are summarized in the following figures:

- Figure 2: macroinvertebrate taxa richness as a function of dominant vegetation type;
- Figure 3: proportion of dragonflies and damselflies as a function of dominant vegetation type; and
- Figure 4: average proportion of climbing invertebrates as a function of dominant vegetation type.

As discussed above, the macroinvertebrate taxa richness metric (Figure 2) was selected for inclusion in the IERM2 model.

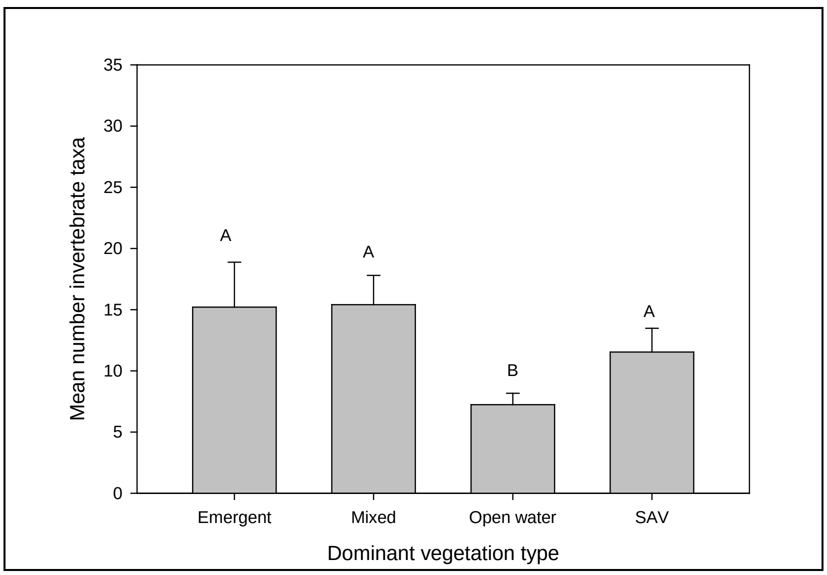

Figure 2. Average number of invertebrate taxa (± 95% confidence interval) in various types of coastal wetland vegetation. Different letters signify a significant difference at p=0.05. Mixed = mixed emergent/submergent. SAV = submerged aquatic vegetation.

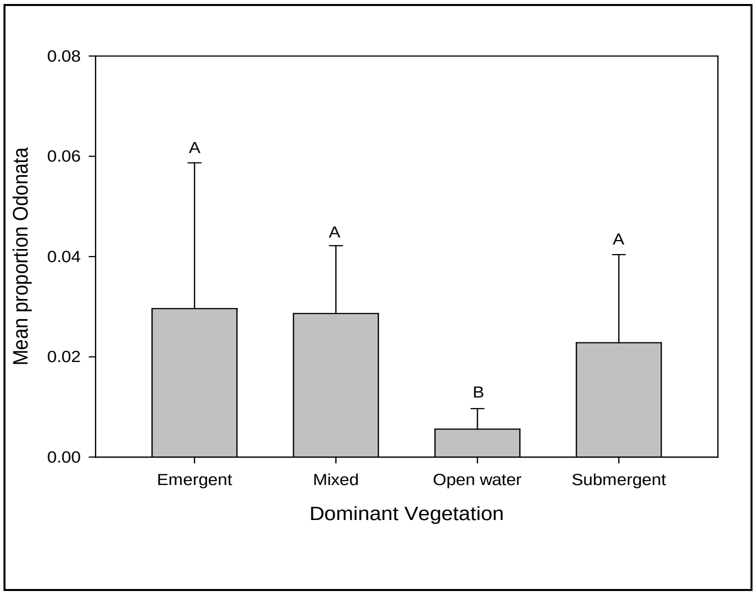

Figure 3. Average proportion of dragonflies and damselflies (± 95% CI) in various types of coastal wetland vegetation. Mixed = mixed emergent/submergent vegetation. Different letters signify a significant difference at p=0.05.

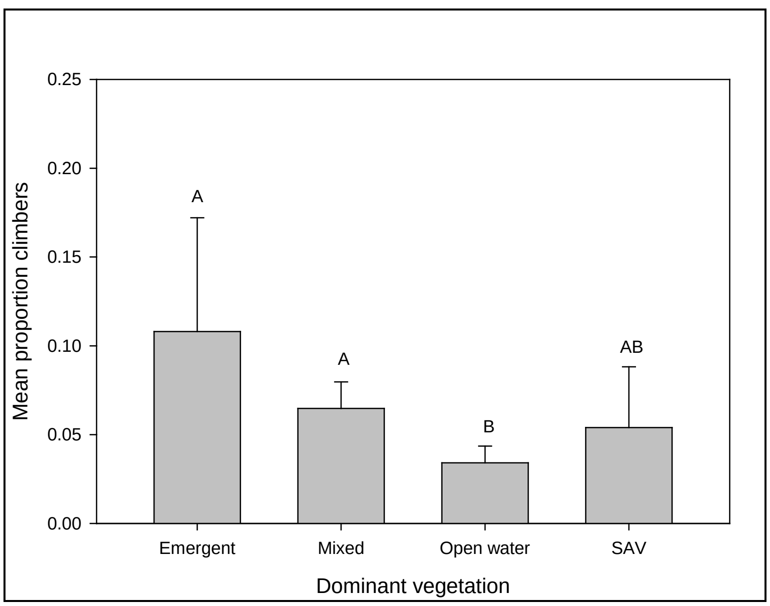

Figure 4. Average proportion of climbing invertebrates (± 95% CI) in various types of coastal wetland vegetation. Mixed = mixed emergent/submergent vegetation. SAV = submerged aquatic vegetation. Different letters signify a significant difference at p=0.05.

Coping Zone Criteria: Great Lakes coastal wetland invertebrate communities respond to both water levels and habitat structure. These PIs relate to habitat structure, which is primarily created by wetland vegetation of various types (e.g., emergent, submergent, floating, and mixed). Maintaining "natural" wetland invertebrate communities requires maintaining natural vegetation types, which requires preserving the water level depth ranges and daily, seasonal, annual, and decadal variability that supports a full suite of wetland vegetation zones that site bathymetry will permit. These zones include wet meadow, shallow emergent, mixed emergent-submergent-floating leaved, and deep emergent. Unimpaired Great Lakes coastal wetlands typically contain a mixture of vegetation types that are maintained by naturally fluctuating and variable water levels. As long as wetlands have room to migrate upslope and downslope, absolute water levels may be less important than the maintenance of natural daily, seasonal, annual, and decadal water level fluctuations that are required to maintain a diverse assortment of vegetation zones and wetland vegetative diversity. As has been shown on Lake Ontario, reducing water level variability reduces the number of wetland vegetation zones and plant diversity, and may make these wetlands more vulnerable to takeover by aggressive, non-native vegetation. This would have negative consequences on the invertebrate communities in the upper Great Lakes coastal wetlands.

Unfortunately, in many areas along the Great Lakes coast, wetlands may be prevented from migrating upslope if water levels increase due to shoreline alteration and anthropogenic (human related) development. Wetlands may also be prevented from migrating downslope as water levels fall if the slope drops suddenly offshore. Thus, for any given wetland, the upper and lower thresholds of the wetland's ability to migrate will depend on topography/bathymetry and land use upslope of the wetland. The rate of water level change may also be an issue. If water level changes dewater or flood large areas horizontally, wetland plants may not be able to migrate quickly enough to keep pace. Human actions may also play a role, as has been seen in Michigan in the early 2000's when property owners mowed dewatered coastal wetlands during very low water years. This mowing was shown to be highly detrimental to wetland recovery when water levels naturally rebounded, resulting in much more harm to wetlands than the naturally low water level. Finally, natural ranges of water level fluctuations must be maintained at the appropriate seasons, which differ somewhat from lake to lake, in order to match vegetation and invertebrate life cycle requirements. Shifting the natural seasonal high-low water level cycle out of sync with plant and animal life cycles would likely be detrimental to wetland ecosystem condition.

No additional Coping Zone criteria were developed for the macroinvertebrate taxa richness PI. As suggested by Figure 2, the success of the macroinvertebrate community is highly dependent on the abundance and diversity of wetland vegetation. Therefore, this PI is cross-referenced to the range compression metrics developed by Doug Wilcox with respect to maintaining abundant and diverse wetland vegetative communities (SUP-01 and SUP-02 for Lake Superior, and LMH-01 and LMH-02 for Lake Michigan-Huron). These range compression metrics are presented below:

For Lake Superior:

- **SUP-01 Metric:**
    - For peak water level events: plan-to-Pre-Project ratio for the maximum peak summertime water level (relative to the 109-year mean) when the Pre-Project peak is greater than 0.37 meter above the 109-year mean water level.

- **SUP-02 Metric:**
    - For post-peak drawdown events: plan-to-Pre-Project ratio of the maximum drawdown of summertime high water levels occurring within 5 years of a 'peak' water level event (only evaluated when the maximum drawdown for Pre-Project is at least 0.45 meter).

For Lake Michigan-Huron:

- **LMH-01 Metric:**
    - For peak water level events: plan-to-Pre-Project ratio for the maximum peak summertime water level (relative to the 109-year mean) when the Pre-Project peak is greater than 0.65 meter above the 109-year mean water level.

- **LMH-02 Metric:**
    - For post-peak drawdown events: plan-to-Pre-Project ratio of the maximum drawdown of summertime high water levels occurring within 5 years of a 'peak' water level event (only evaluated when the maximum drawdown for Pre-Project is at least 0.75 meter).

For the suite of range compression metrics, performance is evaluated based on how closely the plan mimics Pre-Project behavior for peak water level and post-peak event. For example, if the plan-to-PreProject ratios for a given alternative plan are *closer* to 1.0 than the Plan 77A ratio, this indicates that the alternative plan permits more natural water level range relative to 77A.

Calibration Data: Although not pursued in this study due to time constraints, there are several other datasets of Great Lakes coastal wetland invertebrates that cover a smaller spatial range that could potentially be used for calibration.

Validation Data: Although not pursued in this study due to time constraints, there are several other datasets of Great Lakes coastal wetland invertebrates that cover a smaller spatial range that could potentially be used for validation.

Risk and Uncertainty Assessment: The data used to derive these indicators were not collected for the purpose of investigating invertebrate response to water level change. Sampling was done during two consecutive summers, one of which had very low water levels and the other with water levels having recovered only slightly; thus, sampling did not cover a wide range of water levels. Therefore, these indicators are very general indicators of overall wetland condition, rather than specific indicators of response to water level.

Confidence, Significance and Sensitivity:

Confidence:
a) Spatial Confidence: The northern invertebrate indicators are based on samples collected from a variety of types of coastal wetlands across much of the upper Great Lakes (see Figure 1); therefore, the indicators should be valid within this range. The indicators are also fairly general, which adds to their spatial robustness. However, the indicators have not been tested for validity across the lower Great Lakes and should be used with caution in more southerly areas until they have been verified.

b) Temporal (seasonal) Confidence: Samples collected outside the late summer season may not produce the same indicator values as would samples collected at the same site between mid-July and early September. This is particularly true of indicators containing odonate taxa and climbing invertebrates because of their life cycle and the development stage of macrophytic vegetation. Samples collected between November and May are likely to produce different indicator values.

c) Temporal (duration) Confidence: While there is considerable interannual variability in wetland invertebrate densities, simple indicators such as those presented here tend to be relatively robust over time as long as samples are collected during the correct season with similar methods.

Significance: Aquatic invertebrates are a vital component of healthy ecosystems and food webs, and a valuable tool in determining overall habitat condition. Invertebrate populations are relatively non-mobile; thus, they reflect current and recently-past conditions within a sample area. Aquatic insects are extremely diverse and provide a variety of structural and functional traits common both regionally and throughout the world. While the indicators presented here show somewhat high variability (see Figures 2-4), significant reductions in the means of these broad and general indicators may indicate relatively large changes to the invertebrate community, which in turn could have negative consequences for fish, birds, and other higher levels of the food web.

Sensitivity: Aquatic invertebrate taxa exhibit a large of array of sensitivities to point and nonpoint source impacts, often attributed to the range of life cycles exhibited on a short (multiple days) and long-term basis (multiple years). The sensitivity of these broad and general indicators to water level disruption is unknown. The taxonomic richness indicator is likely to be relatively insensitive because it is quite general. However, the climbing invertebrate indicator is assumed to be quite sensitive to the presence or absence of emergent and submergent vegetation. The sensitivity of the Odonate indicator is unknown, but is assumed to be moderately sensitive because odonates are relatively long-lived, large-bodied, predatory invertebrates that should be relatively more sensitive to major disturbances than other taxa.

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Fact Sheet ID: 04

Performance Indicator (PI) Name/Short Description: Northern Wetland Fish – fish habitat richness (St. Louis River Estuary, Lake Superior and Green Bay, Lake Michigan)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: V. Brady and D. Breneman

Modeled by: LimnoTech (Redder, DePinto)

PI Metrics: Potential metrics for northern wetland fish consist of proportions of fish exhibiting preference for vegetation, proportion of piscivorous (fish eating) fish, and proportion of bluegill sunfish (*Lepomis macrochirus*). Because these potential metrics respond in a generally similar manner across the vegetation types, fish habitat richness was selected as a representative fish diversity PI for wetland sites in both St. Louis River Estuary and Green Bay.

Ecological Importance/Niche: Coastal wetlands serve as spawning grounds, nurseries and feeding areas for many Great Lakes fishes (Jude and Pappas 1992; Tanner et al. 2004). Important sport fish species such as northern pike, yellow perch, walleye, black crappie and smallmouth and largemouth bass, along with forage species such as minnows, suckers, darters and bullheads, use coastal wetlands during some part of their life history (Stephenson 1990) because of the unique ecological features of these shallow, vegetated habitats (Brazner and Beals 1997). Coastal wetlands provide fish with vegetative cover from predators, abundant invertebrate food, and warmer water for faster growth. Fish with a preference for vegetative cover is an obvious metric for demonstrating the suitability of a wetland as fish habitat. Bluegill sunfish (*L. macrochirus*) prefer vegetated areas. Large zooplankton that thrive among these vegetative cover-types, are an important prey item for sunfish. Finally, piscivorous fish, particularly sit-and-wait predators such as gar, pike, and muskellunge, and other predatory fish such as bass, are at the top of the food chain. Presence of these fish in wetlands is a good indication of an adequate forage fish food supply and a complex wetland community that supports these top predators.

Temporal Validity: Metrics are based on samples collected from late July to early September. Data from samples collected earlier in the season may not produce the same results due to incomplete development of the vegetation, presence or absence of seasonally-migrant fish, and maturity of fish. In addition, samples collected later in the season may not produce the same results due to senescence (biological aging) of the vegetative habitat and fish migration. Moderate to large interannual variability can occur among samples collected at the same location due to the spatial variability and mobility of fish. However, the general nature of these metrics should make them relatively robust despite this level of variability.

Spatial Validity: These metrics were generated from samples collected in coastal wetlands across the US side of the northern Great Lakes, from Duluth, Minnesota in the northwest, to the southern end of Green Bay, and across coastal wetlands along the northern half of Michigan's Lower Peninsula on both Lake Michigan and Lake Huron (Figure 1).

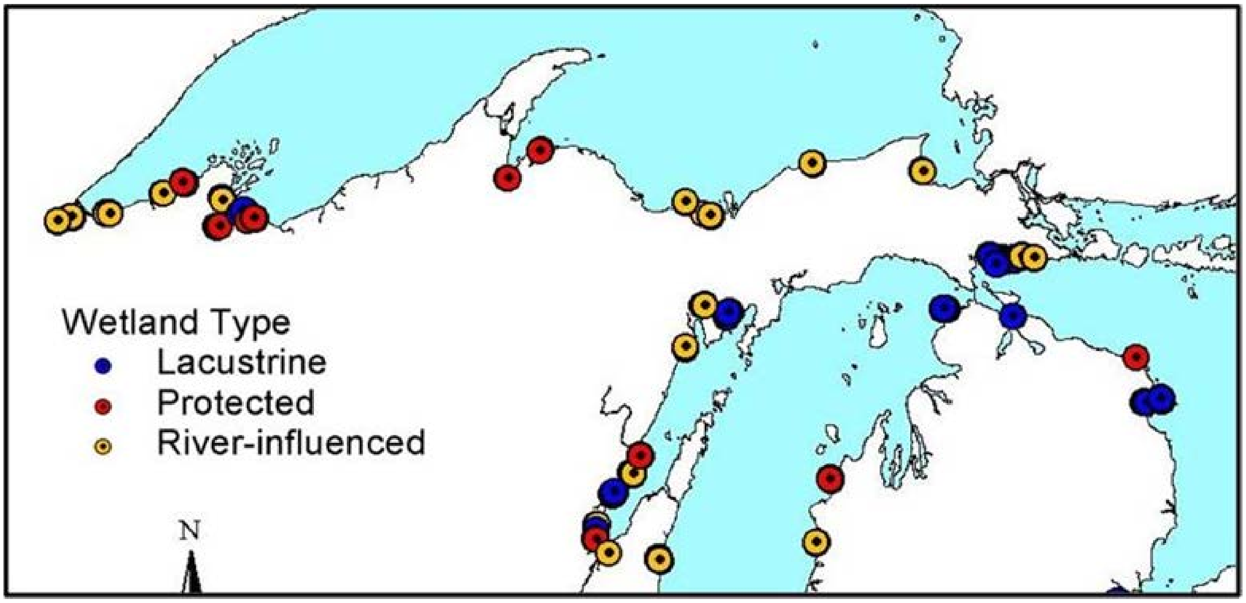

Figure 1. Location and type of wetlands sampled by the Great Lakes Environmental Indicators Project (GLEI). These data were re-analyzed to produce the northern wetland fish indicators.

Hydrology Link: Fish are expected to respond to water level fluctuations both directly and indirectly. Fish can easily move to follow changing water levels. However, many fish also are expected to respond to water level fluctuations indirectly, as habitat structure and aquatic vegetation change with fluctuating water levels. For many fish, as long as water is of a reasonably appropriate depth, the more important variables may be the presence, density, and type (or form) of macrophytic (rooted or floating aquatic plants) vegetation. The water level models predict the presence and type of vegetation, which in turn is useful in predicting wetland fish metrics.

Algorithms:

All relationships are based on Great Lakes Environmental Indicator (GLEI) project data collected in 2002-2003 across all five Great Lakes (Danz et al. 2005; L. Johnson et al. unpublished data; Niemi et al. 2009). Data analyzed for this effort are from 46 Great Lakes coastal wetland sites across the US side of the upper Great Lakes, covering all but the most southerly portion of Lake Michigan. Fish were collected using fyke (trap) nets. Small frame nets with small mesh were set in shallow water (0.25 – 0.6 m), and large frame nets with large mesh were set in deeper water (0.5 – 1.2 m). In most wetlands, nets were set as arrays with two nets set lead-to-lead, parallel to the shore, with wings extending at 45 degree angles. However, some sites were not amenable to this set-up due to steep slopes. In these cases, nets were set singly, perpendicular to shore, with no wings. Nets fished for 24 to 48 hrs, but were checked daily. Fish abundances were converted to catch-per-unit effort and averaged to the site level. Nets could not be separated based on depth due to the confounding factor of net depth with net frame and mesh size. Fish data were then converted to metrics based on taxa counts, feeding groups, and behaviors. Data were ANOVA-tested among locations grouped by dominant vegetation type near nets. The results of this analysis are summarized in the following figures:

- Figure 2: average number of vegetation-preferring fish taxa as a function of dominant vegetation type;
- Figure 3: average proportion piscivorous fish as a function of dominant vegetation type;
- Figure 4: average proportion of bluegill sunfish as a function of dominant vegetation type; and
- Figure 5: fish habitat richness as a function of dominant vegetation type.

As discussed above, the fish habitat richness metric (Figure 5) was selected for inclusion in the IERM2 model.

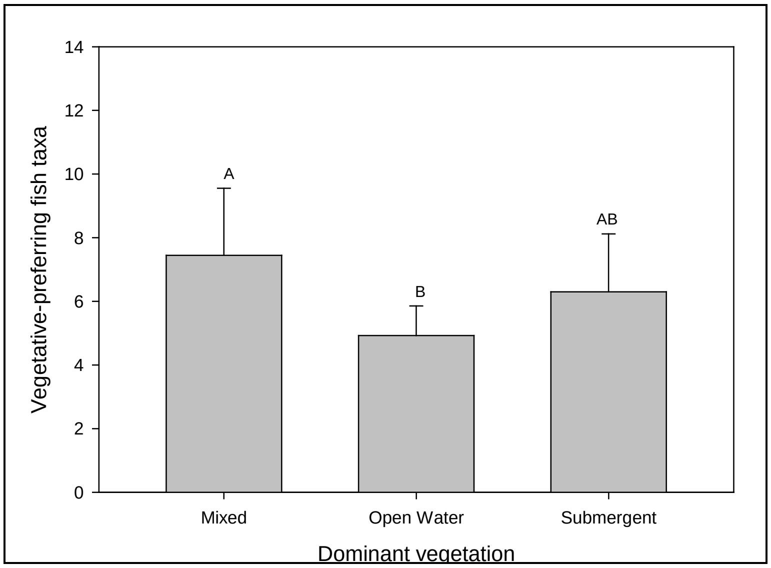

Figure 2. Average number of vegetative-preferring fish taxa (± 95% confidence interval) at sites dominated by different types of vegetation. There are significantly more types of these fish at sites dominated by mixed emergent/submergent than at sites dominated by open water. Different letters signify a significant difference at p=0.05.

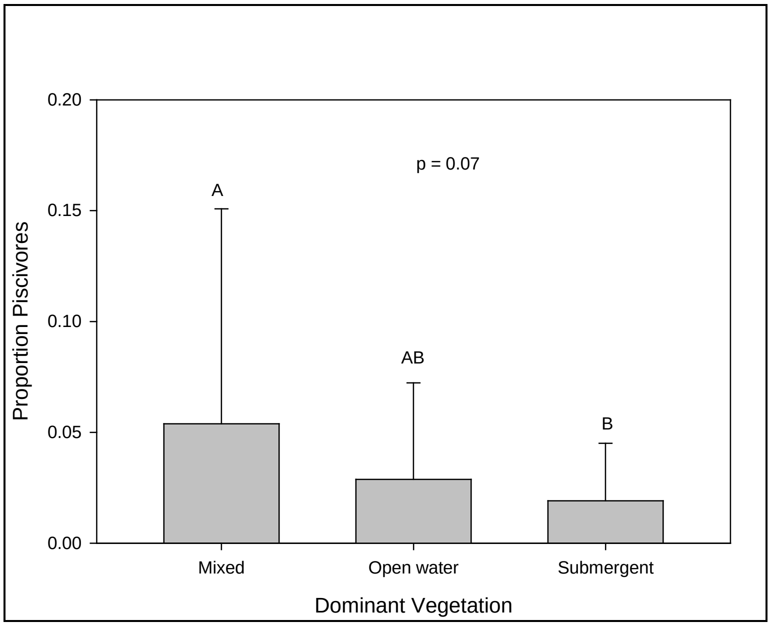

Figure 3. Average proportion piscivorous fish (± 95% CI) in various types of coastal wetland vegetation. There are significantly more fish-eating fish at sites dominated by mixed emergent/submergent vegetation than at sites dominated by submergent vegetation, and also more than at open water sites; however, this difference is not statistically significant. Different letters signify a significant difference at p=0.07.

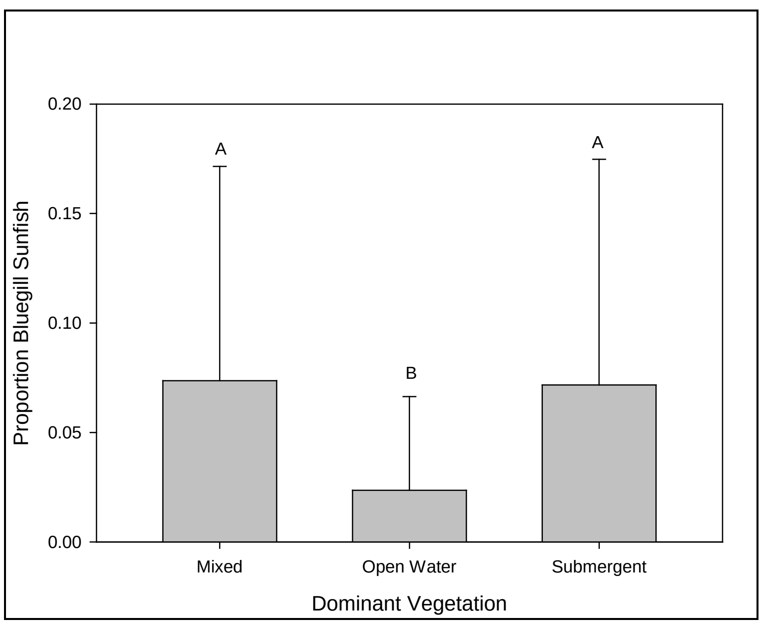

Figure 4. Average proportion bluegill sunfish (Lepomis) (± 95% CI) in various types of coastal wetland vegetation. There are significantly more bluegills at sites dominated by mixed emergent/submergent and submergent vegetation than at sites dominated by open water. Different letters signify a significant difference at p=0.05.

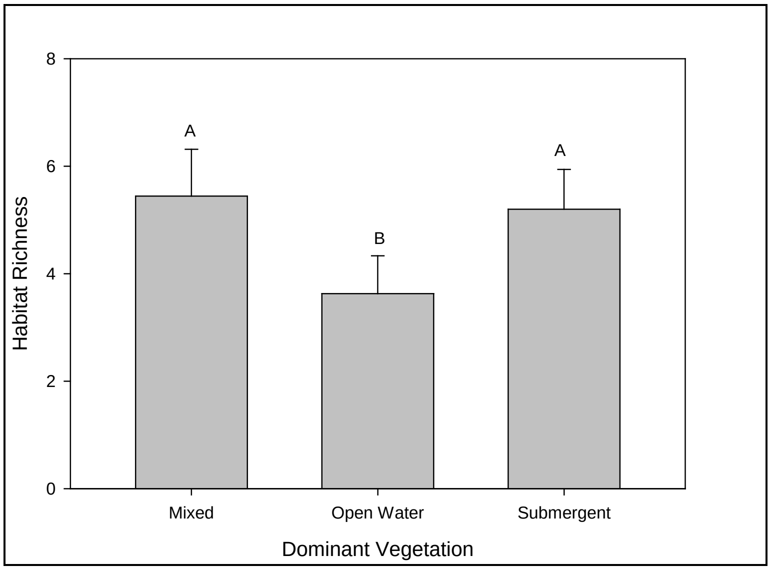

Figure 5. Number of different habitats (± 95% CI) in sites dominated by either mixed emergent/submergent vegetation, open water, or submergent vegetation. There were significantly more habitats in sites dominated by mixed and submergent vegetation than at sites dominated by open water. Different letters signify a significant difference at p=0.05.

Coping Zone Criteria: Great Lakes coastal wetland resident fish communities respond to both water levels and habitat structure. These PIs relate to habitat structure, which is primarily created by wetland vegetation of various types (e.g., macrophytes, submergent plants, floating leaved plants, and mixed stands). Maintaining "natural" wetland fish communities requires maintaining natural vegetation types, which requires preserving the water level depth ranges and daily, seasonal, annual, and decadal variability that supports a full suite of wetland vegetation zones that site bathymetry will permit. These zones include wet meadow, shallow emergent, mixed emergent-submergent-floating leaved plants, and deep emergent. Unimpaired Great Lakes coastal wetlands typically contain a mixture of vegetation types that are maintained by naturally fluctuating and variable water levels. As long as wetlands have room to migrate upslope and downslope, absolute water levels may be less important than the maintenance of natural daily, seasonal, annual, and decadal water level fluctuations that are required to maintain a diverse assortment of vegetation zones and wetland vegetative diversity. As has been shown on Lake Ontario, reducing water level variability reduces the number of wetland vegetation zones and plant diversity, and may make these wetlands more vulnerable to takeover by aggressive, non-native vegetation. This would have negative consequences on the fish communities of upper Great Lakes coastal wetlands.

Unfortunately, in many areas along the Great Lakes coast, wetlands may be prevented from migrating upslope if water levels increase due to shoreline alteration and anthropogenic development. Wetlands may also be prevented from migrating downslope as water levels fall if the slope drops suddenly offshore. Thus, for any given wetland, the upper and lower thresholds of the wetland's ability to migrate will depend on topography/bathymetry and land use upslope of the wetland. The rate of water level change may also be an issue. If water level changes dewater or flood large areas horizontally, wetland plants may not be able to migrate quickly enough to keep pace. Human actions may also play a role, as has been seen in Michigan in the early 2000's when property owners mowed dewatered coastal wetlands during very low water years. This mowing was shown to be highly detrimental to wetland recovery when water levels naturally rebounded, resulting in much more harm to wetlands than the naturally low water level. Finally, natural ranges of water level fluctuations must be maintained at the appropriate seasons, which differ somewhat from lake to lake, in order to match vegetation and fish life cycle requirements. Shifting the natural seasonal high-low water level cycle out of sync with plant and animal life cycles would likely be quite detrimental to wetland ecosystem condition.

No additional Coping Zone criteria were developed for the fish habitat richness PI. As suggested by Figure 5, the quantity and quality of wetland fish habitat is highly dependent on the abundance and diversity of wetland vegetation. Therefore, this PI is cross-referenced to the Coping Zone range compression metrics developed by Doug Wilcox with respect to maintaining abundant and diverse wetland vegetative communities (SUP-01 and SUP-02 for Lake Superior, and LMH-01 and LMH-02 for Lake Michigan-Huron). These metrics are presented below:

For Lake Superior:

- **SUP-01 Metric:**
    - For peak water level events: plan-to-Pre-Project ratio for the maximum peak summertime water level (relative to the 109-year mean) when the Pre-Project peak is greater than 0.37 meter above the 109-year mean water level.

- **SUP-02 Metric:**
    - For post-peak drawdown events: plan-to-Pre-Project ratio of the maximum drawdown of summertime high water levels occurring within 5 years of a 'peak' water level event (only evaluated when the maximum drawdown for Pre-Project is at least 0.45 meter).

For Lake Michigan-Huron:

- **LMH-01 Metric:**
    - For peak water level events: plan-to-Pre-Project ratio for the maximum peak summertime water level (relative to the 109-year mean) when the Pre-Project peak is greater than 0.65 meter above the 109-year mean water level.

- **LMH-02 Metric:**
    - For post-peak drawdown events: plan-to-Pre-Project ratio of the maximum drawdown of summertime high water levels occurring within 5 years of a 'peak' water level event (only evaluated when the maximum drawdown for Pre-Project is at least 0.75 meter).

For the suite of range compression metrics, performance is evaluated based on how closely the plan mimics Pre-Project behavior for peak water level and post-peak event. For example, if the plan-to-PreProject ratios for a given alternative plan are *closer* to 1.0 than the Plan 77A ratio, this indicates that the alternative plan permits more natural water level range relative to 77A.

Calibration Data: Although not pursued in this study due to time constraints, there are several other datasets of Great Lakes coastal wetland fish that cover a smaller spatial range that could potentially be used for calibration.

Validation Data: Although not pursued in this study due to time constraints, there are several other datasets of Great Lakes coastal wetland fish that cover a smaller spatial range that could potentially be used for validation.

Risk and Uncertainty Assessment: The data used to derive these indicators were not collected for the purpose of investigating fish response to water level change. Sampling was done during two consecutive summers, one of which had very low water levels and the other with water levels having recovered only slightly; sampling did not cover a wide range of water levels. Therefore, these indicators are very general indicators of overall wetland condition, rather than specific indicators of response to water level.

Confidence, Significance and Sensitivity:

Confidence:
a) Spatial Confidence: The northern wetland fish indicators are based on samples collected from a variety of types of coastal wetlands across much of the upper Great Lakes (see Figure 1); therefore, the indicators should be valid within this range. The indicators are also fairly general, which adds to their spatial robustness. However, the indicators have not been tested for validity across the lower Great Lakes and should be used with caution in more southerly areas until they have been verified.

b) Temporal (seasonal) Confidence: Samples collected outside the late summer season may not produce the same indicator values as would samples collected at the same site between mid-July and early September. Samples collected earlier in the summer or later in the fall would likely contain a larger component of seasonally-migrant fish.

c) Temporal (duration) Confidence: While there is considerable interannual variability in wetland fish densities, simple indicators such as those presented here tend to be relatively robust over time as long as samples are collected during the correct season with similar methods.

Significance: Fish are components of Great Lakes ecosystems that are highly valued by humans, particularly the large predatory fish prized by anglers. Fish not only represent an important ecosystem and food web component, they are also valued by people for recreational angling and as a food source. Coastal wetlands represent important habitat for many species of Great Lakes fish. The indicators suggest which wetlands provide appropriate habitat for wetland-resident fish. While the indicators presented here show somewhat high variability (see Figures 2-4), significant reductions in the means of these broad and general indicators may indicate changes to the fish community. For example, it would be unusual to not capture piscivores in a large healthy Great Lakes coastal wetland.

Sensitivity: Fish taxa exhibit a large of array of sensitivities to point and nonpoint source impacts, and are capable of moving large distances in search of preferred habitat. The sensitivity of these broad and general indicators to water level disruption is unknown. Indicators such as proportion of vegetative-preferring fish and proportion of piscivores are likely to be relatively insensitive because they are quite general. The proportion of bluegills indicator is based on a single species and is likely to be more sensitive to all manner of habitat changes and disturbances, particularly loss of preferred vegetation for cover, loss of preferred zooplankton prey, and presence of greater predation risk.

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Fact Sheet ID: 05

Performance Indicator (PI) Name/Short Description: Emergent Vegetation and Submerged Aquatic Vegetation (SAV) surface area (Batchawana Bay, Lake Superior)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Chow-Fraser, Midwood

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI is the total surface area of emergent vegetation and SAV in Batchawana Bay in Lake Superior. Surface areal cover of emergent vegetation and submerged aquatic vegetation (SAV) in Batchawana Bay, Lake Superior was quantified between water levels 177.0 to 185.5 (m asl). A relationship was derived between potential areal cover of emergent vegetation and SAV as a function of water level.

Ecological Importance/Niche: Coastal wetlands along the northeastern shoreline of Lake Superior occur in protected embayments. Due to high wind and wave action, as well as intense winter ice-scour, these wetlands do not naturally contain dense vegetation stands. Any vegetation that does exist serves as a valuable spawning and nursery habitat for many fishes. Batchawana Bay, located in the northeastern shoreline, contains some of the largest stands of this type of sparse wetland habitat in eastern Lake Superior (Figure 1).

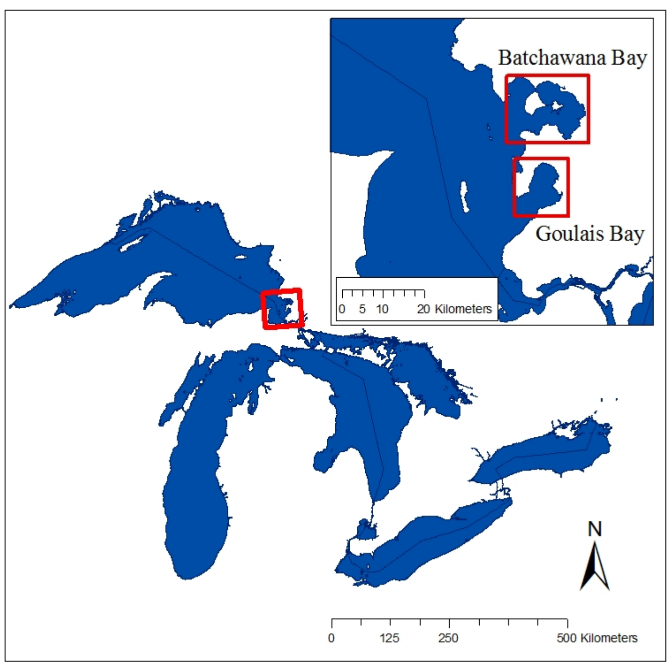

Figure 1. Location of Batchawana Bay in context of the Great Lakes. Inset shows its relative location to another large embayment, Goulais Bay, located 20 km north of the city of Sault Ste Marie, Ontario.

Temporal Validity: An area estimate is computed for each simulation year and is assumed to represent the growing season for that year.

Spatial Validity: Four wetlands in Batchawana Bay were surveyed in this study. They are known to contain important spawning habitat for yellow perch (Goodyear et al. 1982; Chow-Fraser, McMaster University). These are the only large embayments in the eastern end of Lake Superior and are assumed to be the only areas with sufficient protection to allow establishment of aquatic macrophytes (rooted or floating aquatic plants) in the region.

Hydrology Link: Typically, coastal wetlands of the Great Lakes develop at the mouth of rivers or in protected embayments that can limit the influence of wind and wave action and ice-scour on vegetation. Wei and Chow-Fraser (2005) have shown that growth of emergent vegetation is governed by depth of marsh inundation while that of SAV is governed by light penetration (Hudon 2000), which diminishes with depth. Wei and Chow-Fraser (2008) combined water level data with a digital elevation model (DEM) to predict the potential amount of aquatic macrophyte cover corresponding to given water level scenarios for 10 wetlands in eastern Lake Ontario.

Algorithm:

Bathymetry Data Collection: High-resolution bathymetric data were not available for this region. To create the DEM for these four wetlands, we collected elevations and locations using four methods: 1) we used an automatic level to survey the terrestrial portion of the wetlands; 2) we collected depth measurements manually with a graduated pole and global positioning system (GPS) in water from the water's edge to ~1.2 m depth (hereafter referred to as Mobile GPS); 3) we used a 5 m stadia rod and a Mobile GPS unit in depths from 1.2 to 5 m; and 4) we used both a portable hand-held depth sounder and Mobile GPS unit and a boat-mounted sonar depth sounder equipped with GPS to collect depths and locations for depths >5 m. The vertical accuracies associated with each method varied, with the automatic level being the most accurate followed by the Mobile GPS. The depth sounders were the least accurate (~30 cm vertical accuracy) but were used only in water depths greater than 5 m. Data collected from the boat were paired with GPS data that had an accuracy of <50 cm. All other GPS coordinates were collected with hand-held GPS units that had positional accuracies ranging from 1to 3 m. All these methods were used because both inundated and terrestrial habitat had to be surveyed.

Vegetation Data Collection: When possible, at each location where bathymetry data were collected, we identified the dominant vegetation type to the species level, noted the sediment composition, and estimated the vegetation coverage (Figure 2). The use of an underwater camera allowed us to run transects in water deeper than 1.5 m to estimate SAV distribution.

Figure 2. Example of observed vegetation locations in Batchawana Bay. Green points represent confirmed observations of either SAV or emergent vegetation. Based on this information we were able to estimate potential vegetation depth zones for both vegetation categories.

Deriving Elevation: We established a Temporary Benchmark (TBM) using the automatic level and water transfer from BM 69U381 (The Geodetic Survey of Canada). Daily water levels were derived from the TBM. We then related all elevations back to The Great Lakes Information Network (GLIN), which uses IGLD85 as its vertical datum; however, the Geodetic Survey uses CGVD28 as its vertical datum, so a conversion factor of +22.4 cm was applied to all final elevations. To convert depth data collected in the field to elevation, we subtracted depth data from the daily water level data to derive elevation for the depth sounder and Mobile GPS data sources.

DEM Creation: All data, with the exception of the boat mounted sonar data, were manually entered into a geographic information system (GIS) with ArcMap 9.2 software (ESRI Inc., Redlands, California, US,2006). Data collected with the boat-mounted sonar were entered into a handheld GPS unit and exported directly into a shapefile format. Since all data were tied back to a consistent elevation, they were combined into one single shapefile (Figure 3).

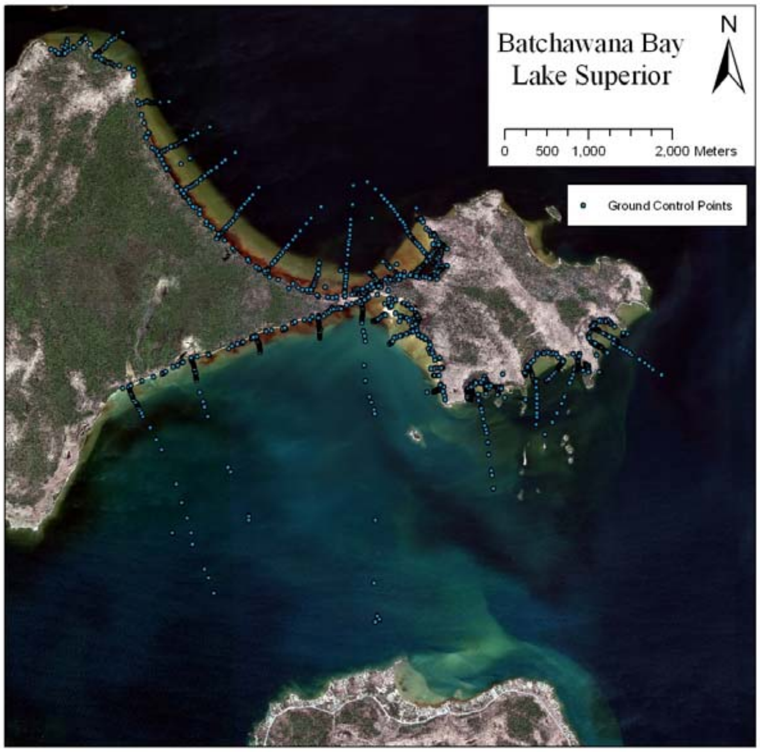

Figure 3. Example of depth measurements (blue points) collected for Batchawana Bay. Using the depth associated with these points, isolines were created and interpolated into a DEM.

The data we collected were too coarse to support the creation of a DEM directly; therefore, we used the ground control points to create isolines at 0.5 to 1.0 m intervals. Using these isolines and the ArcMap 9.2 3D Analyst extension software, we were able to create a Triangular Irregular Network (TIN, a vector based representation of the physical land surface or sea bottom) file, which could then be converted into a DEM (Figure 4).

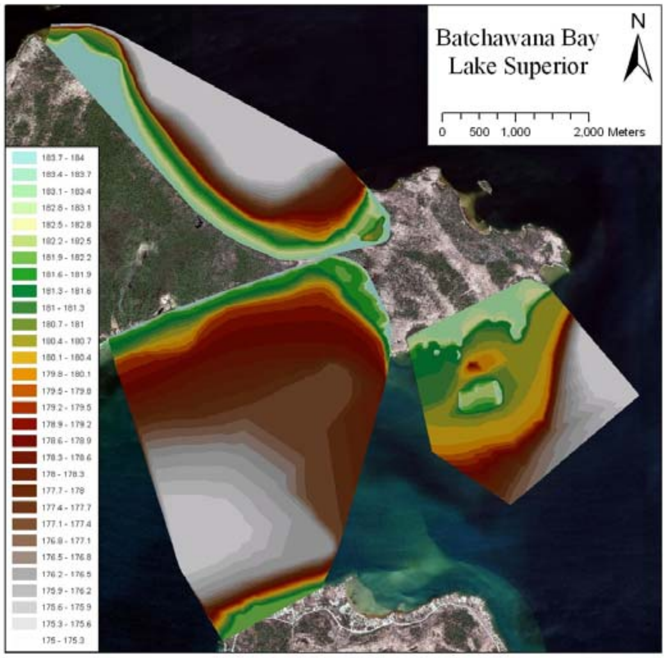

Figure 4. Example of TINs for three sites in Batchawana Bay. Depths are given as meters above sea level. Data gaps prevented us from extending our TINs further into the bay and therefore only a limited range of depths could be used for estimating emergent vegetation and SAV areal coverage.

Estimating Vegetated Areas in the DEM: Based on *in situ* observations, we identified potential emergent vegetation habitat from the shoreline to the 2-meter isocline, and potential SAV habitat between 2.0 and 6.0 m isoclines. Based on our derived DEMs, we calculated the surface area in each wetland at 0.5-meter elevation intervals. We were then able to calculate the total area of each wetland that fell within the two potential habitat zones at water levels ranging from 177.0 to 185.5 m. This excluded predictions generated from incomplete depth profiles. For instance, if a water elevation of 175.0 m created a depth profile for SAV that only covered depth ranges from 2.0 to 4.5 m, it was excluded. These types of truncated predictions would have biased our estimates of potential habitat since they do not include areas that are outside of the bathymetry models. Due to these exclusions, SAV areal cover was calculated at water levels ranging from 181.0 to 185.5 m (asl) and emergent areal cover from 177.0 to 185.5 m (asl). To account for differences in the size of the DEMs, we expressed emergent and SAV areal cover as a proportion of the total area of the DEM (Figures 5 & 6). Raw data for this study are presented below in Table 1.

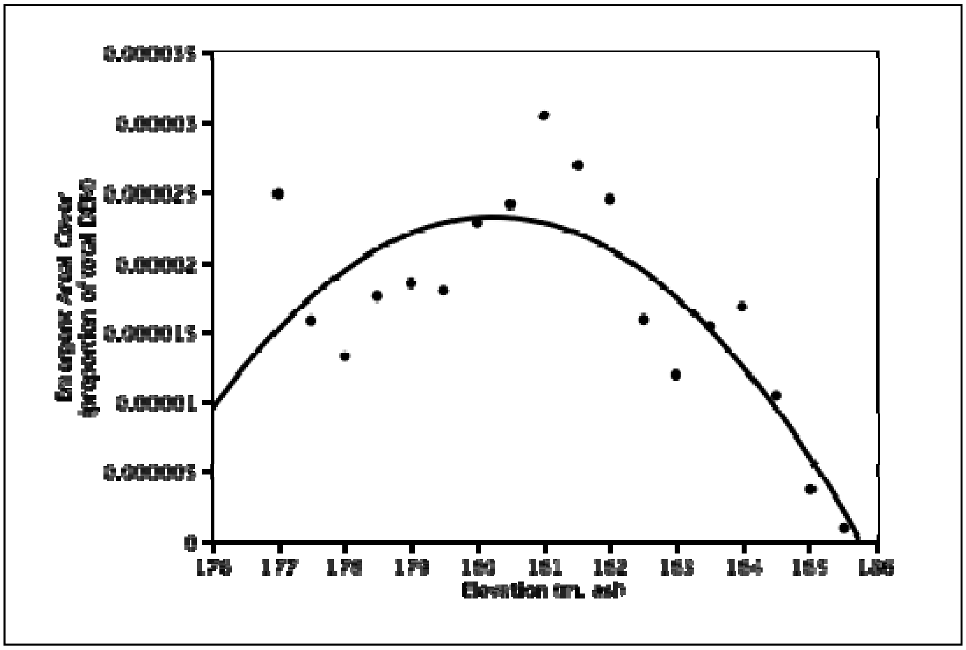

Figure 5. Proportion of total area of the DEM representing the potential emergent vegetation zone (0.0 to 2.0 m). Areal cover is maximized at roughly 180 m (asl). The black line represents the most significant line of fit (Prob>F= 0.0003, R^2 = 0.654). Emergent Areal Cover (proportion of total DEM) = 0.000299 – (1.5263e^{-6} x Elevation (m, asl)) – (7.6266e^{-7} x (Elevation (m, asl) -181.25)^2)

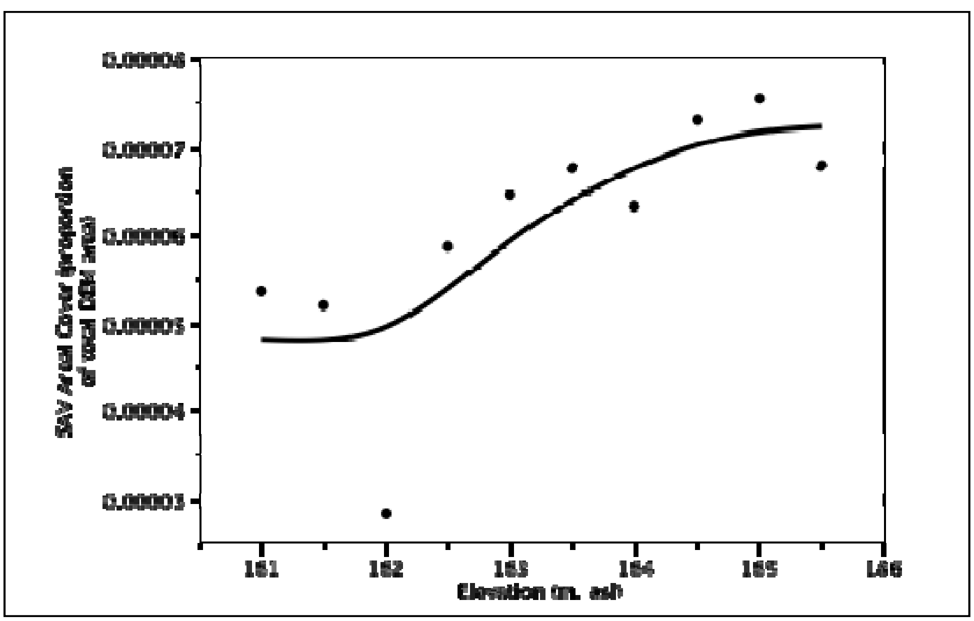

Figure 6. Proportion of total area representing the potential SAV zone (2.0 to 6.0 m). The black line is a spline fit (lambda=1, R^2 = 0.632) that provided the best and most realistic fit based upon in situ observations.

Table 1. Summary of raw data for this study. SAV coverage estimates were limited by the extent of the DEM; therefore, total SAV areal coverage could not be calculated for elevations from 177.0 to 180.5 m (asl).

Elevation (m, asl)	SAV Total Areal Coverage (m^2)	Emergent Vegetation Total Areal Coverage (m^2)	SAV Areal Cover (proportion of total DEM area)	Emergent Vegetation Areal Cover (proportion of total DEM)
177.0	—	143.8	—	2.48E-05
177.5	—	196.1	—	1.57E-05
178.0	—	163.8	—	1.31E-05
178.5	—	446.7	—	1.75E-05
179.0	—	471.6	—	1.84E-05
179.5	—	457.4	—	1.79E-05
180.0	—	581.5	—	2.27E-05
180.5	—	617.3	—	2.41E-05
181.0	655.2	777.1	5.34E-05	3.04E-05
181.5	646.4	687.5	5.18E-05	2.69E-05
182.0	353.1	625.3	2.83E-05	2.44E-05
182.5	1497.5	404.2	5.85E-05	1.58E-05
183.0	1651.3	301.9	6.45E-05	1.18E-05
183.5	1727.7	392.0	6.75E-05	1.53E-05
184.0	1619.5	427.6	6.33E-05	1.67E-05
184.5	1866.9	197.3	7.29E-05	1.03E-05
185.0	1930.6	47.9	7.54E-05	3.65E-06
185.5	1734.1	12.2	6.77E-05	9.33E-07

Coping Zone Criteria: No coping zone criteria were developed for this PI due to uncertainties stemming from the relatively limited digital elevation model (DEM) coverage in Batchawana Bay.

Calibration Data: See discussion in preceding sections.

Validation Data: Not available

Risk and Uncertainty Assessment: Not available

Confidence, Significance and Sensitivity:

Confidence (Potential Errors): Due to time constraints and the large size of the coastal wetlands in northeastern Lake Superior, we had to rely on transect data and observed occurrences of vegetation coverage to complete our analysis. The combination of the different depth survey methods was necessary in order to complete the analysis in a timely fashion. A difference in the accuracy across the methods likely limits the accuracy of our final DEM. The results for this PI represent coarse estimates of both emergent vegetation and SAV coverage. We have kept our estimates as “potential” habitat; however, in reality, we observed low coverage of aquatic macrophytes in all areas. We would estimate that within the "potential" macrophytes zones, vegetation would cover only between 1 to 5% of the potential area.

***Significance**:* For emergent vegetation, the largest potential habitat zone occurs at 180 m (asl) given current water-level scenarios. It is possible that as water levels decrease, this band of emergent zone would continue lakeward. Consequently, the upland coastal marsh complexes would likely become dried out as water levels decline, which is a concern because these wet meadows are known to support high biodiversity value within the nearshore zone (J. Gilbert, personal communication). Unfortunately, we did not have time and it was not within the scope of our work to determine the impacts of water level decline on these upland ecosystems.

Based on our estimates, we do not believe that SAV is sensitive to water level changes. Batchawana Bay is a large open embayment and as water levels fluctuate, there is ample room for SAV to migrate either onshore or further offshore. A fitted spline of the data provided the best ($R^2 = 0.632$) and in our opinion, is the most realistic relationship between SAV and water level. Given the current contours and available bathymetric information, the highest cover of SAV occurs at water levels over 185 m (asl); however, this cannot be considered a complete assessment of SAV cover because we did not have depth data below 177 m to determine the lowest depth of colonization for SAV. In other studies, including wetlands of eastern Georgian Bay that are also located on Precambrian Shield, the lowest depth of colonization is governed by a combination of light penetration, water current, substrate type and slope (J. Midwood, personal observation). Since the water is exceptionally clear in this part of Lake Superior, we believe SAV cover would be primarily governed by substrate type, slope and water current. In our opinion, SAV should be able to migrate lakeward with a drop in elevation of 2 m.

Sensitivity: In general, we do not think that eastern Lake Superior coastal wetland vegetation will be negatively affected by water level reductions in the order of 1to 2 m. Important spawning habitat in the river systems will naturally be maintained and vegetation in the coastal zone will migrate in response to water level fluctuations.

Documentation and References:

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Fact Sheet ID: 06

Performance Indicator (PI) Name/Short Description: Wetland Meadow Marsh Community – surface area (Arcadia Marsh, Lake Michigan)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Doug Wilcox

Modeled by: Wilcox, LimnoTech (Redder, DePinto)

PI Metric: Wetland-specific surface area estimate of meadow marsh vegetation (hectares) in Arcadia Marsh, located on the eastern shore of Lake Michigan.

Ecological Importance/Niche: Meadow marsh vegetation typically develops between the maximum long-term high water level and the long-term mean. Plant species within this community are intolerant of prolonged flooding; however, occasional flooding is required to prevent woody plant species from expanding downslope into the meadow marsh community. In addition, periodic low water levels are also required to prevent the expansion of aggressive emergent (partially in the water and air) plants expanding upslope into the meadow community. Meadow marsh habitats typically contain some emergent, shrub, and upland plant species. The relative amount of these species is dictated by the years since the last high or low water-level cycle. For this reason, the meadow marsh community supports a diversity of plant species, but often occurs in a relatively narrow hydrologic range in comparison to the other wetland vegetation communities. However, in drowned river mouth wetlands along the northern portion of the eastern shore of Lake Michigan, meadow marsh is dominant.

Temporal Validity: The surface area (percent) of meadow marsh was determined by photointerpretation of imagery over the span of 17 years (1954-2010) in which suitable aerial photographs were available. This time period includes several high and low lake-level events. An area estimate is computed for each model simulation year and is assumed to represent the growing season for that year. Monthly mean water levels, representing the annual peak, are used to determine frequency of flooding and dewatering at specific elevations.

Spatial Validity: The rules-based approach uses topographic/bathymetric data specific to Arcadia Marsh. To apply the model to other sites, topographic/bathymetric data would be required, as well as photointerpretation data for validation. Alternatively, Arcadia Marsh could be used alone and considered representative of drowned river mouth wetlands along the northern portion of the eastern shore of Lake Michigan.

Hydrology Link: Wetland plant community evolution is strongly dependent on the hydroperiod (i.e., flooding and dewatering history) at a particular elevation. The models use flooding and dewatering intervals determined from recorded lake-level history of Lake Michigan to estimate the area of Meadow Marsh that would occur in a given year based on the number of years since various land areas were last dewatered.

Algorithm:

The modeling approach follows the rules-based procedure used in the IERM for the International Joint Commission (IJC) Lake Ontario-St. Lawrence (LOSL) study, which assigns portions of the elevation model to different vegetation types based on how many years since last flooded and how many years since last dewatered (Wilcox and Xie, 2007; LimnoTech 2005). Bathymetry and topography data collected during summer 2010 have been used to develop a digital elevation model (DEM) for Arcadia Lake extending from the deeper portions of the lake to the upland extent of the wetland area. The DEM was used to create a set of elevation contour “bins” in similar fashion to Saginaw Bay and other wetland site vegetation models described in the accompanying fact sheets.

The following approach is used to calculate the areal coverage of the meadow marsh-dominated zone in Arcadia Lake:

1. The Lake Michigan annual maximum water level is identified for each model simulation year. This elevation is defined as 1) the elevation above which all areas have been effectively dewatered for the current growing season, and 2) the elevation below which all areas have effectively been flooded for the current season.
2. Meadow marsh areas are assigned to elevations characterized by the flooding/dewatering and water depths conditions marked by “MM” in Table 1.
3. The total area of meadow marsh is calculated for a given year by summing all of the surface area associated with elevations that were characterized as being dominated by meadow marsh in step #2.

The current set of rules as described above for predicting meadow marsh coverage (Table 1) have been applied to predict the annual total meadow marsh area in Arcadia Lake based on the Lake Michigan observed monthly water levels for the 1900-2006 historical period.

Table1. Matrix of Vegetation Assignment Rules for Arcadia Lake Marsh based on Flooding and Dewatering History

Height "Above" Water Line:		Number of years dewatered:														
		0	1	2	3	4	5	6	7	8	9	10	11	21	31	40
Min	Max	0	1	2	3	4	5	6	7	8	9	10	20	30	40	999
-101	-999	n/a	MM	MM	MM	MM	MM	T	T	T	T	T	T	T	T	T
-91	-100	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-81	-90	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-71	-80	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-61	-70	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-51	-60	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-41	-50	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-31	-40	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-21	-30	n/a	EM	EM	EM	EM	EM	MM	MM	MM	MM	MM	MM	MM	MM	MM
-11	-20	n/a	EM	EM	EM	EM	EM	MM	MM	MM	MM	MM	MM	MM	MM	MM
0	-10	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM

Height "Below" Water Line:		Number of years flooded:														
		0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-21	-31	-40
Min	Max	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-20	-30	-40	-999
1	10	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
11	20	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
21	30	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
31	40	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
41	50	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
51	60	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
61	70	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
71	80	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
81	90	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
91	100	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
101	110	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
111	120	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
121	130	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
131	140	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
141	150	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
151	160	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
161	170	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
171	180	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
181	190	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
191	200	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL

The specific flooding/dewatering rules for the meadow marsh zone were established based on air photo interpretation for 17 years during the 1954-2010 period. For Arcadia Lake Marsh, there were no trends related to number of years since last flooded, largely because the flooding peaks are usually short-term events (i.e., 1952-55, 1973-76, 1985-86, and 1997). The high water years resulted in more submerged aquatic vegetation (SAV)/Open Water vegetation types; however, that vegetation does not persist when the water level decreases. When the water level goes down, the meadow marsh still exists because the vegetation that comprises the marsh can withstand short-term flooding. However, if flooding lasts long enough, the meadow marsh will be replaced by short emergent vegetation or SAV/Open Water vegetation. This response is represented with the LOSL IERM approach, which consists of determining the number of years since the last dewatering (lower summertime peak levels). Anything above the peak summertime water level elevation was dewatered that summer, thus favoring meadow marsh. The cut-off point appears to be about 4 years. For example, regarding the 2010 air photo: the lowest summertime peak over the previous 4 years was in 2007 (176.08 meters). Based on a review of the 2010 vegetation types that occurred in different elevation intervals, meadow marsh was found from the upper boundary of the DEM down to an elevation of 176.08 meters. Below 176.08 meters, the vegetation type switches to *Phragmites*, short emergent, and SAV/Open Water. The 4-year rule for flooding meadow marsh works quite well for most years, with the exception of years immediately after the 1986 high and in some early photo years when the DEM was not applicable due to ensuing erosion events. Elevations that were last dewatered 4 or more years ago are assigned to non-meadow marsh vegetation (a mix of short emergent and SAV/Open Water). Elevations that were last dewatered for less than 4 years are assigned to meadow marsh. Therefore, 4 or more years of summertime flooding are required to convert meadow marsh to short emergent or SAV/Open Water.

Coping Zone Criteria:

The following Coping Zone metrics were developed for Lake Michigan-Huron to identify circumstances where compression of the natural (i.e., pre-project) water level range is expected to have a significant detrimental impact on the abundance and diversity of meadow marsh and emergent marsh vegetative communities in Saginaw Bay and other wetland areas:

- **<u>LMH-01 Metric</u>:**
  - <u>For peak water level events</u>: plan-to-Pre-Project ratio for the maximum peak summertime water level (relative to the 109-year mean) when the Pre-Project peak is greater than 0.65 meter above the 109-year mean water level.

- **<u>LMH-02 Metric</u>:**
  - <u>For post-peak drawdown events</u>: plan-to-Pre-Project ratio of the maximum drawdown of summertime high water levels occurring within 5 years of a 'peak' water level event (only evaluated when the maximum drawdown for Pre-Project is at least 0.75 meter).

For the suite of range compression metrics, performance is evaluated based on how closely the plan mimics Pre-Project behavior for peak water level and post-peak event. For example, if the plan-to-PreProject ratios for a given alternative plan are *closer* to 1.0 than the Plan 77A ratio, this indicates that the alternative plan permits more natural water level range relative to 77A.

Note that analogous metrics related to water level range were developed for Lake Superior (SUP-01 and SUP-02). Those metrics are not associated with a specific vegetation PI, but are instead based on expert opinion that water level range requirements to maintain vegetation in Lake Superior are similar to those for Lakes Michigan-Huron and the other Great Lakes.

Calibration Data: The surface area of wetland in meadow marsh vegetation was determined by photointerpretation of imagery from 17 different years that represent a variety of hydrologic conditions: lake levels exceeding 177.19 m in 1952, 1974, 1986, and 1997 followed by decreases in lake levels by at least 0.75 m within four years after the high lake levels. Root Mean Square Error (RMSE) calculations for all images were very low.

Validation Data: Similar procedures have not been conducted at other sites on Lake Michigan-Huron. However, other meadow marsh dominated drowned river mouth wetlands that occur along the eastern shore of Lake Michigan (i.e., Pentwater, Pere Marquette, Lincoln, Little Manistee, and Betsie) could be used for validation. The rules-based modeling approach used in the IERM2 model was validated by Wilcox and Xie (2007).

Risk and Uncertainty Assessment: Data used in the assessment include three years during which ground-truthing was conducted as part of individual study protocols, thus providing control on accuracy of interpretations. Similar work was conducted at five other sites along this section of the Lake Michigan shoreline in 1995. The Arcadia Marsh data in 1995 are consistent with data at other sites.

Confidence, Significance and Sensitivity:

Confidence:

Spatial accuracy in comparing total area of the study site among sites was high. The quality of the aerial photographs varied; however, the images were viewed using Geographic Information System (GIS) software for photointerpretation, which allowed greater accuracy in delineating vegetation types. The temporal accuracy was high, as all aerial photographs were taken during the growing season at known dates in each year.

Significance: This and other wetland habitat models are significant because many other wetland PIs are dependent on the wetland vegetation/habitat model outputs. Specifically, the meadow marsh community represents vegetation that typically develops between the maximum, long-term high water level and the mean, long-term water level. Plant species within the meadow marsh community are intolerant to prolonged flooding; however, occasional flooding is required to prevent woody plant species from expanding downslope into the marsh. More importantly, periodic low water level cycles are required to prevent the expansion of aggressive emergent plants upslope into the meadow marsh community. During the low water period, emergent plant species will die back at higher elevations where the hydrology is no longer suitable. Coincidently, the hydrology does become suitable for meadow marsh plant species, which will expand, and result in the meadow marsh habitat expanding downslope. This low water cycle is of critical importance for maintaining the area of meadow marsh within coastal wetlands. As water levels fluctuate between the high and low water level cycles, the meadow marsh will typically contain some emergent, shrub, or upland plant species. The relative amount of these species is dictated by the number of years since the last high or low water level cycle. For this reason, the meadow marsh community supports a diversity of plant species but occurs in a relatively narrow hydrologic range in comparison to the other wetland vegetation communities. There are many species of amphibians, reptiles, birds and fish that require meadow marsh habitat at some point within their life cycle.

Sensitivity: The rules-based approach incorporated into the IERM2 model was sensitive for Lake Ontario but has not been tested on Arcadia Marsh of Lake Michigan.

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Fact Sheet ID: 07

Performance Indicator (PI) Name/Short Description: Sediment-water phosphorus flux in Arcadia Lake Marsh (Lake Michigan) and Saginaw Bay (Lake Huron)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Steinman, Ogdahl, Uzarski, and Cooper

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: Total soluble reactive phosphorus (SRP) mass released (kg) as a result of re-wetting of desiccated wetland sediments in Arcadia Lake Marsh (Lake Michigan) and Saginaw Bay (Lake Huron).

Ecological Importance/Niche: Both absolute nutrient concentrations and nutrient ratios (stoichiometry) can profoundly influence organismal physiology, species-level interactions, and ecosystem metabolism. In most aquatic ecosystems, external load is usually viewed as the major source of nutrients, but in certain systems such as shallow lakes and wetlands, internal loading can be a significant source of critical elements, including nitrogen (N), phosphorus (P), and sulfur (S). This is particularly true in Great Lakes coastal wetlands, where water level fluctuations can result in a range of redox conditions: under low water levels, wetland sediments become exposed, leading to oxidation; in contrast, a state of continual inundation can lead to reducing conditions. Hence, the type and availability of nutrients that may diffuse from the sediments into the overlying water column can be strongly influenced by the hydrologic regime. Because water levels in the Upper Great Lakes fluctuate naturally on both intra-annual and longer timescales (Baedke and Thompson 2000; Hanrahan et al. 2009), the release of nutrients from coastal sediments is an important driver of coastal ecosystem structure and function. Therefore, changes to the hydrologic regime may influence coastal communities by altering the magnitude and timing of nutrient release from wetland sediments.

Elements such as N and P are critical for autotrophic (e.g., green plants) growth, but there is a balance between nutrient sufficiency and excess. Nutrient release from the sediments can help drive the productivity of benthic and planktonic algae, as well as submerged aquatic vegetation; these autotrophs serve as critical food resources for herbivores and omnivores in coastal wetlands and as important substrate (material organisms can grow on) for invertebrate fauna. However, if too much N or P becomes available, then algal blooms can form which can 1) potentially release cyanotoxins; 2) shade out autotrophs growing below the surface scum; and 3) change the algal flora from a more preferred food resource (e.g., diatoms) to a less preferred resource (e.g., cyanobacteria).

We conducted experiments that involved the following procedure: sediment cores were collected from eight different sites (five eastern Lake Michigan drowned river mouth wetlands and three sites in Saginaw Bay); intentionally desiccated the sediment in a controlled environment; and then rewet the sediment for 48 hours. We then measured the resulting SRP, NO_3, NH_3, sulfate (SO_4), and chloride (Cl) concentrations in the overlying water column of each sediment core.

Temporal Validity: Sediment cores were collected on April 13 and 14, 2010, with desiccation beginning on April 15, 2010. Rewetting began on June 18, 2010.

Nutrient release rates are influenced by temperature (Steinman et al. 2009). Therefore, these release rates are likely to be lower in the colder season months. However, we believe the calculated rates should be valid for the coastal wetland growing season (June through August).

There is uncertainty with respect to how long the sediment cores are desiccated before rewetting. The longer the desiccation, the greater the opportunity for oxidation and mineralization of soils, with greater release rates (Reddy et al. 1999). Our data are based on a maximum of nine weeks desiccation—hence, rates may be higher if low water periods were longer than that duration; and how long the measured rate of release will continue. At some point, a new equilibrium will be established between the P in the sediment and water column, and the release rates will plateau. Hence, our release rates represent short-term maximum rates and should not be extrapolated over the entire summer (or year).

Spatial Validity: There is reasonably high certainty for the eight sampled wetlands, but data could be extrapolated with some degree of certainty to other drowned river mouth sites and throughout Saginaw Bay. Extrapolation to other coastal wetlands will likely result in low to moderate certainty, depending on sediment characteristics and wetland type. We do not recommend extrapolating these rates to Lake Superior coastal wetlands, given their different lithology, productivity, and geomorphology. Rather, we strongly recommend conducting experiments analogous to ours in coastal wetlands throughout Lake Superior.

Ultimately, specific PIs were developed for two areas where sufficient wetland bathymetry/topographic data were available: Saginaw Bay wetland areas and Arcadia Lake Marsh, which is representative of drowned river mouth wetlands in eastern Lake Michigan. The application of the eastern Lake Michigan flux data to Arcadia Lake Marsh was done to take advantage of the extensive bathymetric/topographic data available for this site. However, it is important to note that the flux analyses were not specifically conducted for sediments in Arcadia Lake Marsh, and therefore the flux data are being extrapolated to this site without any specific calibration or site-specific studies.

Hydrology Link: There are two major hydrologic links. The primary link is the drying and re-wetting of wetland sediments under differing water level regulation scenarios. As noted above, this phenomenon could increase nutrient flux to the water column, and consequently, primary production and respiration. The secondary link relates to factors that may affect the magnitude of nutrient flux upon re-wetting including: 1) whether the wetland is protected (allowing organic matter accumulation and greater opportunity for nutrient flux) or exposed (reducing sediment accrual); 2) duration of water drawdown; and 3) seasonality of drawdown and re-inundation. This study addressed only the primary link.

Algorithm: Algorithms were developed for SRP, NO_3, and NH_3, the most bioavailable forms of P and N, respectively (Figs. 1-3). Ultimately, only the SRP algorithm demonstrated a significant response to the desicattion/re-wetting cycle (Figure 1 and Table 1). Therefore, the PI was developed to specifically represent SRP flux from sediments to water.

We calculated mean release rates (mg $X/m^2/d$), where X = nutrient, for either drowned river mouths (n = 5) or Saginaw Bay (n = 3) sites, for each of the five (5) water level depths: upland (at treeline); 0 m (land-water interface); 0.25 m water depth; 0.50 m water depth; and 1.0 m water depth. With knowledge of system bathymetry, one can multiply the amount of exposed surface area by the appropriate release rate to calculate the amount of nutrient that would be released if water levels declined to that depth and then were rewetted. We normalized release rates by unit area and organic matter—rates were similar in both cases; we report here the areal release rates for the algorithms. We also explored if there were statistically significant functions that could be fit to the data. If so, these are reported.

Three Important Caveats:

1) The extrapolation should be based only on the areas in each system composed of coastal wetland, not on the entire lake system. For example, only a relatively small area of Muskegon Lake consists of coastal wetland. Although a considerable quantity of nutrient is likely to be released from exposed (and rewetted) sediment not located in coastal wetland, we did not sample those areas and do not know if the rates for coastal wetland sediment release are applicable to non-wetland areas. Hence, our system-level nutrient mass release will be underestimates.

2) The release rate from the upland site was based on sediment cores taken at the treeline to ensure we were sampling true upland areas. However, for the bathymetry extrapolations, we recommend multiplying release rates times the area associated with a 0.5 m rise in water levels. The use of the treeline for our upland sites helps us standardize our sampling approach; although, we recognize that the linear distance from water line to treeline varies among sites.

The calculated mass released will be based on sediments located between the land-water interface and 0.5 m water rise, even though we may not have sampled this area in our incubations. This approach may result in liberal estimates of release, as the more exposed the sediment (i.e., the more upland the sediment is located), the greater the likelihood of nutrient release. Ultimately, more intensive sampling in the upland areas is needed to assess soil heterogeneity and associated nutrient release potential.

3) As noted above in the temporal validity section, our two day release rates represent a maximal estimate because sampling is during the linear portion of nutrient release from the sediments. At some point, a new equilibrium is established between the P in the sediment and water column, resulting in a release rate plateau (Steinman et al. 2004). Hence, our release rates should not be extrapolated beyond the two day incubation period without longer incubations to determine when an asymptote is reached. To be conservative, we assume that an asymptote is reached after two days, which factors out any temporal extrapolation, but also clearly results in an underestimate of total release from these systems.

SRP Flux

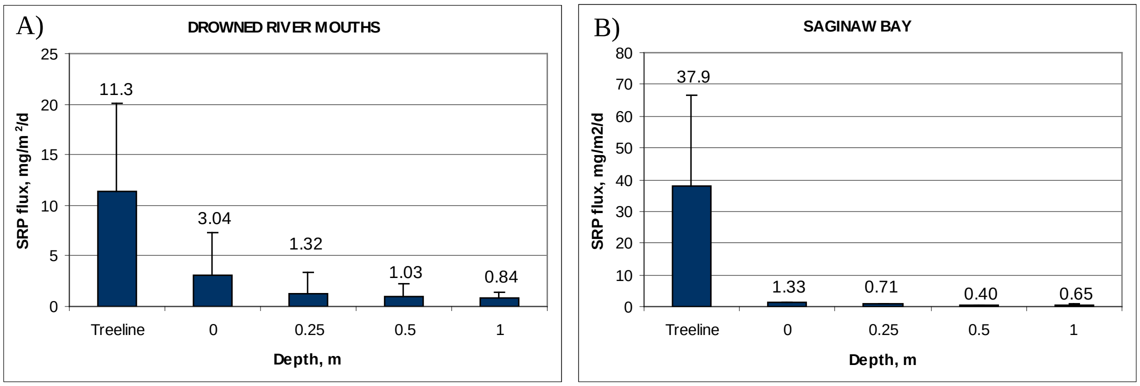

Figure 1: Mean SRP flux (± SD) from re-wetted sediments of five drowned river mouth lakes connected to Lake Michigan (A) and three locations on Saginaw Bay in Lake Huron (B); flux rates are expressed per unit area. The mean flux value is given above each bar.

Table 1. Mean SRP release rates (RR) different water level changes.

Water Level	**Drowned River Mouths**	**Saginaw Bay**
	Release Rate (RR) (mg P/m²/d)	*Release Rate (mg P/m²/d)*
Upland	11.3	37.9
0 m	3.04	1.33
0.25 m	1.32	0.71
0.5 m	1.03	0.40
1.0 m	0.84	0.65

Table 2. Multiply SRP release rate (RR) times exposed/rewetted area[a]:

Water Level Depths[c]	**Equations**
Upland	RR (mg P/m^2/d) x upland area (km^2) x d^b = XX kg P
0 m	RR (mg P/m^2/d) x 0 ± 0.10 m area[c] (km^2) x d^b= XX kg P
0.25 m	RR (mg P/m^2/d) x 0.25-0 m area (km^2)) x d^b = XX kg P
0.50 m	(RR (mg P/m^2/d) x 0.50-0.25 m area) + (RR (mg P/m^2/d) x 0.25-0 m area (km^2)) x d^b= XX kg P
1.0 m	(RR (mg P/m^2/d) x 1.0-0.50 m area) + (RR (mg P/m^2/d) x 0.50-0.25 m area) + (RR (mg P/m^2/d) x 0.25-0 m area (km^2)) x d^b= XX kg P

[a]These functions assume that when the water level fluctuates, it returns to original level.
[b]The value for d is 2; see caveat 3 for rationale in not including temporal extrapolation
[c]We arbitrarily assume water levels fluctuate ± 0.10 m due to wave action and seiches

We also found that an exponential decay function fit the data well (Figure 1):

RR (mg/m^2/day) = $a * e^{-kx}$;

Where a = constant; k = rate of change; x = depth to which lake is desiccated/re-wetted

Table 3. Table of constants for SRP RR function.

System	a	k	R^2
Drowned River Mouths	13.743	-0.6292	0.8708
Saginaw Bay	25.637	-0.9318	0.6478

Ammonia Flux

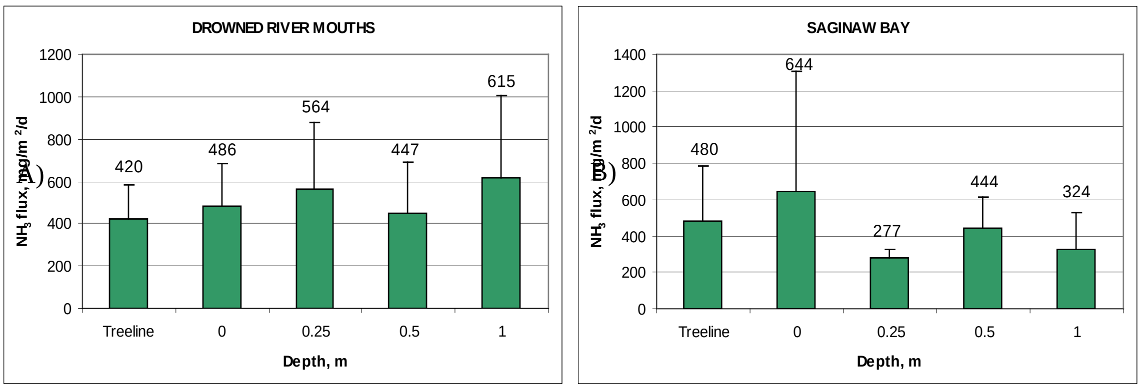

Figure 2: Mean NH_3 flux (± SD) from re-wetted sediments of five drowned river mouth lakes connected to Lake Michigan (A) and three locations on Saginaw Bay in Lake Huron (B); flux rates are expressed per unit area. The mean flux value is given above each bar.

Table 4. Mean NH_3 RR and associated surface area for different water level changes.

Water Depth	Drowned River Mouths	Saginaw Bay
	Release Rate (mg NH_3-N/m^2/d)	Release Rate (mg NH_3-N/m^2/d)
Upland	420	480
0 m	486	644
0.25 m	564	277
0.5 m	447	444
1.0 m	615	324

Table 5. Multiply NH_3 RR) times exposed/rewetted area[a]:

Water Level Depths[c]	Equations
Upland	RR (mg N/m^2/d) x upland area (km^2) x d[b]= XX kg N
0 m	RR (mg N/m^2/d) x 0 ± 0.10 m area[c] (km^2) x d[b]= XX kg N
0.25 m	RR (mg N/m^2/d) x 0.25-0 m area (km^2)) x d[b]= XX kg N
0.50 m	(RR (mg N/m^2/d) x 0.50-0.25 m area) + (RR (mg N/m^2/d) x 0.25-0 m area (km^2)) x d[b]= XX kg N

Water Level Depths[c]	Equations
1.0 m	(RR (mg N/m^2/d) x 1.0-0.50 m area) + (RR (mg N/m^2/d) x 0.50-0.25 m area) + (RR (mg N/m^2/d) x 0.25-0 m area (km^2) x d^b= XX kg N

[a]These functions assume that when the water level fluctuates, it returns to original level.
[b]The value for d is 2; see caveat 3 for rationale in not including temporal extrapolation
[c]We arbitrarily assume water levels fluctuate ± 0.10 m due to wave action and seiches

No statistically significant function fit the area-normalized data.

Nitrate Flux

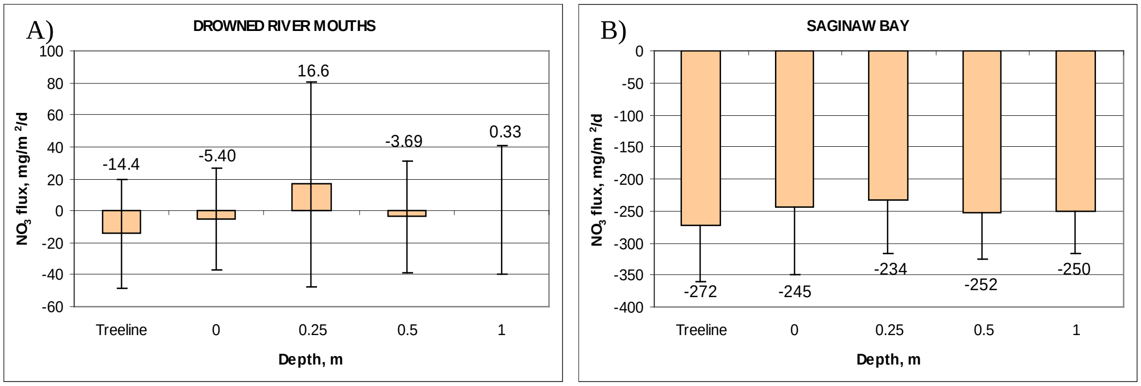

Figure 3: Mean nitrate flux (± SD) from re-wetted sediments of 5 drowned river mouth lakes connected to Lake Michigan (A) and 3 locations on Saginaw Bay in Lake Huron (B); flux rates are expressed per unit area. The mean flux value is given above each bar.

Table 6. Mean NO_3 RR and associated surface area for different water level changes.

Water Depth	Drowned River Mouths	Saginaw Bay
	Release Rate (mg NO3-N/m^2/d)	*Release Rate (mg NO_3-N/m^2/d)*
Upland	-14.4	-272
0 m	-5.40	-245
0.25 m	16.6	-234
0.5 m	-3.69	-252
1.0 m	0.33	-250

Table 7. Multiply NO_3 RR times exposed/rewetted area[a]:

Water Level Depths[c]	Equations
Upland:	RR (mg N/m^2/d) x upland area (km^2) x d^b= XX kg N
0 m:	RR (mg N/m^2/d) x 0 ± 0.10 m area[c] (km^2) x d^b = XX kg N
0.25 m:	(RR (mg N/m^2/d) x 0.25-0 m area (km^2)) x d^b = XX kg N

0.50 m:	((RR (mg N/m^2/d) x 0.50-0.25 m area) + (RR (mg N/m^2/d) x 0.25-0 m area (km^2)) x d^b = XX kg N
1.0 m:	((RR (mg N/m^2/d) x 1.0-0.50 m area) + (RR (mg N/m^2/d) x 0.50-0.25 m area) + (RR (mg N/m^2/d) x 0.25-0 m area (km^2)) x d^b = XX kg N

[a] *These functions assume that when the water level fluctuates, it returns to original level.*
[b] *The value for d is 2; see caveat 3 for rationale in not including temporal extrapolation*
[c] *We arbitrarily assume water levels fluctuate ± 0.10 m due to wave action and seiches*

No statistically significant function fit the area-normalized data.

Coping Zone Criteria:

The SRP flux PI depends on water level fluctuations to facilitate periodic drying and re-wetting of wetland sediments in order to recycle bioavailable phosphorus back to the water column. These requirements are consistent to the requirements for maintaining macroinvertebrate diversity and fish abundance in Saginaw Bay wetlands; therefore, the SRP flux PI was associated with the Coping Zone criteria that were developed by Uzarski et al. for inter-annual and intra-annual water level fluctuations:

LMH-03 Criterion:

- Zone B: Annual peak water level monotonically increases or decreases for a 7 consecutive year within a 10-year window.

- Zone C: Annual peak water level monotonically increases or decreases for 10 consecutive years.

LMH-04 Criterion:

- Zone B: Water level increases by less than 0.30 meter between January and July for any 7 years in a 9-year window.

- Zone C: Water level increases by less than 0.30 meter between January and July for 9 consecutive years.

Calibration Data: No specific calibration data are available from the Great Lakes; however, similar studies have been conducted in other regions of the world and may be useful for comparison purposes.

Validation Data: No specific validation data are available from the Great Lakes; however, similar studies have been conducted in other regions of the world and may be useful for comparison purposes.

Risk and Uncertainty Assessment: This PI metric is based on the following assumptions, which help create the appropriate "story":

- Redox reactions associated with desiccation and rewetting will affect nutrient release rates.
- Degree of wetland exposure will influence organic matter accumulation, which in turn will influence nutrient release rates.
- Nutrient release rates will affect system metabolism, which in turn will influence the wetland's productive capacity, an important ecosystem service.

Confidence, Significance and Sensitivity:

Confidence:
a) Spatial Confidence: Confidence in estimates is high at the sampled sites, moderate at sites in similar region (i.e., other Eastern Shore Lake Michigan drowned river mouth wetlands and Saginaw Bay wetlands), and unknown at sites outside those regions. One area of uncertainty is whether the release rates in the wetland regions can be extrapolated to non-wetland regions (of similar depths) in the same system. Given our lack of knowledge, we recommend applying release rates only to the percent surface area covered by wetland in each system, with the recognition this will highly underestimate the total mass of nutrient released in each system.

In addition, we are covering a gradient of anthropogenic disturbance in both regions, which make our results potentially applicable to a range of systems in each region. Additional studies, targeting new regions and employing a stratified random sampling approach, are needed to assess the generality of the results from the current study.

b) Temporal (seasonal) Confidence: Confidence is high for the spring season, when this study is conducted. However, it is unknown how applicable these results will be to other times of year, even if the times of desiccation and reflooding were the same. For example, release rates may be higher during warmer months than colder months because higher temperatures will increase metabolic activity and associated remineralization rates (Baldwin et al. 2005; Steinman et al. 2009).

c) Temporal (duration) Confidence: Confidence is high for hydroperiods (period of time a wetland is covered by water) that mimic our experimental conditions (four to eight week drawdown followed by short re-inundation). However, it is likely that longer drawdowns will result in greater oxidation and greater potential for nutrient release. An additional uncertainty stems from not knowing how long it takes after re-inundation for a quasi-equilibrium in nutrient concentration to be reached. At some point, nutrient release rates will plateau or decline, and then fluctuate around a steady state until a new hydrologic regime develops.

An estimate of uncertainty regarding release rates can be calculated by using the standard deviations of the mean release rates at each water depth. Currently, release rates are based on mean values (Tables 1, 4, and 6). However, high and low range estimates can also be calculated using the +1 (high) and -1 (low) standard deviation at each site. The calculation is exactly the same as outlined in the algorithm section; only the RR value is modified.

Significance: As a functional indicator, significance is high especially in nutrient-limited areas, where release rates may strongly influence system productivity. In nutrient-replete areas, this PI metric may be of less significance. Additionally, since the timing of the annual water level peak in the Upper Great Lakes coincides with peak vegetative biomass in coastal wetlands, nutrient-sediment interactions are likely important in determining algal and plant productivity. Alterations to the magnitude or timing of the annual water level peak could affect nutrient conditions and the coastal wetland food web.

Sensitivity: The sensitivity is unknown at present, but believed to be high based on studies in other wetlands. However, sensitivity is likely to be influenced by degree of wetland exposure (more protected ➔ more organic matter accumulation ➔ more nutrient release potential) and antecedent nutrient conditions.

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Fact Sheet ID: 08

Performance Indicator (PI) Name/Short Description: Wetland Connectivity – percentage of coastal wetland area connected to Georgian Bay (Georgian Bay, Lake Huron)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Chow-Fraser, Fracz

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: Relationship between proportion of wetlands or wetland area that are hydrologically connected to Georgian Bay as a function of water level for spring and fall spawning periods.

This PI metric provides information on the amount of fish habitat in eastern Georgian Bay (between Severn Sound and Key River) that is inaccessible to fish for any given water level between 162 and 176 m (above sea level (asl)).

Ecological Importance/Niche:

Summary:
Coastal wetlands of Georgian Bay are known to support critical spawning and nursery habitat for the fish community of Lake Huron. Midwood and Chow-Fraser (unpublished data) have shown that majority of the fish stay within their home wetland and do not migrate to adjacent wetlands even when they are in close proximity (within 750 m). Therefore, wetlands that are hydrologically disconnected from Georgian Bay are "lost" fish habitat, and this likely has serious implications for recruitment of the Lake Huron fishery.

Detailed Discussion:
The Great Lakes contain 78,405 ha of coastal wetland habitat in Canada, of which 30,882 ha (47.6%) are in Lake Huron; of those in Lake Huron, more than 50% (17,350 ha) are found in Georgian Bay (see McMaster Coastal Wetland Inventory (MCWI); Midwood et al. 2010). The coastal wetlands of eastern and northern Georgian Bay are some of the most pristine and diverse wetland assemblages in the Great Lakes basin (Chow-Fraser 2006; Croft and Chow-Fraser 2007). The water is exceptionally clear and nutrient poor, with good light penetration that support many plant taxa that would otherwise be excluded by competitive species. Such plant assemblages provide critical spawning and foraging habitat for a diverse fish community (Wei et al. 2004; Jude et al. 2005; Seilheimer and Chow-Fraser 2007) as well as many freshwater turtles (DeCatanzaro and Chow-Fraser 2010), some of which are species at risk including the Blanding's and Musk turtles (listed as threatened status in Ontario), and the Northern Map and Snapping turtles (listed as species of concern in Ontario). Since macrophyte coverage and density are directly tied to interannual water level variation (Quinlan and Mulamoottil 1987; Hudon 2004), water-level variation in the wetland through hydrologic connections to Georgian Bay is critical for maintaining diverse macrophyte communities (Wilcox and Meeker 1991; Midwood and Chow-Fraser unpublished data).

A recent study documented the effects of declining water levels on vegetation and muskellunge nursery habitat in five regions of Severn Sound in southeastern Georgian Bay (Hurley 2008, unpub. ms.). Shorelines in each habitat moved lakeward from 1987 to 2007, decreasing the amount of submerged aquatic habitat that had once supported nursery habitat for juvenile muskellunge (Black and Craig 1986). During a 1981 survey, biologists found a good representation of emergent and submergent vegetation (Black and Craig 1986); in 2007, however, when water levels were an average of 70 cm lower than that in 1982, only a very limited community of emergent vegetation, and almost no submergent cover was observed. These differences in water levels and in the plant communities corresponded with significant changes in the fish communities. The most notable difference was the complete absence of juvenile muskellunge, a lower proportion of yellow perch and largemouth bass, and a concomitant increase in the proportion of minnow species, especially banded killifish, which had not been present during the 1981 survey and which accounted for 25% of the total abundance in the 2007 survey. Compared with 1987 water levels (97 cm higher than that in 2007), fish habitat was estimated to have decreased by 39 to 81 % in 2007. Water level decline also changed the site morphology and increased exposure to wind and wave action that appeared to have prevented the re-establishment of aquatic plant communities. These areas will not likely become revegetated with the type of aquatic vegetation present during the 1980s until water levels increase to levels experienced prior to 1999. Midwood and Chow-Fraser (unpub. data) have also found that vegetation communities in two regions of eastern Georgian Bay have become significantly transformed following 6 years of sustained low water levels (net decline in water level of 10 cm between 2002 and 2008, and no more than 20 cm fluctuations during the intervening years). Consistent with Wilcox and Meeker (1991), they also observed that during periods of minimal water level fluctuation, aquatic vegetation increased in density and the structure of the habitat became increasingly homogeneous. On average, there was a significant increase in high-marsh (HM) vegetation cover (seasonally inundated; after OMNR 1993) and a significant decline in low-marsh (LM) vegetation (permanently inundated, which was associated with a structural change to a more homogenous community dominated by high-density floating vegetation.

Typically, coastal wetlands of the Great Lakes develop at the mouth of rivers or where many rivers empty into a delta, and where near-shore currents cause shifting sediments to accumulate. Lakes Ontario, Erie and Michigan are all surrounded by softer glacial deposits and sedimentary bedrock, materials that can be easily eroded and carried by rainwater or snowmelt to maintain the wetland substrate. By comparison, the igneous and metamorphic bedrock that surround much of eastern and northern Georgian Bay are resistant to erosion and therefore contribute very little nourishment to maintain the substrate layer that is so important to support plant roots. Therefore, wetlands there have developed from glacial deposits transported by coastal processes over the past four thousand years and are essentially irreplaceable. Furthermore, the bedrock material prevents hydrologic undercutting of streambeds in channels that connect the wetland to Georgian Bay. Consequently, wetlands become increasingly hydrologically disconnected from Georgian Bay as water levels decline. The result will be a dampening of annual water-level fluctuations that typically maintain diversity (Quinlan and Mulamoottil 1987; Hudon 2004), and a gradual transformation of wetland structure and species composition as described above.

Temporal Validity: An area estimate is computed for each model simulation year and is assumed to represent the growing season for that year. Quarter monthly water levels surrounding the annual peak are used to determine the proportion of wetlands that are hydrologically connected.

Spatial Validity: The McMaster Coastal Wetland Inventory (MCWI) was completed in April 2010 and identifies all the coastal wetlands along Eastern Georgian Bay (MCWI; Chow-Fraser unpublished data). In this study, we are only considering wetlands that are > 2 ha since this is the size criterion used by the Ontario Ministry of Natural Resources. In total, there are 404 wetland complexes >2 ha between Severn Sound and Key River, and it would have been impossible to collect information at all sites during the time available in 2010. Therefore, we performed a stratified random sampling procedure to ensure that we obtained at least 100 wetlands in proportion to their availability in quaternary (fourth level drainage area) watersheds (Figure 1). We used ArcMap 9.2 to import a shapefile of quaternary watershed boundaries (obtained from the Land Information Ontario, Ontario Ministry of Natural Resources) into the MCWI, and then assigned all wetlands into quaternary watersheds before selecting approximately 100 wetlands. We have high certainty that the data collected are representative of wetlands in eastern Georgian Bay since wetlands had been selected randomly and according to their availability in quaternary watersheds (Figure 2).

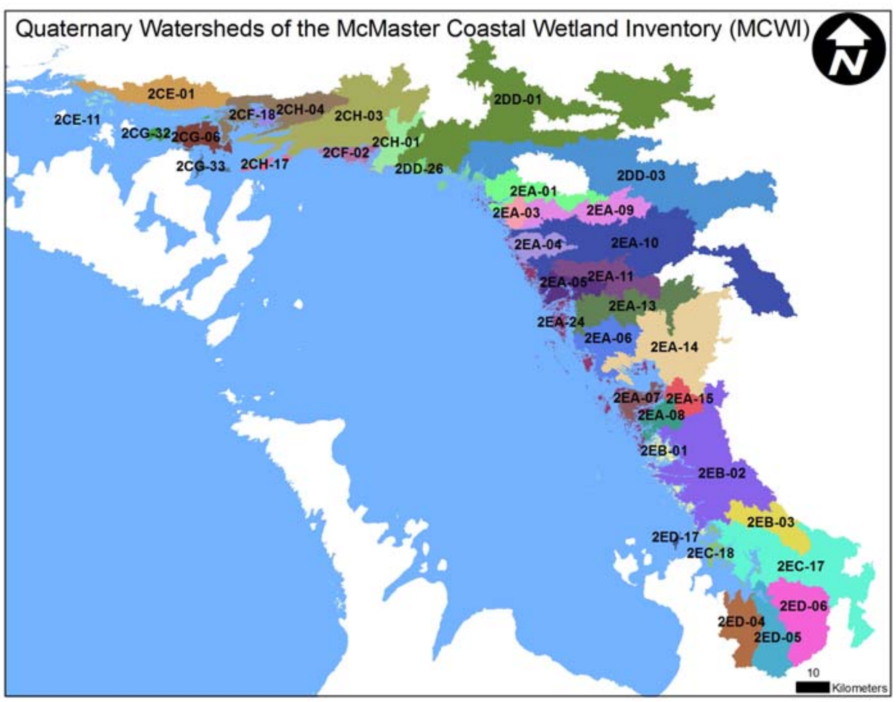

Figure 1. Boundaries and identifier of the quaternary watersheds delineated by Ontario Ministry of Natural Resources

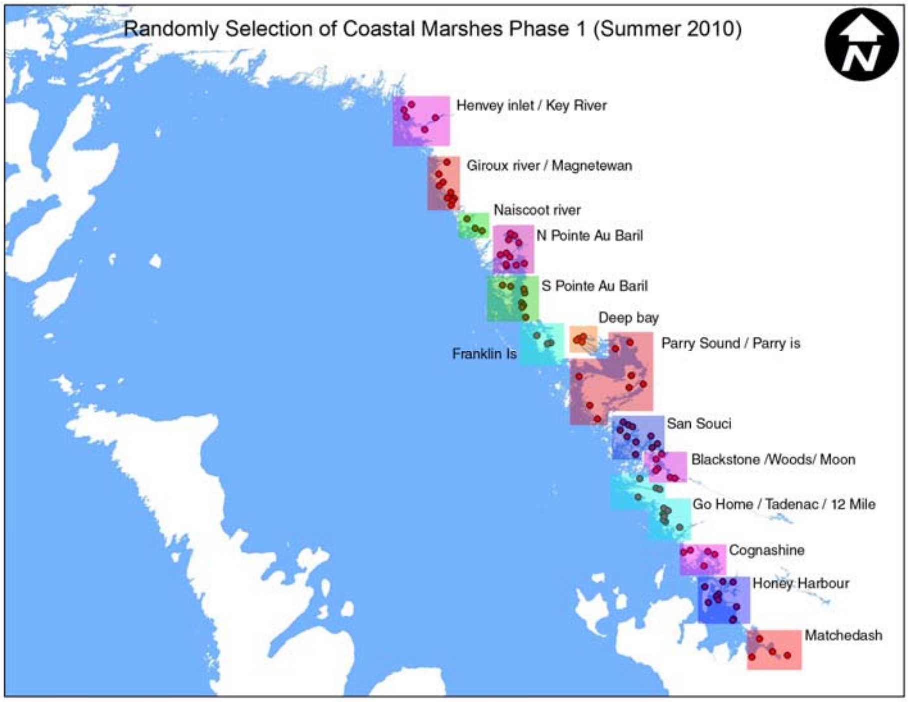

Figure 2. Location of study sites in Georgian Bay included in this study.

Hydrology Link: Typically, coastal wetlands of the Great Lakes develop at the mouth of rivers or where many rivers empty into a delta, and where nearshore currents cause shifting sediments to accumulate. Lakes Ontario, Erie and Michigan are all surrounded by softer glacial deposits and sedimentary bedrock, which are materials that can be easily eroded and carried by rainwater or snowmelt to maintain the wetland substrate. By comparison, the igneous and metamorphic bedrock that surrounds much of eastern and northern Georgian Bay are resistant to erosion and therefore, contribute very little nourishment to maintain the substrate layer that is so important to support plant roots. Therefore, wetlands in this region have developed from glacial deposits transported by coastal processes over the past four thousand years and are essentially irreplaceable. Furthermore, the bedrock material prevents hydrologic undercutting of streambeds in the channels that connect the wetland to Georgian Bay. Consequently, wetlands become hydrologically disconnected or "stranded" from Georgian Bay as water levels drop below the bottom of rock sills or the entrance to the wetland. We assume that any wetland stranded in this manner will be inaccessible to fish migration from Georgian Bay.

Algorithm:

Sill Depth Data Collection

All data were collected between May and September in 2010. We used three different methods to collect raw depth and elevation data: 1) a differential Global Positioning System (dGPS; Magellan ProMark 3®) base and roving unit; 2) a graduated pole to collect depth information manually together with a Garmin Etrex GPS (herein referred to as the Mobile GPS); and 3) a boat-mounted GPS and sonar depth sounder. We had to use all three methods because the water was too shallow on approach to the wetland entrances (<2 m) for us to use the boat safely, and too deep for us to use the dGPS while wading. To avoid water damage to the roving unit, we only used the dGPS and Mobile GPS equipment to a depth of ~1.2 m. For water depths between 1m and about 3 m, we used the graduated pole in a canoe. The accuracies associated with each source varied, with the dGPS being the most accurate (sub-meter horizontal accuracy and centimeter vertical accuracy). The Mobile GPS had 1m accuracy horizontally and a 0.5 cmaccuracy for depth. The depth sounder was the least accurate, with approximately 3m horizontal accuracy with good depth accuracy to 1 cm.

Deriving Elevation
Hourly water-level data (m, asl; IGLD 1985 datum) from Parry Sound are available from the Canadian Hydrographic Service (CHS) of the Department of Fisheries and Oceans (http://waterlevels.gc.ca/C&A/wldata/parythis.htm). Depth measurements recorded with the depth sounder and mobile GPS were converted to elevation (m, asl) with these hourly water-level data. The dGPS data were adjusted to actual elevation by scaling the values back to the water level recorded at Parry Sound for the specific day and time.

Identifying Sill Depths
All of the digital information was merged in ArcMap 9.2 and shapefiles were created for each wetland and overlain onto IKONOS (commercial earth observation satellite) imagery made available from Georgian Bay Forever for this project. Most of the images were acquired in 2002, but some had been acquired in 2005 and 2008. Elevation data were visually inspected to determine the sill depth at the entrance to the wetland. In total, 109 wetlands were selected and sampled (Figure 3). Of these, 4 were already stranded (i.e. hydrologically disconnected), 3 were heavily impacted by human activities, and of these only 1 were sufficiently intact to be included in subsequent analyses. Therefore, data for 103 wetlands were used to produce the empirical relationship between sill depth or maximum depth of wetland entrance and water level.

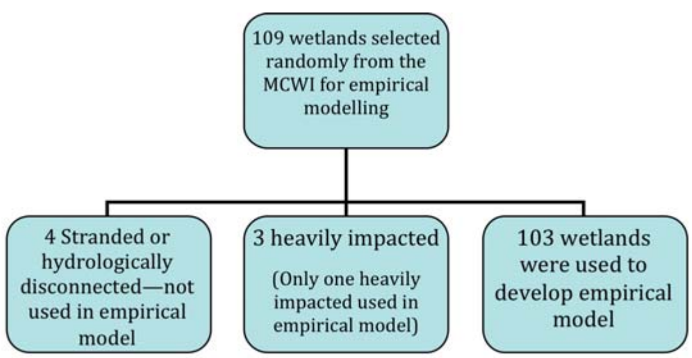

Figure 3. Flowchart for inclusion of wetlands in the empirical modeling.

The cumulative relative frequency of wetlands that would be stranded were calculated and expressed as percentages and plotted against the water level that corresponds to the elevation of the sill depth or maximum depth of wetland entrance (Figure 4).

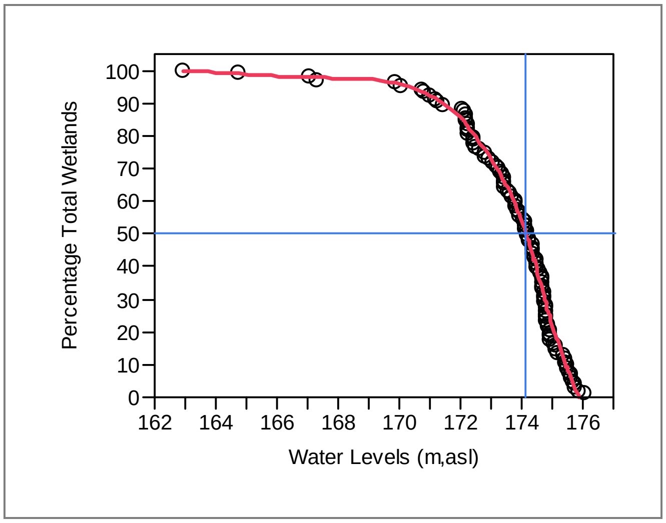

Figure 4. Percentage of wetlands that would be stranded as a function of water level. The red line is a spline fit (lambda=1). The water level that corresponds to a stranding of 50% of wetlands in this study is approximately 174.15 m above sea level, and is highlighted in blue.

Similarly, the total cumulative area expressed as percentages were also calculated and plotted against water levels (Figure 5).

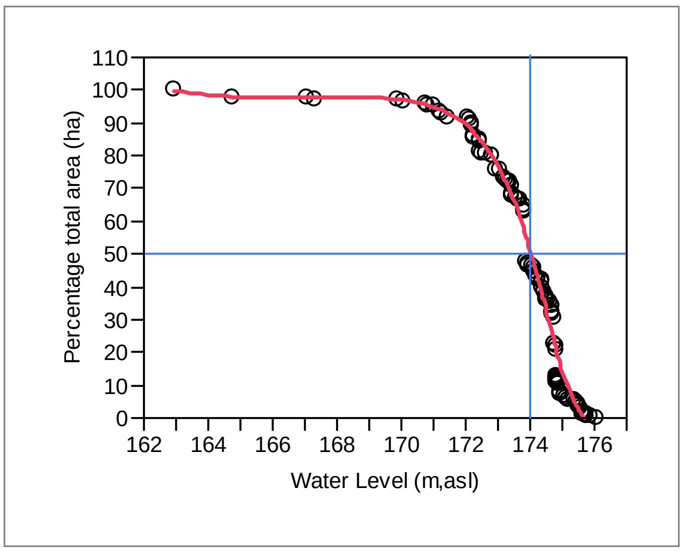

Figure 5. Percentage of total area that would be stranded as a function of water level. The red line is a spline fit (lambda=1). The water level that corresponds to a stranding of 50% of total wetland area in this study is approximately 174.00 m above sea level, and is highlighted in blue.

Raw data collected for this study can be found in Table 1, located at the end of this fact sheet.

Coping Zone Criteria:

Summary:
Coping zone criteria for Georgian Bay were developed based on joint consideration of this wetland connectivity PI and the accompanying aquatic vegetation transformation PI. The following coping zone criterion was developed to identify circumstances where extended low water levels and associated disconnection of wetland area would have a significant detrimental impact on fish spawning and aquatic vegetation in coastal wetlands along eastern Georgian Bay:

- **LMH-07:**
  - Zone B: Mean growing season (April-October) water level is less than 176.2 meters for any 3 years within a 5-year window.
  - Zone C: Mean growing season (April-October) water level is less than 176.0 meters for a period of 4 or more consecutive years.

An additional consideration in the eastern Georgian Bay region is the uplift rates associated with glacial isostatic adjustment. Ongoing uplift of the land surface in this region will tend to exacerbate the problem of coastal wetlands in the region becoming disconnected from Georgian Bay and Lake Huron in the future. Uplift rates at Parry Sound (located in Georgian Bay) are approximately 24 centimeters per century relative to the Lake Huron outlet (URL: http://www.iugls.org/the-glaciers-are-long-gone-but-theyre-still-affecting-water-levels.aspx). In order to recognize and account for the ongoing and future impact of glacial isostatic adjustment, a second coping zone criterion was developed to complement criterion "LMH-07". The rules for criterion "LMH-08" are the same as for criterion "LMH-07", but with a 12 cm adjustment to the water level thresholds to account for the effects of GIA over the next 50 years:

- **LMH-08:**
  - Zone B: Mean growing season (April-October) water level is less than 176.32 meters for any 3 years within a 5-year window.
  - Zone C: Mean growing season (April-October) water level is less than 176.12 meters for a period of 4 or more consecutive years.

Detailed Discussion:

It is important to recognize that the PIs developed for eastern Georgian Bay only account for water levels below 176 m. As noted in the PI fact sheet for amount of transformed wetland habitat, the increase in LM habitat associated with high water levels ranged from 39 to 81% in one case study. We do not have sufficient elevation data for sites above 176 m to determine the degree to which these results are representative of wetlands in the rest of eastern Georgian Bay, but such information is critical for understanding how much lost habitat has already accrued because of the past decade of near-record low water levels. It is also clear that there is a sharp, linear increase in habitat loss between 176 and 173 m (asl) in Figures 3 and 4 (PI fact sheet for restricted access to fish habitat), in the order of 28% loss per meter drop. *Based on this, we believe that significant, irreversible damage to the fish and wildlife community in eastern Georgian will occur at depths below 176 m, and that efforts should ensure that lake elevation* *are kept above this threshold level*. This is consistent with the findings of the 1993 IJC Levels Reference Study (LRS; International Joint Commission 1993), which also identified **176.0 m (576.8 ft; Table 1)** as the lower threshold for "crisis condition" for Huron-Michigan, beyond which damages would occur. They stated that "since major adverse impacts occur at these levels, they are extremes that are not wanted to be reached or exceeded; damages, however, could start occurring prior to reaching these levels." In addition, the LRS recognized that wetlands are the key measure of the aquatic health of the ecosystem, and that there is much still unknown about how wetlands react to changing water levels. "With past knowledge from prior crises periods, extreme events usually last no more than 5 years from the onset."

The health of coastal wetlands of eastern Georgian Bay is intimately tied to water level. Sustained water levels have resulted in less LM habitat, while remaining vegetation is denser and more homogeneous. There is a total of 6 157 km of shoreline in eastern Georgian Bay, covering 404 wetlands that are >2 ha in size, accounting for 5 182 ha of wetlands. Our analysis of hydrologic connection reveals that small decreases in the hydrograph between 173 and 176 m (asl) can lead to large changes in vegetation areal coverage, and will lead to loss of critical spawning and nursery habitat. Ongoing research in our lab also point to the importance of wetlands maintaining a minimum of 1 m of water in order for the Blanding's turtle (species at risk in Ontario) to overwinter in wetlands (Edge et al. 2009).

Calibration Data: See discussion above under "Algorithm" section.

Validation Data: None available.

Risk and Uncertainty: See discussion in following section.

Confidence, Significance and Sensitivity:

Confidence** (potential errors)**: Depending on the complexity of the wetland geomorphology, we may not have located the highest elevation associated with a sill, and in those instances, the sill elevation would have been underestimated. There was insufficient time in this study for us to conduct exhaustive field work to obtain anything other than a coarse coverage. In a few instances, water levels had dropped sufficiently so that portions of wetlands had already become hydrologically disconnected. In those cases, we subdivided the wetlands and carried out measurements accordingly.

Significance: The graphs show that 50% of wetlands would become stranded (hydrologically disconnected from Georgian Bay) if water levels were to drop to 174.1 m and that 50% of total wetland area would no longer be accessible to fish if water levels dropped to 174.0 m (Figures 4 and 5, respectively). Another way to interpret this relationship is that wetlands and wetland area are extremely sensitive to water level fluctuations between 173 and 176 m. Hence, a drop or increase of 30-40 cm has a significant impact within this range.

Sensitivity: There is a total of 6,157 km of shoreline in eastern Georgian Bay, covering 404 wetlands that are over 2 ha in size, accounting for 5,182 ha of wetlands. Small alterations in the water level can lead to large changes in area of wetlands that provide critical spawning and nursery habitat for many species of Lake Huron fish.

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Wilcox DA and Meeker JE (1991) Disturbance effects on aquatic vegetation in regulated and non-regulated lakes in northern Minnesota. Canadian Journal of Botany 69:1542-1551.

Table 1. Table of raw data for this study.

Elevation Depth	***Cumulative Frequency***	***Percent Cumulative Frequency***	***Area (ha)***	***Cumulative Area (ha)***	***Percent Cumulative Area***
162.9386	103	100	17.8741	814.21077	100
164.7752	102	99.029126	2.5169	796.33667	97.804733
167.0725	101	98.058252	0.6086	793.81977	97.495612
167.3007	100	97.087379	1.8162	793.21117	97.420864
169.8694	99	96.116505	5.9335	791.39497	97.197802
170.0809	98	95.145631	5.5462	785.46147	96.469059
170.7359	97	94.174757	3.2163	779.91527	95.787884
170.7904	96	93.203884	2.361	776.69897	95.392864
170.9975	95	92.23301	12.425	774.33797	95.10289
171.1769	94	91.262136	6.968	761.913	93.576876
171.246	93	90.291262	7.348	754.945	92.721078
171.4441	92	89.320388	3.3958	747.597	91.818609
172.0336	91	88.349515	2.6828	744.2012	91.401543
172.1022	90	87.378641	10.5691	741.5184	91.072046
172.1759	89	86.407767	1.0562	730.9493	89.773967
172.1946	88	85.436893	2.7302	729.8931	89.644246
172.2053	87	84.466019	27.0673	727.1629	89.308927
172.2447	86	83.495146	0.8812	700.0956	85.984567
172.2447	85	82.524272	1.5549	698.5407	85.793597
172.2485	84	81.553398	1027.349	.	.
172.2628	83	80.582524	3.8599	697.6595	85.685369
172.4202	82	79.611651	1.471	693.7996	85.211303
172.4202	81	78.640777	24.9292	684.3117	84.046015
172.4202	80	77.669903	9.4879	659.3825	80.984252
172.4979	79	76.699029	1.1413	657.9115	80.803587
172.6428	78	75.728155	3.0333	656.7702	80.663414
172.807	77	74.757282	3.6926	653.7369	80.290869
172.809	76	73.786408	31.4752	650.0443	79.83735
172.9257	75	72.815534	2.4633	618.5691	75.971619
173.0703	74	71.84466	16.6402	616.1058	75.669081
173.2163	73	70.873786	6.7462	599.4656	73.625359
173.2519	72	69.902913	4.9247	592.7194	72.796802
173.3039	71	68.932039	3.1342	587.7947	72.191959
173.4006	70	67.961165	6.1005	584.6605	71.807022
173.449	69	66.990291	23.3037	578.56	71.057768
173.4517	68	66.019418	3.1123	555.2563	68.195647
173.4527	67	65.048544	2.0058	552.144	67.8134
173.4674	66	64.07767	4.1309	550.1382	67.567051
173.5424	65	63.106796	4.3492	546.0073	67.0597
173.5943	64	62.135922	1.3793	541.6581	66.525539
173.6939	63	61.165049	13.4073	540.2788	66.356136
173.788	62	60.194175	8.4096	526.8715	64.709474
173.8212	61	59.223301	7.6082	518.4619	63.676621
173.8242	60	58.252427	122.8171	510.8537	62.742194

Elevation Depth	***Cumulative Frequency***	***Percent Cumulative Frequency***	***Area (ha)***	***Cumulative Area (ha)***	***Percent Cumulative Area***
173.8806	59	57.281553	5.9304	388.0366	47.658004
173.9068	58	56.31068	1.5165	382.1062	46.929642
173.9489	57	55.339806	4.224	380.5897	46.743388
174.0594	56	54.368932	5.3384	376.3657	46.224604
174.0995	55	53.398058	5.926	371.0273	45.56895
174.1012	54	52.427185	3.6851	365.1013	44.841129
174.1306	53	51.456311	6.1423	361.4162	44.388531
174.1898	52	50.485437	3.4707	355.2739	43.634144
174.2058	51	49.514563	4.8639	351.8032	43.207879
174.2229	50	48.543689	3.0208	346.9393	42.610503
174.2493	49	47.572816	1.882	343.9185	42.239493
174.362	48	46.601942	2.3765	342.0365	42.008349
174.3699	47	45.631068	16.0059	339.66	41.716471
174.3775	46	44.660194	1.6969	323.6541	39.750654
174.403	45	43.68932	7.9159	321.9572	39.542243
174.4103	44	42.718447	9.6317	314.0413	38.570026
174.4691	43	41.747573	4.5574	304.4096	37.387076
174.5275	42	40.776699	6.2724	299.8522	36.827344
174.5299	41	39.805825	2.4779	293.5798	36.056978
174.5721	40	38.834952	2.1427	291.1019	35.752647
174.6205	39	37.864078	11.122	288.9592	35.489484
174.6668	38	36.893204	0.4404	277.8372	34.123499
174.6671	37	35.92233	11.4259	277.3968	34.06941
174.6681	36	34.951456	4.5228	265.9709	32.6661
174.6681	35	33.980583	2.8976	263.0733	32.310221
174.684	34	33.009709	11.6141	258.5505	31.754739
174.7237	33	32.038835	61.0853	246.9364	30.328314
174.7263	32	31.067961	2.0669	185.8511	22.82592
174.7623	31	30.097087	1.368	183.7842	22.572067
174.7713	30	29.126214	1.5881	182.4162	22.404052
174.7896	29	28.15534	9.1802	180.8281	22.209004
174.7956	28	27.184466	64.9474	171.6479	21.081507
174.8112	27	26.213592	5.8288	106.7005	13.104776
174.8168	26	25.242718	6.21	100.8717	12.388893
174.8194	25	24.271845	2.6213	94.6617	11.626191
174.8433	24	23.300971	2.1573	92.0404	11.304248
174.8762	23	22.330097	6.0057	89.8831	11.039292
174.8794	22	21.359223	18.4707	83.8774	10.301682
174.9137	21	20.38835	0.9664	65.4067	8.0331412
174.9574	20	19.417476	3.0513	64.4403	7.9144495
174.9588	19	18.446602	0.66	61.389	7.539694
174.9682	18	17.475728	7.7209	60.729	7.4586339
175.0817	17	16.504854	1.5949	53.0081	6.5103659
175.114	16	15.533981	3.5977	51.4132	6.314483
175.1284	15	14.563107	2.2129	47.8155	5.8726195
175.16	14	13.592233	0.9881	45.6026	5.6008348

Elevation Depth	***Cumulative Frequency***	***Percent Cumulative Frequency***	***Area (ha)***	***Cumulative Area (ha)***	***Percent Cumulative Area***
175.38	13	12.621359	2.4749	44.6145	5.479478
175.4601	12	11.650485	1.322	42.1396	5.175515
175.4637	11	10.679612	6.398	40.8176	5.0131491
175.4688	10	9.7087379	4.9663	34.4196	4.2273575
175.52	9	8.7378641	2.933	29.4533	3.6174049
175.548	8	7.7669903	10.7554	26.5203	3.2571788
175.6229	7	6.7961165	4.9037	15.7649	1.9362186
175.6245	6	5.8252427	0.7064	10.8612	1.3339544
175.6936	5	4.8543689	1.8413	10.1548	1.2471955
175.771	4	3.8834952	2.5386	8.3135	1.0210501
175.776	3	2.9126214	0.6702	5.7749	0.7092635
175.849	2	1.9417476	2.7459	5.1047	0.6269507
176.058	1	0.9708738	2.3588	2.3588	0.2897039

Appendix

Use of the McMaster Coastal Wetland Inventory (MCWI) to develop Performance Indicators

The 1993 LRS recommended that appropriate wetland inventories be completed to support further work to understand the impacts of water levels on wetlands throughout the Great Lakes. The McMaster Coastal Wetland Inventory (MCWI) is such a comprehensive inventory for eastern and northern Georgian Bay and complements earlier efforts by the Great Lakes Coastal Wetland Consortium (GLCWC; Ingram et al. 2004) to document the distribution of coastal wetland complexes in all five Great Lakes. Where Georgian Bay is concerned, however, the MCWI is the only inventory that provides consistent wetland coverage because it was delineated with imagery acquired during similar water-level conditions (between 2002 and 2008; mean of 176.12 m ± 0.13). By comparison, wetlands in the GLCWC were digitized from aerial photos or satellite images acquired at different years (from 1983 to 1999; mean of 176.78 ± 0.29), and were not standardized to a consistent water level. If there is any temporal discrepancy in image acquisition, wetlands in images that are acquired during low water levels may have greater amounts of emergent and wet-meadow habitat (Hudon 2004) than the same wetlands delineated with imagery acquired during higher water levels. Another difference is that only high-resolution satellite imagery (IKONOS (pan-sharpened 1 m resolution) and Quickbird (60-cm resolution) were used to digitize the MCWI (Midwood, J., Rokitnicki-Wojcik, D. and Chow-Fraser, P., in submission).

The MCWI and the GLCWC inventory also differ with respect to the level of detail provided by each inventory for eastern and northern Georgian Bay. The GLCWC inventory only identified 21% of wetlands (by area) available in the MCWI. The MCWI raises some important issues concerning the minimum mapping unit of inventories. The GLCWC inventory used a minimum mapping unit of 2 ha to identify coastal wetland habitat. In our objectives for the MCWI, we decided to identify all coastal marsh habitat possible with the resolution of our imagery. This identified a unique characteristic of this region in that majority of the coastal wetlands are <2ha (Midwood, J., Rokitnicki-Wojcik, D. and Chow-Fraser, P., in submission). To be consistent with OMNR's practice, however, we have excluded all wetlands < 2 ha in developing our Performance Indicators, even though we know that many of the smaller wetlands are known to provide critical fish habitat to the Lake Huron fishery (Cvetkovic et al. 2010; Midwood and Chow-Fraser, unpub. data).

Fact Sheet ID: 09

Performance Indicator (PI) Name/Short Description: Submerged Aquatic Vegetation (SAV) potential – percentage of wetland area not transformed to a non-diverse aquatic vegetation community (Georgian Bay, Lake Huron)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Midwood, Fracz and Chow-Fraser

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: Percentage of wetland area that has not been transformed to non-diverse aquatic vegetation cover, as a function of hydrologic connectivity to Georgian Bay. This PI metric provides information on the amount of transformed aquatic vegetation in coastal wetlands of eastern Georgian Bay as a function of water level between 163 and 176 m (above sea level, asl).

Ecological Importance/Niche:

Pre-eminent quality of Georgian Bay coastal wetlands
The coastal wetlands of eastern Georgian Bay support one of the most pristine and diverse macrophyte communities in the Great Lakes basin (Chow-Fraser 2006; Croft and Chow-Fraser 2007). This vegetation provides critical spawning and foraging habitat for a diverse fish community (Wei et al. 2004; Jude et al. 2005; Seilheimer and Chow-Fraser 2007) as well as many freshwater turtles (DeCatanzaro and Chow-Fraser 2010). Macrophyte coverage and density are directly tied to interannual water level variation (Quinlan and Mulamoottil 1987; Hudon 2004) and consequently, water level variation through hydrologic connections is critical for maintaining diverse macrophyte communities (Wilcox and Meeker 1991; Midwood and Chow-Fraser unpublished data).

Effect of water-level decline on fish communities
We have conducted a study on the effects of changing water levels on vegetation and muskellunge nursery habitat in the Severn Sound area of southeastern Georgian Bay (Hurley 2008, unpublished master's thesis.). The musky fishery in Georgian Bay is recognized as being a world-class trophy fishery, and there is concern that their nursery habitat has been adversely impacted by the past decade of declining water levels. Shorelines for five historical muskellunge nursery habitats have moved lakeward from 1987 to 2007, decreasing the amount of submerged aquatic habitat that had once supported nursery habitat for juvenile muskellunge (Black and Craig 1986). During a 1981 survey, biologists found a good representation of emergent and submergent vegetation (Black and Craig 1986) when water levels had been on average 70 cm higher than in 2007; however, we found a very limited community of emergent vegetation and almost no submergent cover during the summer of 2007. These differences in water levels and in plant communities corresponded with significant changes in fish communities. The most notable differences were the complete absence of juvenile muskellunge, a lower proportion of yellow perch and largemouth bass, and a concomitant increase in the proportion of minnow species, especially banded killifish. The banded killifish had not been

present during the 1981 survey and accounted for 25% of the total abundance in the 2007 survey. Compared with 1987 water levels (97 cm higher than in 2007), we estimate that fish habitat had decreased by 39 to 81 % in 2007. Water level decline changed site morphology and increased exposure to wind and wave action, which appeared to have prevented the re-establishment of aquatic plant communities. We do not expect these areas to become revegetated with aquatic plants until water levels return to pre-1999 conditions.

Effect of sustained water levels on aquatic vegetation communities

We report results from an ongoing study (Midwood and Chow-Fraser, unpublished data) that examines the transformation of vegetation communities in two regions of eastern Georgian Bay following six consecutive years of sustained low water levels (i.e., 2002 and 2008). Consistent with Wilcox and Meeker (1991), we have also observed that aquatic vegetation increases in density and the structure of the habitat becomes increasingly homogeneous during periods of minimal water level fluctuation. IKONOS (commercial earth observation satellite) images of Tadenac Bay and North Bay regions of eastern Georgian Bay were acquired in July 2002 and 2008. A process tree classification (PTC) was developed to identify four vegetation classes; meadow (M), high-density floating (HD; >50% surface cover), low-density floating (LD; <50% surface cover), and emergent (E; Midwood and Chow-Fraser 2010). Between 2002 and 2008, there was a net decline in water level of about 10 cm, and during the intervening years, water levels fluctuated interannually by no more than 20 cm (Figure 1). Using a post-classification comparison (Lillesand et al. 2005) we were able to assess changes in wetland vegetation coverage between 2002 and 2008. On average, there was a significant increase in meadow vegetation cover (paired t-test; mean = +2020.9 m^2, prob>|t| = <0.0001, DF=83) and a significant decline in aquatic vegetation (HD, LD and E; paired t-test; mean = -1181.5m^2, prob>|t| = <0.0001, DF=83), which was associated with a structural change to a more homogenous community dominated by HD vegetation.

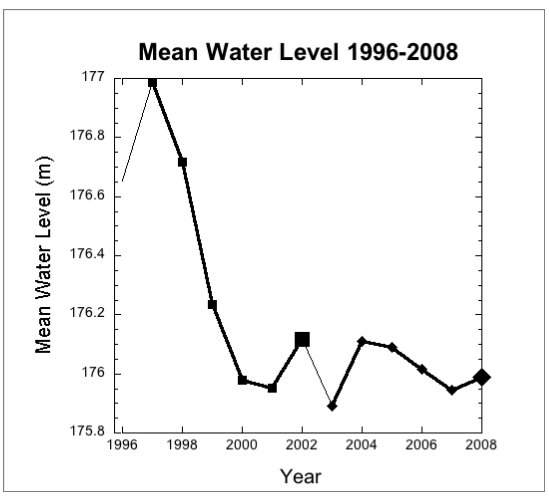

Figure 1. Change in water levels of Lake Huron from 1996 to 2008 (Data from Canadian Hydrographic Services, Department of Fisheries and Oceans). The large square and diamond represent the years IKONOS imagery acquisition. Thicker lines show the water levels in the five years preceding imagery

Development of PI for amount of aquatic vegetation
This PI is an estimate of total wetland area that would become transformed from a diverse aquatic vegetation community to one that is homogeneous and lacking a diverse community of submersed aquatic vegetation. We believe that wetlands must be hydrologically connected with Georgian Bay at least once every three years, and the point of connection must be at least 30 cm deep. Additionally, water levels must fluctuate by more than 30 cm over a five year period.

Temporal Validity: An area estimate is computed for each model simulation year and is assumed to represent the growing season for that year. Quarter monthly water levels surrounding the annual peak are used to determine the proportion of wetlands that are hydrologically connected.

Spatial Validity: The McMaster Coastal Wetland Inventory (MCWI) was completed in April 2010 and identifies all the coastal wetlands along Eastern Georgian Bay (MCWI; Chow-Fraser unpublished data). In this study, we are only considering wetlands that are > 2 ha since this is the size criterion used by the Ontario Ministry of Natural Resources. In total, there are 404 wetland complexes >2 ha between Severn Sound and Key River, and it would have been impossible to collect information at all sites during the time available in 2010. Therefore, we performed a stratified random sampling procedure to ensure that we obtained at least 100 wetlands in proportion to their availability in quaternary (fourth level drainage area) watersheds (Figure 2). We used ArcMap 9.2 to import a shapefile of quaternary watershed boundaries (obtained from the Land Information Ontario, Ontario Ministry of Natural Resources) into the MCWI, and then assigned all wetlands into quaternary watersheds before selecting approximately 100 wetlands. We have high certainty that the data collected are representative of wetlands in eastern Georgian Bay since wetlands had been selected randomly and according to their availability in quaternary watersheds (Figure 3). To assess the impact of sustained low water levels on aquatic vegetation in Georgian Bay wetlands, 84 wetlands (mean size =1.4± 12.0 ha) were selected in two regions, Tadenac Bay and North Bay. This subset of wetlands is not statistically representative of the 400+ wetlands located along the eastern shore of Georgian Bay but can be used to estimate change.

Hydrology Link: Typically, coastal wetlands of the Great Lakes develop at the mouth of rivers or where many rivers empty into a delta, and where nearshore currents cause shifting sediments to accumulate. Lakes Ontario, Erie and Michigan are all surrounded by softer glacial deposits and sedimentary bedrock, which are materials that can be easily eroded and carried by rainwater or snowmelt to maintain the wetland substrate. By comparison the igneous and metamorphic bedrock that surrounds much of eastern and northern Georgian Bay are resistant to erosion and therefore, contribute very little nourishment to maintain the substrate layer that is so important to support plant roots. Therefore, wetlands in this region have developed from glacial deposits transported by coastal processes over the past four thousand years and are essentially irreplaceable. Furthermore, the bedrock material prevents hydrologic undercutting of streambeds in the channels that connect the wetland to Georgian Bay. Consequently, wetlands become increasingly hydrologically disconnected from Georgian Bay as water levels decline. We assume with increasing disconnection from the Bay, vegetation coastal marshes will be influenced less by the annual variation in water levels that typically maintain diversity (Quinlan and

Mulamoottil 1987; Hudon 2004). The result will be a net loss of aquatic vegetation for eastern and northern Georgian Bay.

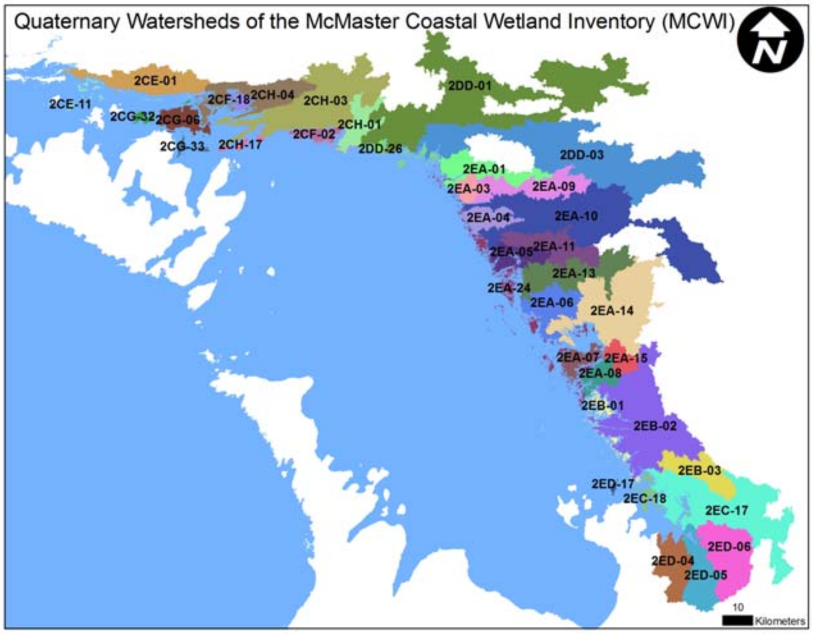

Figure 2. Boundaries and identifier of the quaternary watersheds delineated by Ontario Ministry of Natural Resources

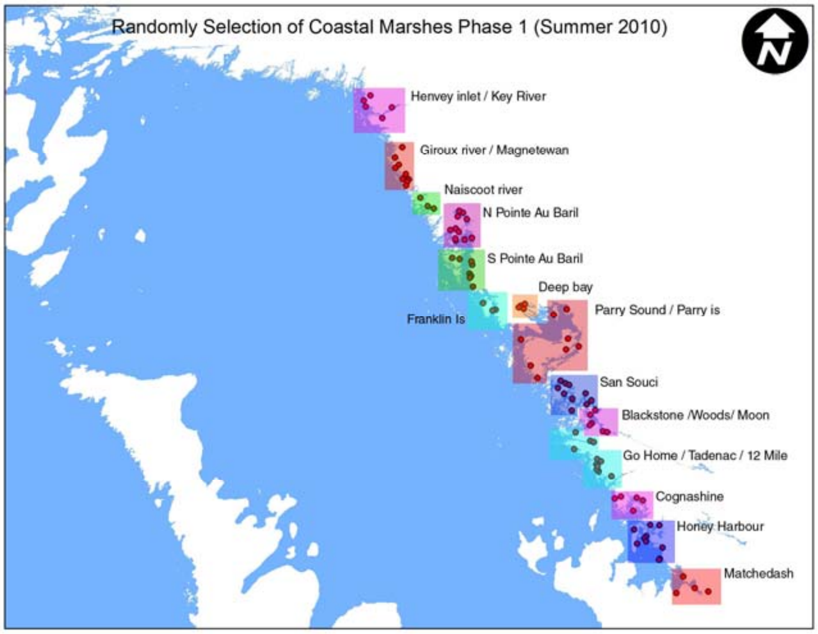

Figure 3. Location of sites sampled for the assessment of hydrologic connectivity in eastern Georgian Bay.

Algorithm:

Depth Data Collection
All data were collected between May and September in 2010. We used three different methods to collect depth and elevation data: 1) a differential Global Positioning System (dGPS; Magellan ProMark 3®) base and roving unit; 2) a graduated pole to collect depth information manually together with a Garmin Etrex GPS (herein referred to as the Mobile GPS); and 3) a boat-mounted GPS and sonar depth sounder. We had to use all three methods because the water was too shallow on approach to the wetland entrances (<2 m) for us to use the boat safely, and too deep for us to use the dGPS while wading. To avoid water damage to the roving unit, we only used the dGPS and Mobile GPS equipment to a depth of ~1.2 m. For water depths between 1m and about 3 m, we used the graduated pole in a canoe. The accuracies associated with each source varied, with the dGPS being the most accurate (sub-meter horizontal accuracy and centimeter vertical accuracy). The Mobile GPS had 1m accuracy horizontally and a 0.5 cmaccuracy for depth. The depth sounder was the least accurate, with approximately 3m horizontal accuracy with good depth accuracy to 1 cm.

Deriving Elevation
Hourly water-level data (m, asl; IGLD 1985 datum) from Parry Sound are available from the Canadian Hydrographic Service (CHS) of the Department of Fisheries and Oceans (http://waterlevels.gc.ca/C&A/wldata/parythis.htm). Depth measurements recorded with the depth sounder and mobile GPS were converted to elevation (m, asl) with these hourly water-level data. The dGPS data were adjusted to actual elevation by scaling the values back to the water level recorded at Parry Sound for the specific day and time.

Identifying Hydrological Connectivity Depth
All digital information was merged in ArcMap 9.2 and shapefiles were created for each wetland and overlain onto IKONOS imagery made available from Georgian Bay Forever for this project. Most images were acquired in 2002, but some had been acquired in 2005 and 2008. Elevation data were visually inspected to determine the shallowest depth at the entrance to the wetland. We assumed that a minimum hydrological connection of 30 cm was necessary to maintain an adequate connection to Georgian Bay and that any drop below this elevation would result in aquatic vegetation in the wetland being transformed to undesirable habitat (see above). For the 103 wetlands in this study, we determined the lake elevation that corresponds to 30 cm above the maximum depth at each wetland entrance (i.e., "*tipping points*"). These tipping points were sorted by descending order to determine the percentage of wetlands that would become transformed as a function of water levels between 163 and 173 m (asl). The cumulative frequency (expressed as percentage of total wetlands) of transformed wetlands was plotted against lake elevation (Figure 4). Similarly, the total cumulative area expressed as percentages were also calculated and plotted against water levels (Figure 5). For this relationship, we excluded Matchedash Bay because it was an outlier, with a total area of 1,027 ha, while most wetland size ranged from <1.0 to 122 ha.

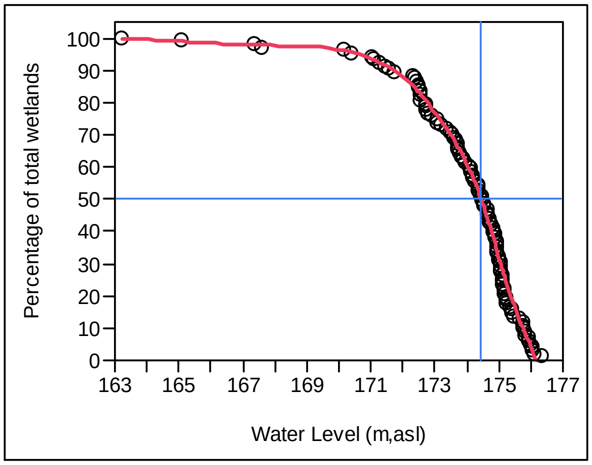

Figure 4. Percentage of coastal wetlands that would become transformed communities as a function of water level decline. The red line is a spline fit (lambda =1). The water level that corresponds to 50% of transformed coastal wetlands is 174.45 m above sea level (n=103).

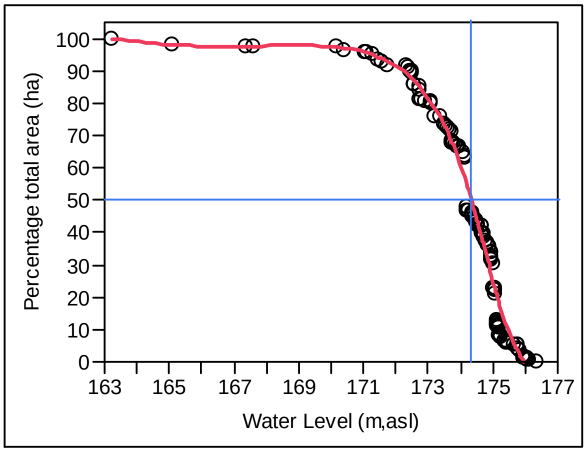

Figure 5. Percentage of coastal wetland area that would become transformed communities as a function of water level decline. The red line is a spline fit (lambda =1). The water level that corresponds to 50% of areal loss of coastal wetlands is 174.30 m above sea level (n=102).

Raw data collected for this study can be found in Table 1, located at the end of this fact sheet.

Coping Zone Criteria:

Summary:
Coping zone criteria for Georgian Bay were developed based on joint consideration of this wetland connectivity PI and the accompanying aquatic vegetation transformation PI. The following coping zone criterion was developed to identify circumstances where extended low water levels and associated disconnection of wetland area would have a significant detrimental impact on fish spawning and aquatic vegetation in coastal wetlands along eastern Georgian Bay:

- **LMH-07:**
  - Zone B: Mean growing season (April-October) water level is less than 176.2 meters for any 3 years within a 5-year window.
  - Zone C: Mean growing season (April-October) water level is less than 176.0 meters for a period of 4 or more consecutive years.

An additional consideration in the eastern Georgian Bay region is the uplift rates associated with glacial isostatic adjustment. Ongoing uplift of the land surface in this region will tend to exacerbate the problem of coastal wetlands in the region becoming disconnected from Georgian Bay and Lake Huron in the future. Uplift rates at Parry Sound (located in Georgian Bay) are approximately 24 centimeters per century relative to the Lake Huron outlet (URL: http://www.iugls.org/the-glaciers-are-long-gone-but-theyre-still-affecting-water-levels.aspx). In order to recognize and account for the ongoing and future impact of glacial isostatic adjustment, a second coping zone criterion was developed to complement criterion “LMH-07”. The rules for criterion “LMH-08” are the same as for criterion “LMH-07”, but with a 12 cm adjustment to the water level thresholds to account for the effects of GIA over the next 50 years:

- **LMH-08:**
  - Zone B: Mean growing season (April-October) water level is less than 176.32 meters for any 3 years within a 5-year window.
  - Zone C: Mean growing season (April-October) water level is less than 176.12 meters for a period of 4 or more consecutive years.

Detailed Discussion:

It is important to recognize that the PIs developed for eastern Georgian Bay only account for water levels below 176 m. As noted in the PI fact sheet for amount of transformed wetland habitat, the increase in LM habitat associated with high water levels ranged from 39 to 81% in one case study. We do not have sufficient elevation data for sites above 176 m to determine the degree to which these results are representative of wetlands in the rest of eastern Georgian Bay, but such information is critical for understanding how much lost habitat has already accrued because of the past decade of near-record low water levels. It is also clear that there is a sharp, linear increase in habitat loss between 176 and 173 m (asl) in Figures 3 and 4 (PI fact sheet for restricted access to fish habitat), in the order of 28% loss per meter drop. *Based on this, we* *believe that significant, irreversible damage to the fish and wildlife community in eastern Georgian will occur at depths below 176 m, and that efforts should ensure that lake elevation are kept above this threshold level.* This is consistent with the findings of the 1993 IJC Levels Reference Study (LRS; International Joint Commission 1993), which also identified **176.0 m (576.8 ft; Table 1)** as the lower threshold for "crisis condition" for Huron-Michigan, beyond which damages would occur. They stated that "since major adverse impacts occur at these levels, they are extremes that are not wanted to be reached or exceeded; damages, however, could start occurring prior to reaching these levels." In addition, the LRS recognized that wetlands are the key measure of the aquatic health of the ecosystem, and that there is much still unknown about how wetlands react to changing water levels. "With past knowledge from prior crises periods, extreme events usually last no more than 5 years from the onset."

The health of coastal wetlands of eastern Georgian Bay is intimately tied to water level. Sustained water levels have resulted in less LM habitat, while remaining vegetation is denser and more homogeneous. There is a total of 6 157 km of shoreline in eastern Georgian Bay, covering 404 wetlands that are >2 ha in size, accounting for 5 182 ha of wetlands. Our analysis of hydrologic connection reveals that small decreases in the hydrograph between 173 and 176 m (asl) can lead to large changes in vegetation areal coverage, and will lead to loss of critical spawning and nursery habitat. Ongoing research in our lab also point to the importance of wetlands maintaining a minimum of 1 m of water in order for the Blanding's turtle (species at risk in Ontario) to overwinter in wetlands (Edge et al. 2009).

Calibration Data: See discussion above in "Algorithm" section.

Validation Data: None available.

Risk and Uncertainty: See discussion in following section.

Confidence, Significance and Sensitivity:

Confidence (potential errors): Depending on the complexity of the wetland geomorphology, we may not have located the highest elevation associated with the wetland opening, and in those instances, the elevation would have been underestimated. There was insufficient time in this study for us to conduct exhaustive field work to obtain anything other than a coarse coverage. In a few instances, water levels had dropped sufficiently so that portions of wetlands had already become hydrologically disconnected. In those cases, we subdivided the wetlands and carried out measurements accordingly.

We are confident in our assessment of the observed vegetation changes that occurred between 2002 and 2008. The lack of statistically representative sampling limits the transferability of the findings to all of eastern Georgian Bay. Despite this concern, the geographic and environmental factors that govern wetland vegetation distribution are largely consistent throughout Georgian Bay. For the purposes of this study, we are confident that the changes observed in two regions can be transferred to other areas of the Bay with a high degree of accuracy.

Significance: Our results show that beyond what habitat has already been lost due to the current sustained low water levels, an additional 50% of currently existing would become sufficiently disconnected with Georgian Bay and the community of aquatic vegetation would become transformed to an undesirable state if water levels were to drop to 174.45 m (asl) (Figure 4). Similarly, 50% of total wetland area would no longer support a healthy and diverse macrophyte community if water levels reached 174.30 m (asl) (Figure 5). Another way to interpret this relationship is that the type of aquatic vegetation in these wetlands is extremely sensitive to water level fluctuations between 173 and 176 m. Hence, a drop or increase of 30-40 cm within this range can have a significant impact.

Our assessment of change in areal vegetation cover between 2002 and 2008 is not directly tied to lake levels. Instead, it is presented to demonstrate the importance of maintaining natural water level fluctuations. In the 404 wetlands identified in eastern Georgian Bay, sustained low water levels have resulted in a net loss of 435.3 ha (8.4% of 5,182 ha) of aquatic vegetation in coastal wetlands. The remaining vegetation is also increasingly homogeneous, providing less desirable habitat for fishes.

Sensitivity: The coastal wetlands of eastern Georgian Bay are intimately tied to water level. We have demonstrated that sustained water levels result in less aquatic vegetation, while remaining vegetation is denser and more homogeneous. There is a total of 6,157 km of shoreline in eastern Georgian Bay, covering 404 wetlands that are over 2 ha in size, accounting for 5,182 ha of wetlands. Our analysis of hydrologic connection reveals that small alterations in water levels can lead to large changes in vegetation areal coverage and consequently, severely impacting critical spawning and nursery habitat for many species of Lake Huron fish. Ongoing research in our lab also points to the importance of wetlands maintaining a minimum of 1 m of water in order for the Blanding's turtle (species at risk in Ontario) to overwinter in wetlands (Edge et al. 2009).

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Table 1. Table of raw data for this study.

Tipping depth	*Cumulative Frequency*	*Percent Cumulative Frequency*	*Area (ha)*	*Cumulative Area (ha)*	*Percent Cumulative Area*
163.238629	103	100.0000000	17.8741	814.2108	100.0000000
165.075159	102	99.0291262	2.5169	796.3367	97.8047330
167.372536	101	98.0582524	0.6086	793.8198	97.4956116
167.600652	100	97.0873786	1.8162	793.2112	97.4208644
170.169443	99	96.1165049	5.9335	791.3945	97.1978017
170.380853	98	95.1456311	5.5462	785.4615	96.4690592
171.035930	97	94.1747573	3.2163	779.9153	95.7878842
171.090422	96	93.2038835	2.3610	776.6990	95.3928637
171.297464	95	92.2330097	12.4250	774.3380	95.1028896
171.476916	94	91.2621359	6.9680	761.9130	93.5768763
171.546000	93	90.2912621	7.3480	754.9450	92.7210782
171.744072	92	89.3203883	3.3958	747.5970	91.8186092
172.333644	91	88.3495146	2.6828	744.2012	91.4015427
172.402225	90	87.3786408	10.5691	741.5184	91.0720457
172.475909	89	86.4077670	1.0562	730.9493	89.7739666
172.494620	88	85.4368932	2.7302	729.8931	89.6442459
172.505280	87	84.4660194	27.0673	727.1629	89.3089273
172.544679	86	83.4951456	0.8812	700.0956	85.9845669
172.544679	85	82.5242718	1.5549	698.5407	85.7935967
172.548538	84	81.5533981	1027.3485	not used	not used
172.562764	83	80.5825243	3.8599	697.6595	85.6853692
172.720179	82	79.6116505	1.4710	693.7996	85.2113028
172.720179	81	78.6407767	24.9292	684.3117	84.0460148
172.720179	80	77.6699029	9.4879	659.3825	80.9842523
172.797856	79	76.6990291	1.1413	657.9115	80.8035865
172.942781	78	75.7281553	3.0333	656.7702	80.6634140
173.106962	77	74.7572816	3.6926	653.7369	80.2908692
173.108989	76	73.7864078	31.4752	650.0443	79.8373502
173.225699	75	72.8155340	2.4633	618.5691	75.9716190
173.370296	74	71.8446602	16.6402	616.1058	75.6690806
173.516326	73	70.8737864	6.7462	599.4656	73.6253592
173.551879	72	69.9029126	4.9247	592.7194	72.7968022
173.603892	71	68.9320388	3.1342	587.7947	72.1919588
173.700589	70	67.9611650	6.1005	584.6605	71.8070216
173.749011	69	66.9902913	23.3037	578.5600	71.0577684
173.751680	68	66.0194175	3.1123	555.2563	68.1956471
173.752727	67	65.0485437	2.0058	552.1440	67.8133996
173.767397	66	64.0776699	4.1309	550.1382	67.5670507
173.842399	65	63.1067961	4.3492	546.0073	67.0597004
173.894347	64	62.1359223	1.3793	541.6581	66.5255390
173.993909	63	61.1650485	13.4073	540.2788	66.3561357
174.088030	62	60.1941748	8.4096	526.8715	64.7094736
174.121240	61	59.2233010	7.6082	518.4619	63.6766206

Tipping depth	***Cumulative Frequency***	***Percent Cumulative Frequency***	***Area (ha)***	***Cumulative Area (ha)***	***Percent Cumulative Area***
174.124205	60	58.2524272	122.8171	510.8537	62.7421943
174.180606	59	57.2815534	5.9304	388.0366	47.6580041
174.206797	58	56.3106796	1.5165	382.1062	46.9296424
174.248886	57	55.3398058	4.2240	380.5897	46.7433884
174.359418	56	54.3689320	5.3384	376.3657	46.2246038
174.399504	55	53.3980583	5.9260	371.0273	45.5689504
174.401178	54	52.4271845	3.6851	365.1013	44.8411291
174.430556	53	51.4563107	6.1423	361.4162	44.3885313
174.489844	52	50.4854369	3.4707	355.2739	43.6341443
174.505837	51	49.5145631	4.8639	351.8032	43.2078787
174.522916	50	48.5436893	3.0208	346.9393	42.6105027
174.549336	49	47.5728155	1.8820	343.9185	42.2394931
174.662047	48	46.6019417	2.3765	342.0365	42.0083490
174.669850	47	45.6310680	16.0059	339.6600	41.7164713
174.677508	46	44.6601942	1.6969	323.6541	39.7506535
174.703000	45	43.6893204	7.9159	321.9572	39.5422431
174.710300	44	42.7184466	9.6317	314.0413	38.5700255
174.769097	43	41.7475728	4.5574	304.4096	37.3870763
174.827524	42	40.7766990	6.2724	299.8522	36.8273441
174.829886	41	39.8058252	2.4779	293.5798	36.0569784
174.872148	40	38.8349515	2.1427	291.1019	35.7526469
174.920464	39	37.8640777	11.1220	288.9592	35.4894841
174.966827	38	36.8932039	0.4404	277.8372	34.1234987
174.967053	37	35.9223301	11.4259	277.3968	34.0694095
174.968055	36	34.9514563	4.5228	265.9709	32.6660997
174.968055	35	33.9805825	2.8976	263.0733	32.3102213
174.983979	34	33.0097087	11.6141	258.5505	31.7547386
175.023685	33	32.0388350	61.0853	246.9364	30.3283143
175.026343	32	31.0679612	2.0669	185.8511	22.8259203
175.062253	31	30.0970874	1.3680	183.7842	22.5720671
175.071254	30	29.1262136	1.5881	182.4162	22.4040516
175.089612	29	28.1553398	9.1802	180.8281	22.2090038
175.095609	28	27.1844660	64.9474	171.6479	21.0815071
175.111158	27	26.2135922	5.8288	106.7005	13.1047764
175.116848	26	25.2427184	6.2100	100.8717	12.3888929
175.119350	25	24.2718447	2.6213	94.6617	11.6261912
175.143298	24	23.3009709	2.1573	92.0404	11.3042475
175.176192	23	22.3300971	6.0057	89.8831	11.0392915
175.179352	22	21.3592233	18.4707	83.8774	10.3016815
175.213738	21	20.3883495	0.9664	65.4067	8.0331412
175.257415	20	19.4174757	3.0513	64.4403	7.9144495
175.258778	19	18.4466019	0.6600	61.3890	7.5396950
175.268249	18	17.4757282	7.7209	60.7290	7.4586339
175.381683	17	16.5048544	1.5949	53.0081	6.5103659
175.414012	16	15.5339806	3.5977	51.4132	6.3144830

Tipping depth	***Cumulative Frequency***	***Percent Cumulative Frequency***	***Area (ha)***	***Cumulative Area (ha)***	***Percent Cumulative Area***
175.428435	15	14.5631068	2.2129	47.8155	5.8726195
175.460000	14	13.5922330	0.9881	45.6026	5.6008348
175.680000	13	12.6213592	2.4749	44.6145	5.4794780
175.760114	12	11.6504854	1.3220	42.1396	5.1755150
175.763700	11	10.6796117	6.3980	40.8176	5.0131491
175.768767	10	9.7087379	4.9663	34.4196	4.2273575
175.820000	9	8.7378641	2.9330	29.4533	3.6174049
175.848000	8	7.7669903	10.7554	26.5203	3.2571788
175.922900	7	6.7961165	4.9037	15.7649	1.9362186
175.924500	6	5.8252428	0.7064	10.8612	1.3339544
175.993613	5	4.8543689	1.8413	10.1548	1.2471955
176.071000	4	3.8834952	2.5386	8.3135	1.0210502
176.076000	3	2.9126214	0.6702	5.7749	0.7092635
176.149000	2	1.9417476	2.7459	5.1047	0.6269507
176.358000	1	0.9708738	2.3588	2.3588	0.2897039

Appendix

Use of the McMaster Coastal Wetland Inventory (MCWI) to develop Performance Indicators

The 1993 LRS recommended that appropriate wetland inventories be completed to support further work to understand the impacts of water levels on wetlands throughout the Great Lakes. The McMaster Coastal Wetland Inventory (MCWI) is such a comprehensive inventory for eastern and northern Georgian Bay and complements earlier efforts by the Great Lakes Coastal Wetland Consortium (GLCWC; Ingram et al. 2004) to document the distribution of coastal wetland complexes in all five Great Lakes. Where Georgian Bay is concerned, however, the MCWI is the only inventory that provides consistent wetland coverage because it was delineated with imagery acquired during similar water-level conditions (between 2002 and 2008; mean of 176.12 m ± 0.13). By comparison, wetlands in the GLCWC were digitized from aerial photos or satellite images acquired at different years (from 1983 to 1999; mean of 176.78 ± 0.29), and were not standardized to a consistent water level. If there is any temporal discrepancy in image acquisition, wetlands in images that are acquired during low water levels may have greater amounts of emergent and wet-meadow habitat (Hudon 2004) than the same wetlands delineated with imagery acquired during higher water levels. Another difference is that only high-resolution satellite imagery (IKONOS (pan-sharpened 1 m resolution) and Quickbird (60-cm resolution) were used to digitize the MCWI (Midwood, J., Rokitnicki-Wojcik, D. and Chow-Fraser, P., in submission).

The MCWI and the GLCWC inventory also differ with respect to the level of detail provided by each inventory for eastern and northern Georgian Bay. The GLCWC inventory only identified 21% of wetlands (by area) available in the MCWI. The MCWI raises some important issues concerning the minimum mapping unit of inventories. The GLCWC inventory used a minimum mapping unit of 2 ha to identify coastal wetland habitat. In our objectives for the MCWI, we decided to identify all coastal marsh habitat possible with the resolution of our imagery. This identified a unique characteristic of this region in that majority of the coastal wetlands are <2ha (Midwood, J., Rokitnicki-Wojcik, D. and Chow-Fraser, P., in submission). To be consistent with OMNR’s practice, however, we have excluded all wetlands < 2 ha in developing our Performance Indicators, even though we know that many of the smaller wetlands are known to provide critical fish habitat to the Lake Huron fishery (Cvetkovic et al. 2010; Midwood and Chow-Fraser, unpub. data).

Fact Sheet ID: 10

Performance Indicator (PI) Name/Short Description: Meadow and Emergent Marsh – surface area in Mackinac Bay and Duck Bay (Les Cheneaux Islands, Lake Huron)

<u>Note</u>: Although the PIs for meadow marsh and emergent marsh described in this fact sheet were specifically applied to Les Cheneaux Islands wetlands (Mackinaw Bay and Duck Bay), the Coping Zone criteria described in the document apply more broadly to wetlands in Lake Michigan, Lake Huron, and the St. Clair River Delta that have been studied by Dennis Albert. The development of specific PIs for these other wetlands was not possible due to limited available topographic/bathymetric information, but anecdotal information is available to help broaden the coping zone criteria beyond the Les Cheneaux Island sites.

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Dennis Albert

Modeled by: LimnoTech (Redder, DePinto)

Ecological Importance/Niche: Both the meadow marsh and emergent marsh zones are recognized as providing important habitat. The meadow marsh is recognized as breeding habitat for waterfowl, including ducks and geese, as well as habitat for rare plants and animals. Emergent marsh is recognized as providing feeding and spawning habitat for many commercially important fish (Jude and Pappus 1992; Jude et al. 2005; Uzarski et al. 2005).

Emergent marsh vegetation has been shown to greatly reduce wave energy (Figure 1) and accumulate sediments (Figure 2) (Albert and Cox, unpublished data). Wave energy reduction is important to the residential and agricultural communities located near to the Great Lakes coast, especially during high water periods. Sediment accumulation within coastal wetlands is important during both high and low water conditions, as demonstrated along Saginaw Bay in the early 2000s, when sand drifted against buildings and across roads following removal of wetland vegetation.

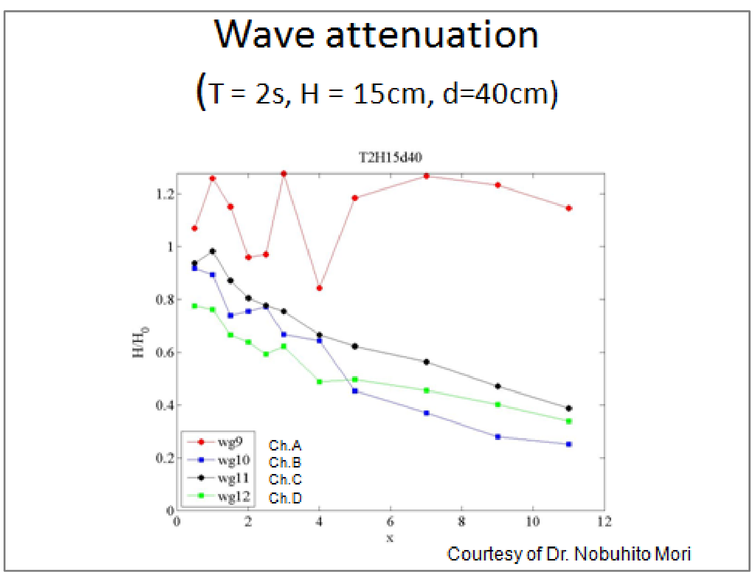
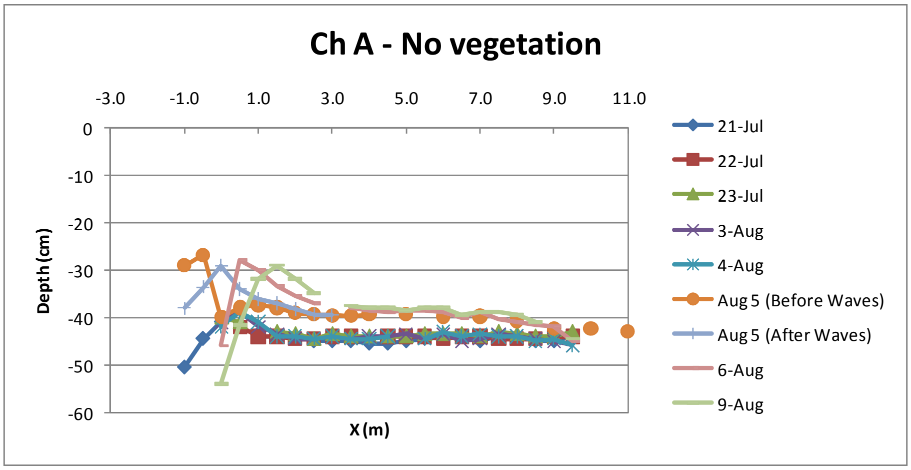


Figure 1. Wave attenuation study. Channel A is a control containing no vegetation, while Channels B and D contain mats of bulrush at typical nearshore densities, and Channel C contains a more thinly planted restoration bed of bulrushes. The height of the waves (H) in the control bed remains similar to the initial height of the waves (H_o) before the waves reach across the entire 10 meters of the plant beds, while wave height decreases rapidly to 0.3 to 0 .4 cm from the initial height over the length of the vegetated beds (B, C, and D).



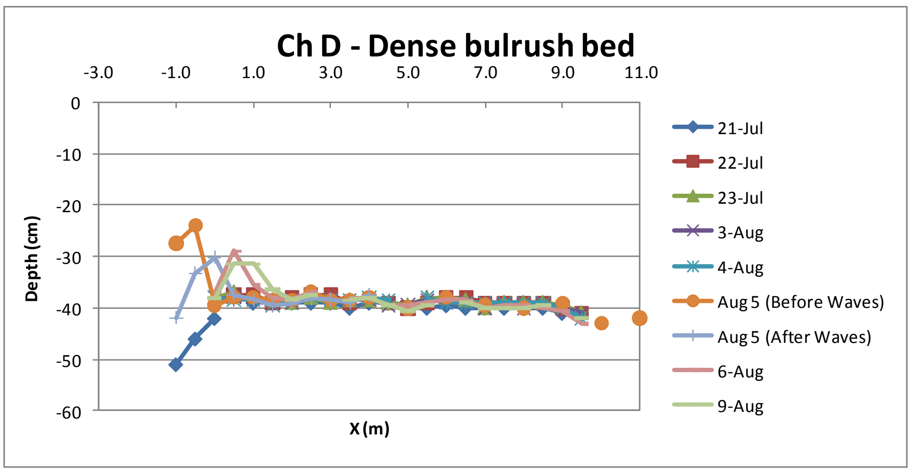


Figure 2. Different rates of sand movement in a 10 meter long bed of bare sand and sand with bulrushes (Schoenoplectus pungens). Sand deposited at the front of the unvegetated bed (Channel A) was moved throughout the entire bed by waves run on August 5-9th. In contrast, sand deposited at the front of the vegetated bed (Channel D) moved very slowly through the vegetation, advancing less than 2 meters by the end of the study on August 9th.

PI Metric: The PI metric represents the surface area of meadow marsh and emergent marsh zones in two Les Cheneaux Islands wetlands (Mackinaw Bay, Duck Bay) based on the response of these two zones to changes in water level fluctuation. The PI metric is based on the following: a) lost zone or reduced zone width, b) replacement of native vegetation by invasive plants, c) replacement of herbaceous plants by trees or shrubs, and d) reduced floristic diversity.

Temporal Validity: The assignment of meadow marsh and emergent marsh vegetation for this PI occurs on an annual basis and is determined by the flooding and dewatering history for the various elevation intervals that occur within Mackinaw Bay and Duck Bay. The long-term temporal validity is limited to the length of our studies of vegetation communities and structure in coastal wetlands. With the introduction of accurate Global Positioning System (GPS) locations and detailed bathymetry to our vegetation studies, there is the potential for developing long-term databases with much greater resolution.

Spatial Validity: Two scales must be evaluated; the regional scale of the marsh types should be considered first, and the scale of the local landscape should be considered second. The regional scale is based on the hydrogeomorphic features where the marshes occur (Albert et al. 2006). Marsh zones have been examined within several marsh types, including fringing wetlands, protected embayments, connecting rivers, and deltas on connecting rivers. On the delta of the St. Clair River there is evidence of meadow marsh loss and as well as large portions of the emergent marsh loss due to competition from invasive plants. There is similar evidence that marshes are being replaced by invasive species in other southern wetlands along Lake Michigan, southern Lake Huron, Lake St. Clair, and the Detroit River and western Lake Erie, but no data sets are available to document these changes.

A second scale of thresholds for wetland persistence occurs where marsh zones can move either upslope in the event of long-term rises in water level, or downslope if water levels continue to drop. While the dynamics of vegetation establishment (as seedlings) or persistence allows such movement, human structures and constraints, as well as geomorphic constraints may exist. Agricultural land use, human settlement along the shoreline, and highway construction limit the upward migration of marshes in most landscapes, including the Les Cheneaux Islands, where roads or homes are located near the current boundaries of most marshes. On Saginaw Bay, Lake St. Clair, and Lake Erie, agricultural land management and residential structures form a boundary for upward migration of coastal wetlands, and this has resulted in dramatic declines of some rare plant species associated with the meadow zone, including *Platanthera leucophaea* (prairie fringed-orchid), *Asclepias sullivantii* (Sullivant's milkweed), *Asclepias hirtella* (tall green milkweed), and *Cypripedium candidum* (white lady slipper).

Another threshold that will become important if water levels drop more than a meter below current water levels is the shallowness of the bays in the Les Cheneaux Islands. Water depths in Mackinac, Duck, Peck, and inner Voight Bays are roughly a meter during current water conditions, limiting the downward expansion of wetlands into these bays. Similar restrictions occur in portions of Saginaw Bay, for example within the Wildfowl Bay Islands area and several of the sand-spit embayments (Pinconning, inner Fish Point, Nayanquing, and Saganing), but most of the remaining bay slopes gradually to deeper water.

Hydrology Link:

a. Lost zone or reduced zone width. Two long-term databases were examined to determine the effects of water level variation on Great Lakes coastal wetland vegetation.

The first transect, sampled from 1973 to 2005 along a fringing wetland at Cecil Bay in the Straits of Mackinac, showed temporary narrowing of bulrush beds during high water conditions in 1986, but showed no indication of loss within the range of water levels encountered over this 32 year time period. The wet meadow zone similarly narrowed during high water conditions, but recovered as water levels dropped following 1986.

Sampling in the second set of transects at Mackinac Bay in the Les Cheneaux Islands between 1996 and 2004 demonstrate that while vegetation zones moved with water level fluctuations, there was no indication that zones were being lost (Figures 3 and 4). Figure 3 demonstrates that meadow plants expand toward the water as water levels continue to be low (dotted lines, 2000 through 2004), but emergent bulrushes persist along most of the transect. Bulrushes were present in plot three, close to the inner edge of the meadow in 1989 and they continue to persist in that portion of the meadow in 2010, although in low numbers. A revisit of the transect in 2010 showed increased movement of the sedges and grasses of the meadow zone further into the zone previously dominated by bulrush. In Figure 4, emergent vegetation persists along almost the entire transect, including those portions of the transect that have been dominated by meadow since data collection in 1989 (part of an earlier study). Stem counts of emergent plants (bulrushes) have fluctuated in the plots considered to be within the emergent zone, plots 9-17, during the nine years of the most recent study (1996-2004).

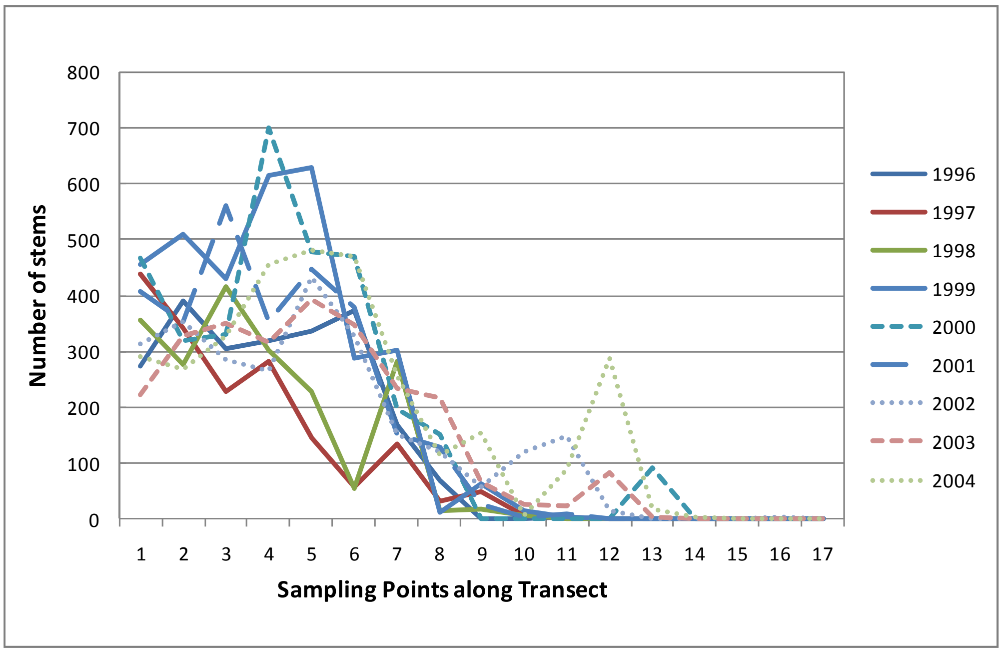


Figure 3. Meadow stem counts by year within Mackinac Bay

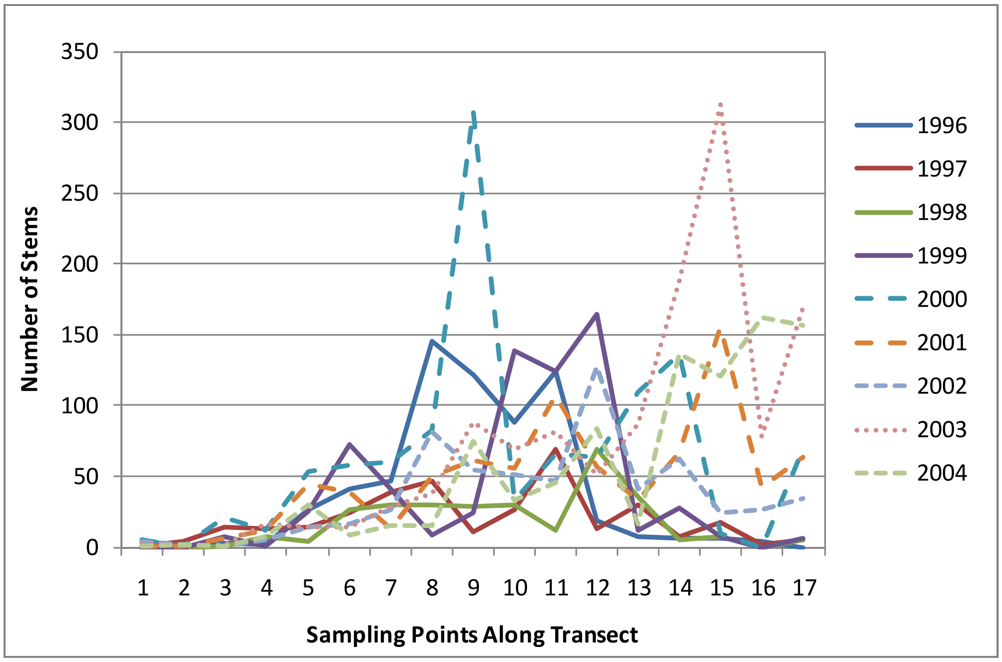


Figure 4. Emergent stem count by year within Mackinac Bay

b. Replacement of native vegetation by invasive plants: While native plants of Great Lakes coastal wetlands are adapted to surviving in an environment of fluctuating water levels, the introduction of invasive plants appears to have changed the dynamics of plant establishment and persistence in coastal wetlands, as well as other wetland habitats. We are examining existing databases to evaluate this trend. The introduction of three aggressive invasive plants into the meadow/emergent marsh edge may cause loss of both the mechanical and faunal functions of coastal wet meadow and emergent (bulrush) beds. The three invasive plants that outcompete both meadow and emergent plants are narrow-leaved cattail (*Typha angustifolia*), hybrid cattail (*T. x glauca*), and tall reed (*Phragmites australis*). Hybrid cattails clones have been documented to grow up to 4 meters in diameter per year (Boers and Zedler 2008), while *Phragmites* grows even more rapidly. *T. glauca* and *Phragmites australis* are also orders of magnitude larger than the native species they replace (Woo and Zedler 2002; Rooth et al. 2003). Due to their high biomass, their persistent above-ground leaf and stem litter, and the slow decomposition rate of the litter (Freyman 2008), large quantities of partially decomposed litter tend to accumulate in *T. glauca* and *P. australis* beds. Once established, *T. glauca* tolerates a wide range of water level conditions (Harris and Marshall 1963).

Data collected along a transect on Dickinson Island of the St. Clair River Delta demonstrate the sensitivity of marsh zones (emergent and meadow zones) dominated by native plants to be replaced by invasive plants (Albert and Brown 2008). A transect conducted across the emergent marsh and wet meadow zones at Dickinson Island in the St. Clair River Delta in 1988 (Albert et al. 1988) and 2005 showed that *Phragmites* can rapidly invade Great Lakes coastal marsh during a prolonged period of low water (Figures 5 and 6). While the submergent plants that were widespread in the 1988 sampling period were almost completely replaced by *Phragmites*, replacement of bulrushes (emergent) and sedges and grasses (meadow) was not as rapid, and these plants persisted in the 2005 sampling. Based on other sites where *Phragmites* has invaded, it is assumed that the native emergent and grass species will not be able to persist for many years, regardless of future water level fluctuations. It should be noted that patches of *Phragmites* had already begun to establish in the 1970s (Robert Humphries, personal communication), and were encountered in the early and late 1990s in a transect near to the 1988/2005 transect. The clones did not expand dramatically until the 1999-2009 low water period.

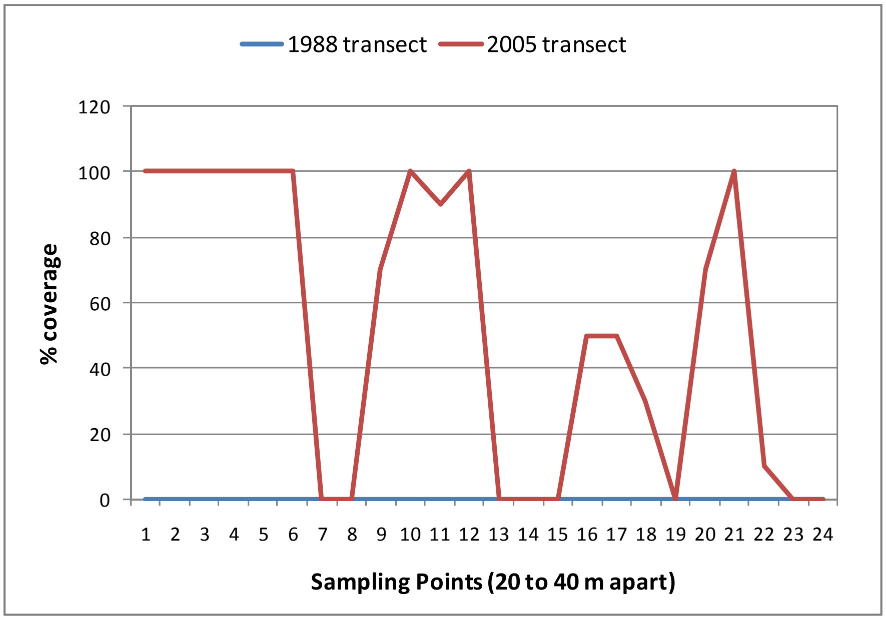


Figure 5. Cover of Phragmites along Dickinson Island marsh transect.

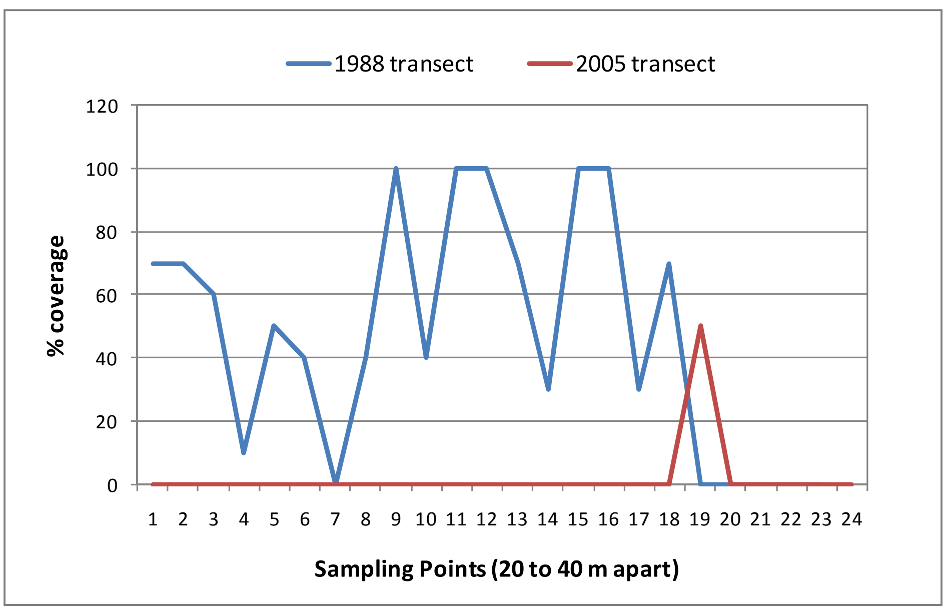


Figure 6. Cover of submerged plants within Dickinson Island marsh.

A study of diked and undiked wetlands along Saginaw Bay and the St. Clair River Delta between 2004and 2006 (Albert and Brown 2008), demonstrated that both narrow-leaved cattails and

Phragmites have a much higher biomass than native plants (Table 2). Because of the high above-ground biomass, the invasive plants are able to outcompete both meadow and emergent species. Remnant rhizomes of three-square bulrush (dead) were found beneath living stands of hybrid cattail and also beneath stands of *Phragmites*, which had outcompeted both three-square and cattails. Because both of these invasive species typically establish first as seedlings along the moist shoreline, they can grow up into the wet meadow, where they can outcompete bulrushes, sedges, and grasses, and they can grow out into shallow water, where they can also outcompete three-square.

A soon to be published paper documents the establishment of hybrid cattail in several marshes of northern Lake Michigan, Lake Huron, and the St. Marys River, with indications that most of that establishment has been during the recent 1998-2010 low water period (Lishawa et al. accepted). For most of the sites studied in this paper, hybrid cattail is competing with hardstem bulrush (*Schoenoplectus acutus*), which has growth rates of less than 50 cm/year. If Great Lakes water levels begin a rapid retreat, as predicted by global climate change models (Kling et al. 2003), the width of the both meadow and emergent beds will narrow as *Phragmites* and cattails expand from the upland edge of the marsh and replace bulrush. As long as there is some interannual water level fluctuation, storms will keep cattails and *Phragmites* from completely replacing bulrush – both cattails and *Phragmites* are easily eroded by storm waves because much of their biomass is above water. However, much of the habitat value of the emergent zone for fish and aquatic insects results from emergent plants growing in the water, so a narrow band of flooded native emergent plants provides much less habitat value than a 200 or 300 meter wide band of the same plants.

c. Replacement of herbaceous plants by trees or shrubs. There is strong evidence of the link between hydrology and the presence and community structure of wetland vegetation along the Great Lakes coast (Wilcox et al. 1984; Keddy and Reznicek 1986; Hudon et al. 2006, Wilcox and Xie 2007). Generally, stabilization of hydrology leads to encroachment of woody vegetation from the upland (Keddy and Reznicek 1986).

A combination of data was used to evaluate the expansion of woody plants into coastal wetlands during the low water years between 1999 and 2010. First, the sampling data from Mackinac Bay was observed to demonstrate an increase in the amount of both tree and shrub seedlings between 1996 and 2004 (Figure 7). While data from Mackinac Bay shows a strong increase in the number of woody stems, many of the stems noted along the transects were seedlings. To evaluate continued growth of woody vegetation at Mackinac Bay and in nearby marshes, tree heights and ages were noted along two transects, one along the eastern edge of Mackinac Bay (Figure 8) and another at nearby Mismer Bay to the west (Figure 9). Five trees were cored along Mackinac Bay, where trees extended approximately 100 meters out into the meadow from the forest edge – all of the cored trees were 10 to 12 years old. Six trees were cored at Mismer Bay, where trees extended 120 meters into the meadow. These trees were as tall as 8 meters and ranged in age from 10 to 16 years, with the three trees closest to the water being 12 years or younger, and the three trees nearest the forest edge being 16 years in age. Thus, the majority of trees established within a year or two of the drop in water levels that began in 1998, with the remaining trees establishing prior to the most recent low water conditions.

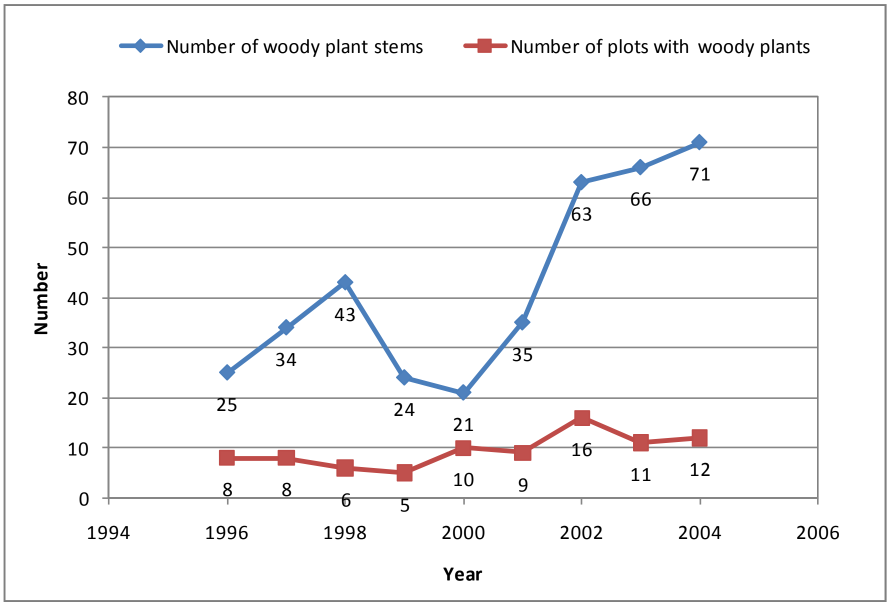


Figure 7. Yearly change in the amount of woody plants at Mackinax Bay, Les Cheneaux Islands.

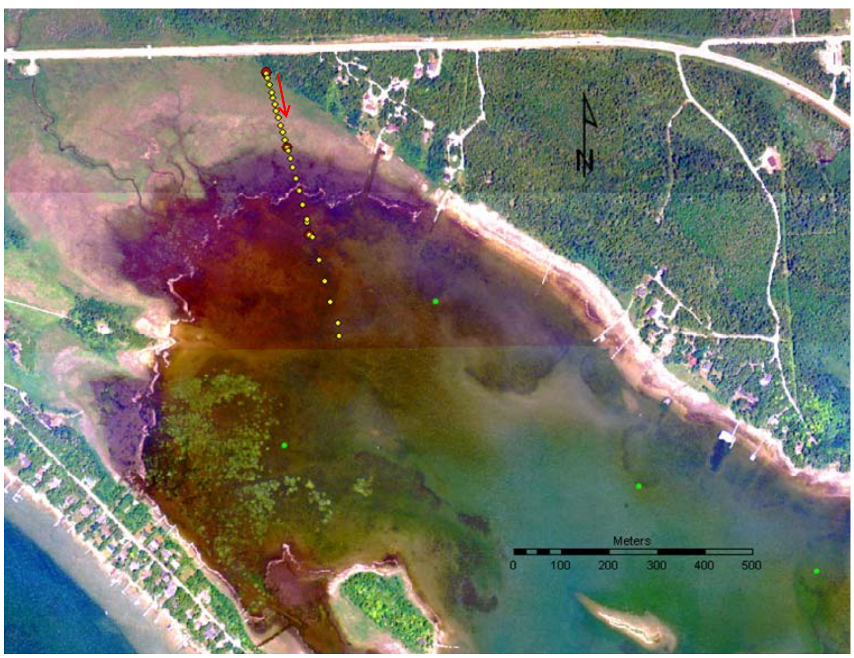


Figure 8. Transect into Mackinac Bay (yellow), with extent of tamarack expansion into the meadow zone shown by red arrow.

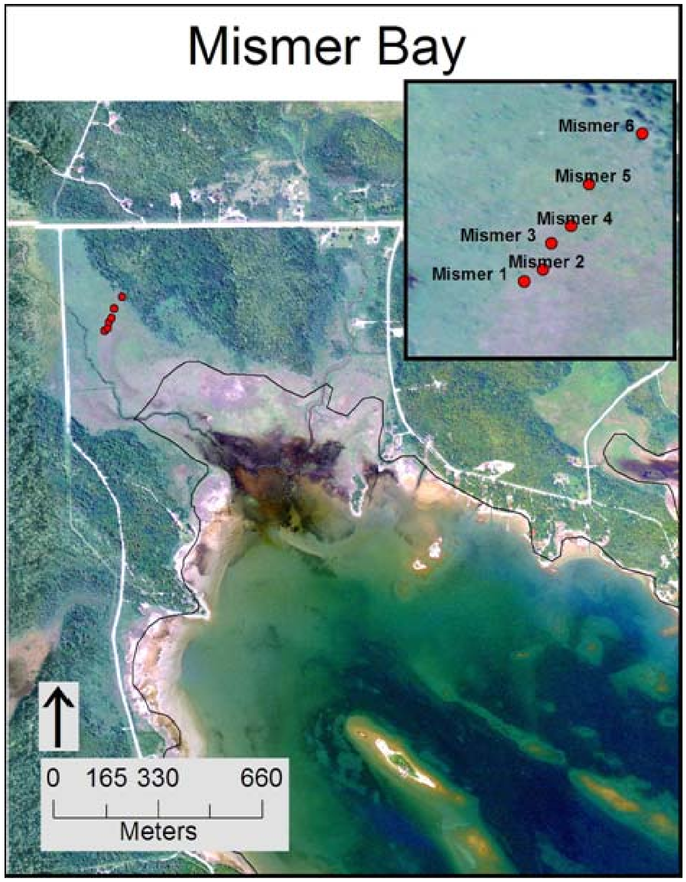


Figure 9. Expansion of tamarack trees from swamp into meadow zone.

d. Reduced floristic diversity: Floristic diversity is one measure of the quality of a wetland. We evaluated the floristic diversity of the meadow at Mackinac Bay to determine if floristic diversity was changing with water levels.

Figures 10 through12 are based on nine years of sampling data at Mackinac Bay and Mismer Bay, Les Cheneaux Islands, during a period of low water levels. Figure 10 shows the trend of increased plant diversity in the meadows of both sites during this period of dropping water levels, following the 1997 high water year. Figure 11, which orders the plots according to water level, shows an even stronger trend toward increasing plant diversity within the meadow as water levels drop. Table 1 summarizes the changes in species composition in the wet meadow zone, with the great change in the number of herbaceous forbs (flowering plants that are not grasses, sedges and rushes), followed by sedges, then species of *Juncus* (rush) and trees. Similar analyses have not been done within the emergent marsh, as sampling within the emergent marsh was only conducted near the inner, shallower edge of the emergent marsh. The deeper, more open portion of the emergent marsh is where greater emergent, floating, and submergent plant diversity is encountered. However, the trend for reduced plant diversity in the shallowest portion of the emergent marsh was readily apparent during the last ten years of low water.

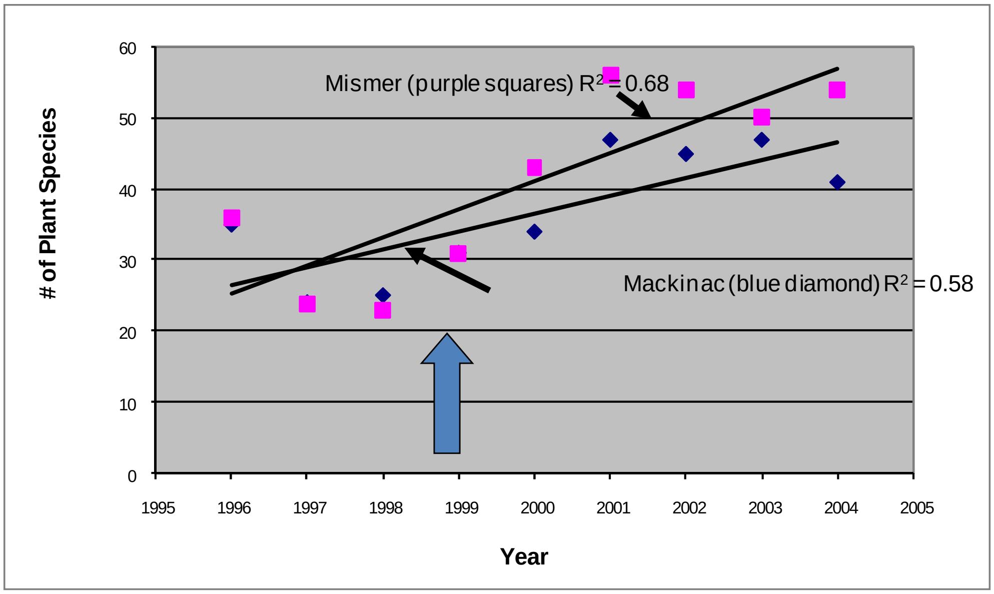


Figure 10. Meadow and Emergent plant diversity in a period of dropping water levels.

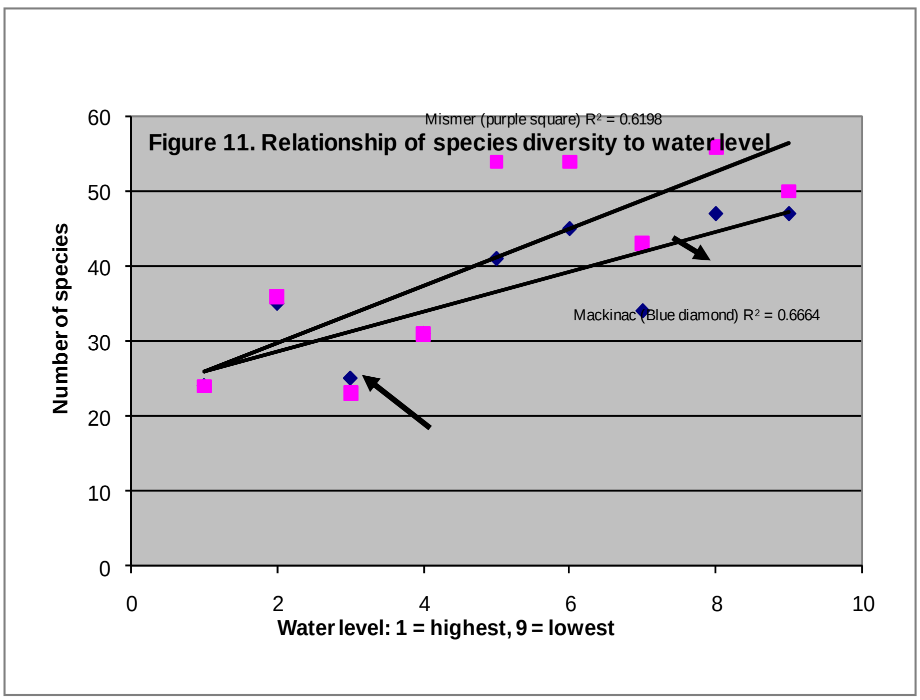


Figure 11. Relationship of species diversity to water level.

Table 1. Comparison of meadow diversity in low and high water years.

	HIGH WATER 1997	LOW WATER 2001
TREES	0	3
SHRUBS	3	4
GRASSES	1	3
CAREX SPP.	3	7
JUNCUS SPP.	0	3
ELEOCHARIS SPP.	1	2
FORBS	14	20
FERNS	1	1
TOTAL	**23**	**43**

Algorithm:

The modeling approach follows the rules-based procedure used in the IERM for the International Joint Commission (IJC) Lake Ontario-St. Lawrence (LOSL) study, which assigns portions of the elevation model to different vegetation types based on how many years since last flooded and how many years since last dewatered (Wilcox and Xie, 2007; LimnoTech 2005). Bathymetry and topography data collected by Scudder Mackey and Dennis Albert during summer 2010 were used to develop digital elevation models (DEMs) for Mackinaw Bay and Duck Bay extending from the deepest areas of these embayments (approximately 175.0 meters) to the extent of the wetland area (i.e., near the edge of trees). The DEM was used to create a set of elevation contour “bins” in similar fashion to Saginaw Bay and other wetland site vegetation models described in the accompanying fact sheets.

The following approach is used in the IERM2 model to calculate the areal coverage of the emergent marsh and meadow marsh dominated zones in Mackinaw Bay and Duck Bay:

1. The Lake Huron annual maximum water level is identified for each model simulation year. This elevation is defined as 1) the elevation above which all areas have been effectively dewatered for the current growing season, and 2) the elevation below which all areas have effectively been flooded for the current season.
2. Meadow marsh-dominated areas are assigned to elevations characterized by the flooding/dewatering and water depths conditions marked by “MM” in Table 2.
3. Emergent marsh-dominated areas are assigned to elevations characterized by the flooding/dewatering and water depths conditions marked by “EM” in Table 2.
4. The total areas of meadow marsh and emergent marsh are calculated for a given year by summing all of the surface area associated with elevations that were characterized as being dominated by meadow/emergent marsh in steps #2 and #3 above.

The current set of rules as described above for predicting meadow marsh and emergent marsh coverage (Table 2) are applied in the model to predict the annual total *combined* area (in hectares) for Mackinaw Bay and Duck Bay for a given hydrologic/hydraulic scenario.

Table 2. Matrix of Vegetation Assignment Rules for Les Cheneaux Islands Wetlands based on Flooding and Dewatering History

Height "Above" Water Line:		Number of years dewatered:														
		0	1	2	3	4	5	6	7	8	9	10	11	21	31	40
Min	Max	0	1	2	3	4	5	6	7	8	9	10	20	30	40	999
-101	-999	n/a	MM	MM	MM	MM	MM	T	T	T	T	T	T	T	T	T
-91	-100	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-81	-90	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T	T	T
-71	-80	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-61	-70	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-51	-60	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-41	-50	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-31	-40	n/a	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	T	T
-21	-30	n/a	EM	EM	EM	EM	EM	MM	MM	MM	MM	MM	MM	MM	MM	MM
-11	-20	n/a	EM	EM	EM	EM	EM	MM	MM	MM	MM	MM	MM	MM	MM	MM
0	-10	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM

Height "Below" Water Line:		Number of years flooded:														
		0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-21	-31	-40
Min	Max	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-20	-30	-40	-999
1	10	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
11	20	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
21	30	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL
31	40	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
41	50	n/a	MM	MM	MM	MM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
51	60	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
61	70	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
71	80	n/a	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	EM	SAV-FL	SAV-FL
81	90	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
91	100	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
101	110	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
111	120	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
121	130	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
131	140	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
141	150	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
151	160	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
161	170	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
171	180	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
181	190	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL
191	200	n/a	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL	SAV-FL

Coping Zone Criteria:

Although the PIs for meadow marsh and emergent marsh described in this fact sheet were specifically applied to Les Cheneaux Islands wetlands (Mackinaw Bay and Duck Bay), the Coping Zone criteria described in this section apply more broadly to wetlands in Lake Michigan, Lake Huron, and the St. Clair River Delta that have been studied by Dennis Albert. The development of specific PIs for these other wetlands was not possible due to limited available topographic/bathymetric information, but anecdotal information is available to help broaden the coping zone criteria beyond the Les Cheneaux Island sites.

At both Cecil Bay (northern Lake Michigan) and Mackinac Bay (northern Lake Huron), there has been no indication that either the meadow or emergent zones were near their thresholds for persistence. Persistence of the meadow might be compromised by persistent water levels above the highway and coastal road elevations, approximately 177.65 meters; although, the meadow plants could potentially migrate further upland in the broad expanses of the wetlands that extend on the upslope side of the highways. Persistence of the emergent marsh is limited to water levels above 175.2 meters, the approximate bottom elevation for the shallow embayments within the Les Cheneaux Islands.

While tree expansion has occurred into the wet meadow zone during this extended period of low water, the meadow zone continues to move outward into the drier edge of the emergent marsh at a pace similar to that of the tree migration; however, the meadow grass and sedge migrate as a zone, whereas trees migrate as individual plants. To replace the meadow with trees will require at least one more meter of water drop to below 175.2 m.

In general, thresholds that result in permanent or major loss of plant diversity have not yet been encountered in either the emergent or wet meadow zones.   Long-term water level rise above 177.65 m, the approximate elevation at the edge of the highway, and many of the shoreline homes for Mackinac Bay would be needed to reduce meadow zone diversity for many of the wetlands in northern Lake Huron and Michigan. Dropping water levels to below 175.2 m would result in severe loss of plant diversity in the emergent marsh zone for northern Lake Huron and Michigan wetlands in shallow protected bays. Similar high and low values would be thresholds for protected embayments on Saginaw Bay; although, slow migration of the broad fringing wetlands of Saginaw Bay might be able to maintain emergent, floating, and submergent plant diversity.

The threshold for large portions of the St. Clair River Delta has probably been passed, with 10 years of low water conditions allowing emergent invasive plants to establish and replace native emergent plants along large sections of the St. Clair River shoreline, as well as up to the upland edge. This replacement cannot be easily reversed. The only reversals have been the result of either intensive controlled burn programs for cattails or herbicide treatment for *Phragmites*. Similar invasions of marshes on Saginaw Bay have resulted in replacement of native emergents with invasive plants at several sites, but the spatial extent of this replacement has not been as well documented. Marshes in western Lake Erie have also been largely replaced with invasive plants, with native emergent species outcompeted by invasives in most wetlands. A return to higher water levels will likely result in minor expansion of native emergent plants, like bulrush, bur reed, and spike-rush, but these expansions will be minor and temporary in terms of overall area.

<u>Coping Zone Rules</u>:

The coping zone rules developed for the emergent marsh and meadow marsh zone indicators for the Les Cheneaux Islands wetlands are as follows:

- **<u>LMH-05 Criterion</u>: (high water level condition)**
    - <u>Zone B</u>: Mean water level during growing season (April-September) is greater than or equal to 177.65 meters for any 3 years within a 5-year window.
    - <u>Zone C</u>: Mean water level during growing season (April-September) is greater than or equal to 177.65 meters for a period of 5 consecutive years.
- **<u>LMH-06 Criterion</u>: (low water level condition)**

- Zone B: Mean water level during growing season (April-September) is below 175.0 meters for any 3 years within a 5-year window.
- Zone C: Mean water level during growing season (April-September) is below 175.0 meters for a period of 5 consecutive years.

An additional set of Coping Zone criteria were developed for the St. Clair River delta based on studies conducted at Dickinson Island. These criteria are designed to limit the spread of invasive plant species (e.g., *Phragmites*) and prevent the associated loss of native vegetation resulting from prolonged water level conditions. The specific rules for the St. Clair River criteria are as follows:

- **LSC-01 Criterion: (low water level condition)**
  - Zone B: Mean water level during growing season (March-October) is at or below 174.1 meters for any 3 years within a 5-year window.
  - Zone C: Mean water level during growing season (March-October) is at or below 174.1 meters for a period of 5 consecutive years.

It should be noted that rules established for criterion "LSC-01" are consistent with the rules proposed for criterion "LSC-02", which was developed based on thresholds for fish spawning habitat (see fact sheet #16).

Calibration Data: See discussion in preceding sections.

Validation Data: See discussion in preceding sections.

Risk and Uncertainty Assessment: See discussion in preceding sections.

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

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Fact Sheet ID: 11

Performance Indicator (PI) Name/Short Description: Bulrush – surface area (Les Cheneaux Islands (Mackinac Bay, Duck Bay), Lake Huron)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Dennis Albert

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: Both three-square and hardstem bulrushes are perennial plants that spread and expand by the growth of below-ground stems called rhizomes. Both plants establish as seedlings on moist sediments during drops in water levels of wetlands, streams, and lakes, however, expansion into deeper water occurs by rhizome expansion. In many Great Lakes coastal wetlands, bulrushes are the dominant vegetation in the emergent zone, growing in water as deep as 1.5 to 2.0 meters, and occasionally in deeper water.

The PI metric is the surface area of three-square and hardstem bulrushes in the Les Cheneaux Islands (Mackinac Bay, Duck Bay), Lake Huron.

Ecological Importance/Niche: Emergent marsh provides feeding and spawning habitat for many commercially important fish (Jude and Pappus 1992; Jude et al. 2005; Uzarski et al. 2005). Emergent marsh vegetation has also been shown to greatly reduce wave energy (Figure 1) and accumulate sediments (Figure 2) (Albert and Cox, unpublished data). Wave energy reduction is important to the residential and agricultural communities located near to the Great Lakes coast, especially during high-water periods. Sediment accumulation within coastal wetlands is important during both high and low water conditions, as demonstrated along Saginaw Bay in the early 2000s, when sand drifted against buildings and across roads following removal of wetland vegetation.

Bulrushes are among the most important plants in the fringing wetlands of the Great Lakes, reducing erosion of coastal sediments along shorelines with high wave energy, accumulating sediments as they reduce wave energy, reducing wave energy sufficiently to allow other weak-rooted submergent and floating plants to grow, and providing important habitat and food for many fish and birds.

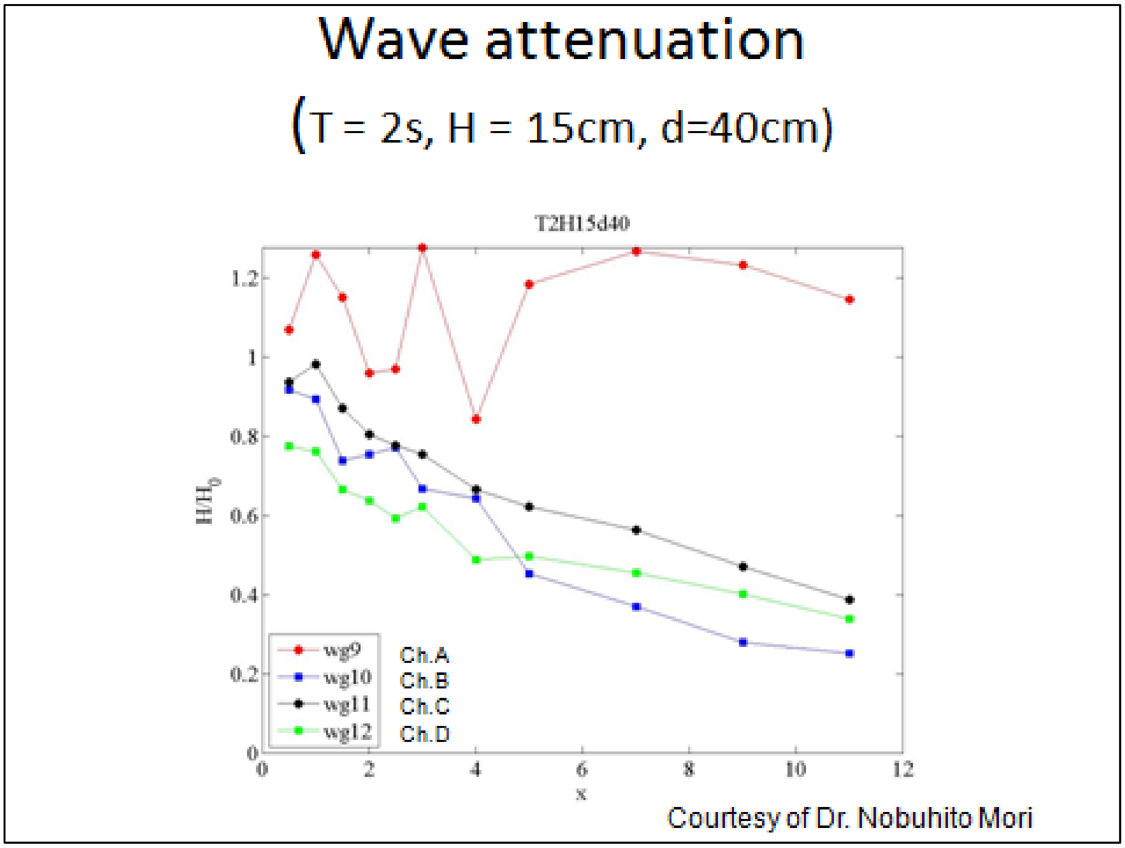
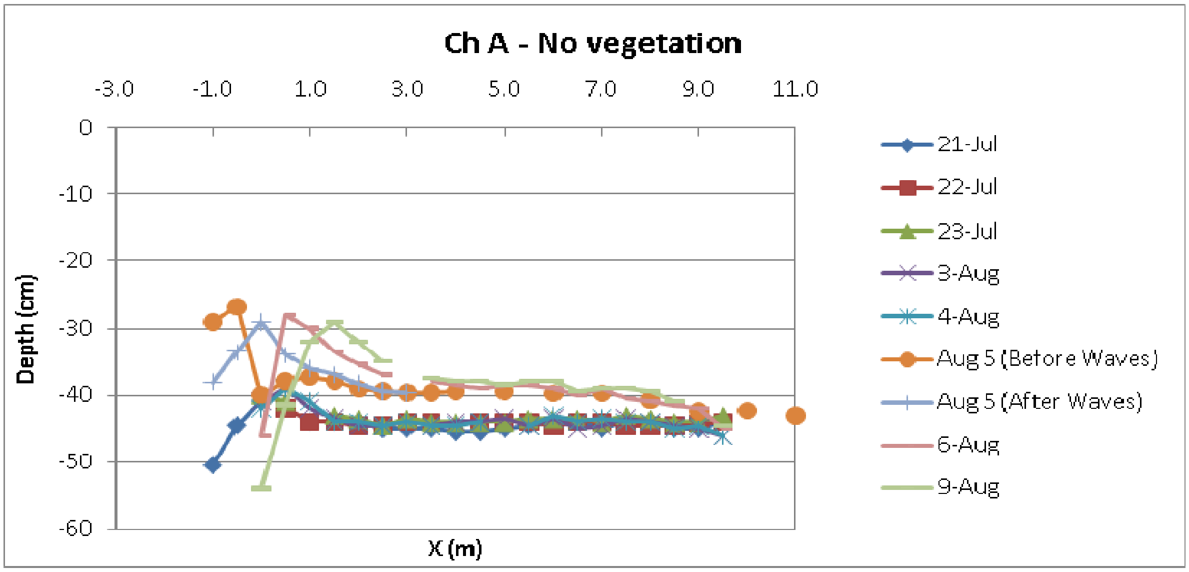


***Figure 1.** Wave attenuation study. Channel A is a control containing no vegetation, while Channels B and D contain mats of bulrush at typical nearshore densities, and Channel C contains a more thinly planted restoration bed of bulrushes. The height of the waves (H) in the control bed remains similar to the initial height of the waves (H_o) before the waves reach across the entire 10 meters of the plant beds, while wave height decreases rapidly to 0.3 to0 .4 cm from the initial height over the length of the vegetated beds (B, C, and D).*



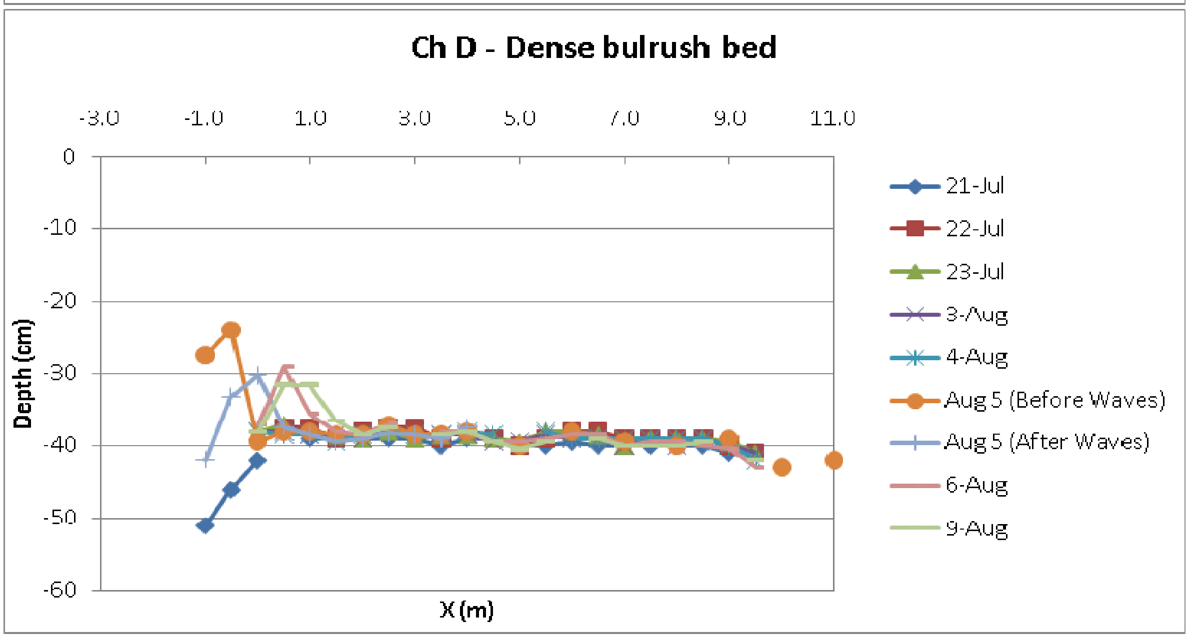


Figure 2. Different rates of sand movement in a 10 meter long bed of bare sand and sand with bulrushes (Schoenoplectus pungens). Sand deposited at the front of the unvegetated bed (Channel A) was moved throughout the entire bed by waves run on August 5-9th. In contrast, sand deposited at the front of the vegetated bed (Channel D) moved very slowly through the vegetation, advancing less than 2 meters by the end of the study on August 9th.

Temporal Validity: The temporal validity is limited to the length/duration of our studies of vegetation communities and structure in coastal wetlands. With the introduction of accurate Global Positioning System (GPS) locations and detailed bathymetry to our vegetation studies, there is the potential for developing long-term databases with much greater resolution. This includes accurate monitoring of bulrush growth rates along the outer fringe of the marsh and bulrush losses due to competition at the upland fringe of the marsh.

Spatial Validity: Bulrush growth rates are limiting in the broad, gently sloping (0.25 % to 0.45 %) coastal marshes that characterize fringing wetlands, protected embayments, connecting rivers (e.g., St. Marys and Detroit Rivers), and deltas on the St. Marys and St. Clair Rivers (Albert et al. 2006).

Hydrology Link: In many Great Lakes coastal wetlands, bulrushes are the dominant vegetation in the emergent zone, growing in water as deep as 1.5 to 2.0 meters, and occasionally in deeper water. While bulrushes are well adapted to the cyclic fluctuations of Great Lakes coastal wetlands, their expansion into deeper water or newly created, moist upland habitat is restricted by their slow growth rate. The maximum annual growth rate of three-square bulrush encountered in over a dozen marshes in the Great Lakes and the coastal estuaries of the Pacific Northwest has been 31 cm/year (12.4 inches/year). Table 1 and Figure 3 document this slow growth rate for over 1,400 rhizome sections at Cecil Bay along the northern shore of Lake Michigan, and similar growth rates have been documented for hundreds of plants along Saginaw Bay, Grand Traverse Bay, and the shoreline of Tillamook Bay and the Columbia River in western Washington and Oregon. The growth rate of hardstem bulrush appears to be equally slow, but sampling of the below-ground rhizomes has been much more restricted, and includes only Cecil Bay on Lake Michigan, Voight Bay on Lake Huron, and an inland marsh near Grand Marais in Michigan's Upper Peninsula.

The slow bulrush growth rate has not been a problem during the thousands of years of Great Lakes wetland history; however, the introduction of three aggressive and fast growing invasive plants into the meadow/emergent marsh edge may cause loss of both the mechanical and faunal functions of coastal bulrush beds. The three invasive plants that outcompete bulrush are narrow-leaved cattail (*Typha angustifolia*), hybrid cattail (*T. x glauca*), and tall reed (*Phragmites australis*). Hybrid cattails clones have been documented to grow up to 4 meters in diameter per year (Boers and Zedler 2008), while *Phragmites* grows even more rapidly. *T. glauca* and *Phragmites australis* are also orders of magnitude larger than the native species they replace (Woo and Zedler 2002; Rooth et al. 2003). Due to their high biomass, their persistent above-ground leaf and stem litter, and the slow decomposition rate of the litter (Freyman 2008), large quantities of partially decomposed litter tend to accumulate in *T. glauca* and *P. australis* beds. Once established, *T. glauca* tolerates a wide range of water level conditions (Harris and Marshall 1963).

Table 1. Bulrush rhizome intermodal lengths by size class collected at Cecil Bay in northern Lake Michigan, with number of internodes for each zone (beach, shore, and deep water). The yellow highlighted rhizome internode in Cecil Bay Deep 2 was 31 cm long.

Size class	***Cecil Bay Beach***	***Cecil Bay Shore***	***Cecil Bay Deep1***	***Cecil Bay Deep 2***
<1 cm	309	190	32	17
1-2.5	205	217	26	41
3-4.5	73	52	23	26
5-6.5	47	33	15	14
7-8.5	38	27	7	10
9-14.5	26	36	23	15
15-19.5	4	7	4	2
20-24.5	0	0	3	2
25-29.5	0	0	0	0
30-34.5	0	0	0	1

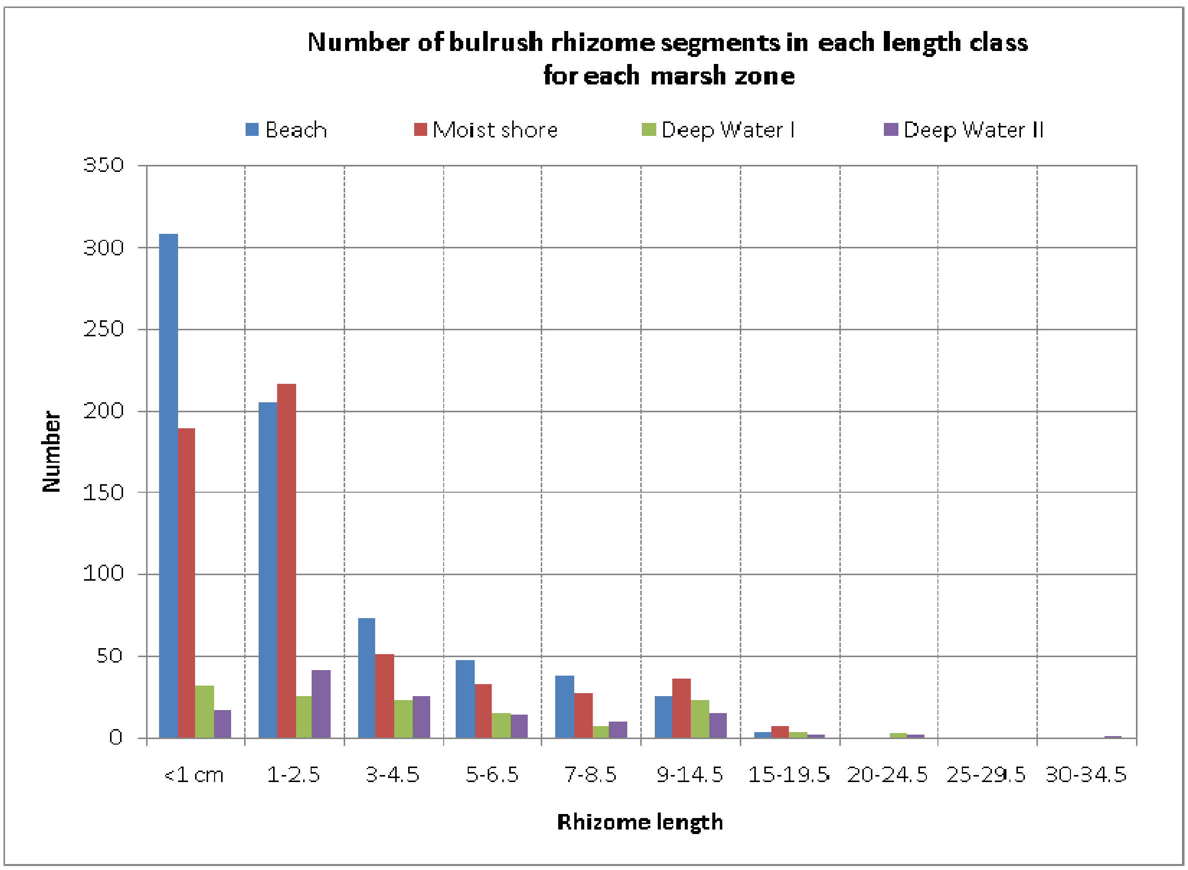


Figure 3. Number of bulrush rhizome segments in each length class for each marsh zone.

A study of diked and undiked wetlands along Saginaw Bay and the St. Clair River delta between 2004and 2006 (Albert and Brown 2008), demonstrated that both narrow-leaved cattails and *Phragmites* have much higher biomass than native plants (Table 2), and because of their high above-ground biomass, are able to outcompete bulrushes. Remnant rhizomes of three-square bulrush (dead) were found beneath living stands of hybrid cattail, and also beneath stands of *Phragmites*, which had outcompeted both three-square and cattails. Because both of these invasive species typically establish first as seedlings along the moist shoreline, they can grow up into the wet meadow, where they can outcompete bulrushes, sedges, and grasses, and they can grow out into shallow water, where they can also outcompete three-square.

Table 2. Maximum biomass for dominant marsh plants at Harsens Island and Dickinson Island.

SPECIES	***Total Biomass (gm)/0.04m^3***	***Below Ground Biomass (gm)/0.04m^3***	***Above Ground Biomass (gm)/0.04m^3***	***Biomass Above Ground (%)***
Narrow-leaved cattail	2775.5	1952.9	822.6	30
Phragmites australis	1820.5	1194.8	625.7	34
Sedge/grass	1975.0	1798.6	159.9	8
Hardstem bulrush	1163.3	953.7	209.6	18
Three-square bulrush	70.9	66.1	4.8	7
Wild rice	132.4	65.1	67.3	51

A soon to be published paper documents the establishment of hybrid cattail in several marshes of northern Lake Michigan, Lake Huron, and the St. Marys River, with indications that most of that establishment has been during the recent 1998-2010 low-water period (Lishawa et al. accepted). For most of the sites studied in this paper, hybrid cattail is competing with hardstem bulrush (*Schoenoplectus acutus*), which has growth rates similar to those for three-square. If Great Lakes water levels begin a rapid retreat, as predicted by global climate change models (Kling et al. 2003), the width of the bulrush beds will narrow as Phragmites and cattails expand from the upland edge of the marsh and replace bulrush. As long as there is some interannual water level fluctuation, storms will keep cattails and Phragmites from completely replacing bulrush – both cattails and Phragmites are easily eroded by storm waves because much of their biomass is above water (D. Albert, personal observation). However, much of the habitat value of bulrushes for fish and aquatic insects results from bulrush growing in the water, so a narrow band of flooded bulrush provides much less habitat value than a 200 or 300 meter wide bulrush marsh.

Algorithm:

The algorithm for the bulrush marsh PI for Mackinaw Bay and Duck Bay is described in fact sheet #10.

Coping Zone Criteria: The coping zone criteria and rules associated with bulrush marsh in the Les Cheneaux Islands wetlands (Mackinaw Bay, Duck Bay) are described in fact sheet #10. Additional commentary related to the sensitivity of bulrush to significant declines in Lake Huron water levels is provided below.

In the present coastal environment, where bulrushes must compete with rapidly growing invasive emergent plants, the loss of three-square and hardstem bulrushes, and the ecological function they provide, is almost certain. If Great Lakes water levels continue to drop at an average rate of greater than 1 cm/year, invasive plants like *Phragmites*, narrow-leaved cattail, and hybrid cattail will replace bulrush along the shoreline at a faster rate than bulrushes can expand outward into deeper water. Periodic increases in water level will reverse the trend of bulrush replacement by invasive plants. This holds true for broad coastal wetlands with a slope less than 0.25%, including most of the wetlands found along northern Lake Michigan and Huron, as well as Saginaw Bay and large portions of the St. Marys River.

Calibration Data: See discussion in preceding sections.

Validation Data: Not available.

Risk and Uncertainty Assessment: See discussion in preceding sections.

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

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Fact Sheet ID: 12

Performance Indicator (PI) Name/Short Description: Wetland Bulrush Marsh and Meadow Marsh Communities –surface area in Saginaw Bay (Lake Huron)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Wilcox

Modeled by: Wilcox, LimnoTech (Redder, DePinto)

PI Metric: Surface area estimate of bulrush marsh and meadow marsh vegetation (hectares) for Saginaw Bay (extrapolated to bay-wide estimates based on vegetation data collected at Fish Point wetland).

Ecological Importance/Niche: Bulrush marsh vegetation typically develops on sediments exposed to air following a reduction in water level; they also expand vegetatively in standing water. Other emergent plants occur within the bulrush zone, as well as submersed aquatic vegetation (SAV), but bulrushes (three-square, softstem, hardstem) are often dominant. The tall, thin bulrushes can withstand wave action, as they bend while waves are breaking around them. They survive in waters up to one meter deep, and dense stands reduce the action of waves. In Saginaw Bay, waves a half-meter in height, in turbid water, can dissipate within a couple dozen meters after moving into the bulrush zone. Landward, waters are often calm and clear. Bulrushes protect the shore and also create more diversity in habitat.

Meadow marsh vegetation typically develops between the maximum long-term high water level and the long-term mean. Plant species within this community are intolerant of prolonged flooding, but occasional flooding is required to prevent woody plant species from expanding downslope into the meadow marsh community. In addition, periodic low water levels are also required to prevent the expansion of aggressive emergent plants upslope into the meadow community. Meadow marsh habitats typically contain some emergent, shrub, or upland plant species. The relative amount of these species is dictated by the years since the last high or low water level cycle. For this reason, the meadow marsh community supports a diversity of plant species, but it often occurs in a relatively narrow hydrologic range in comparison to the other wetland vegetation communities.

Temporal Validity: Area (percent) of bulrush marsh and meadow marsh was determined from six years of elevation-specific data collection at the Fish Point wetland in Saginaw Bay of Lake Huron (1988-1993), a period that reflected a reduction in lake level following the high in 1986. Similar high lake levels followed by periods of low lake levels occur throughout the period of record.

Spatial Validity: The model developed was based on a specific study area in Saginaw Bay. The relationships should be similar across much of the bay. However, topographic/ bathymetric data are required to apply the model to larger areas.

Hydrology Link: Wetland plant community evolution is strongly dependent on the hydroperiod (i.e., flooding and dewatering history) at a particular elevation. The model uses demonstrated relations among plant communities and years since last flooded/ elevation above water level to predict plant communities that may result at differing elevations in response to regulation plans.

Algorithm: Six 500 m long transects follow contours at elevations of 176.3, 176.55, 176.65, 176.9, 177.24, and 177.34 m (IGLD 1985). Incorporating distance between transects creates a 220-500 topographic/bathymetric platform that can be used as a geometric model. Plant communities characterized across years by non-metric multidimensional scaling (NMDS) ordination show distinct groupings of transects/year that reflect response of vegetation to hydrologic history of transects and elevation above water level in the year sampled. A model was derived demonstrating these relationships (Figure 1).

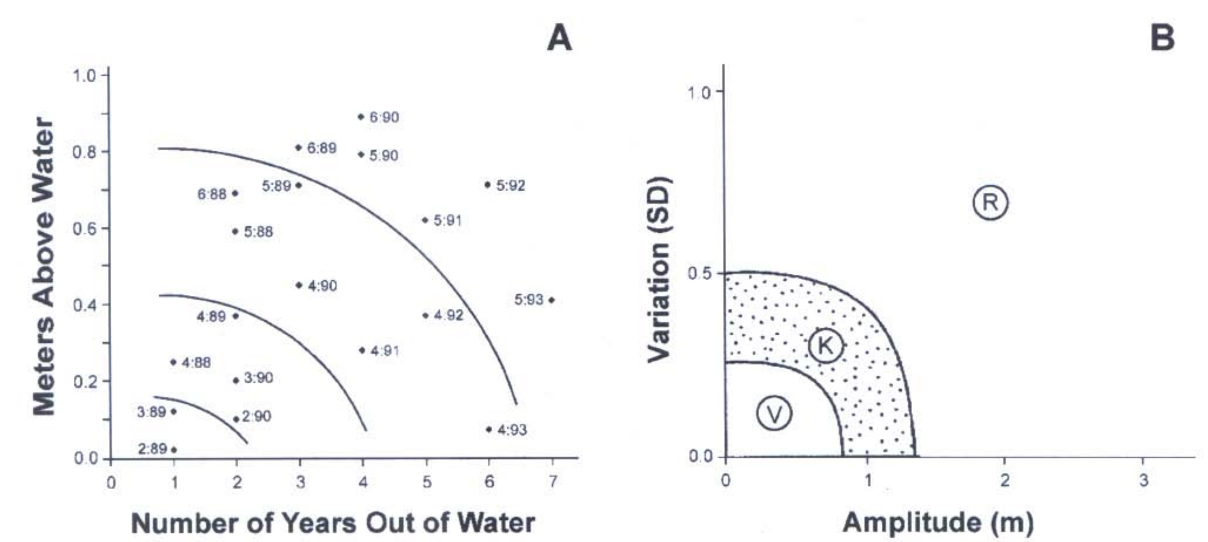

Figure 9. A) Model of response of wetland vegetation at Fish Point wetland to decline in lake level following high levels in 1986. Points plotted are transect:year showing meters above water vs. the number of years out of water at the time of sampling. B) Modeling approach recommended by Keddy and Fraser (2000), as illustrated using data from Hill et al. (1998), where plotting of amplitude of water-level change against standard deviation for three lakes (Vaughn, Kejimkujik, Rossignal) in Nova Scotia, Canada correlates to a corridor of high species richness (K).

Figure 1. Panel A shows the modeled response of wetland vegetation at Fish Point wetland to water level fluctuations. Panel B demonstrates the modeling approach.

These relationships are used to predict the percentage of each vegetation type in the wetland based on the 220-500 m geometric model and the portions of the wetland that fall into specific time-dewatered and elevation classes (Table 1). Comparisons are then made in responses to different regulation plans.

For any given year:

$\sum X1 \ldots + \ldots X7 = 100$

X1 = % wetland under water Veg Type I

X2 = % wetland first year dewatered	Veg Type II
X3 = % wetland dewatered 1 yr [1-15cm]	Veg Type III
X4 = % wetland dewatered 1 yr [16-40 cm] or 2 yr [10-40 cm]	Veg Type IV
X5 = % wetland dewatered 2 yr [41-80 cm] or 3 yr [35-70 cm] or 4 yr [30-65 cm] or 5 yr [25-50 cm]	Veg Type V
X6 = % wetland dewatered 3 yr [71+ cm] or 4 yr [66+ cm] or 5 yr [51+ cm] or 6 yr [40+ cm]	Veg Type VI
X7 = % wetland not flooded	Veg Type VII

Table 1. Summary of vegetation types in each elevation and dewatering class.

Vegetation Type	***Vegetation "Class"***	***Dominant Species***	***Rules***
Veg Type I	Submerged	*N. flexilis, N. marina, Chara, M. sibiricum*	Elevations that are currently inundated.
Veg Type II	Submerged	*Chara, N. flexilis, P. gramineus, H. dubia*	Elevations dewatered during current year.
Veg Type III	Submerged	Chara, P. gramineus, N. flexilis, S. tabernaemontani	*Elevations dewatered for*: 1 year (1-15 cm above water line)
Veg Type IV	**Emergent marsh (wet)**	Chara, S. pungens, T. angustifolia, S. tabernae.	*Elevations dewatered for*: **1 yr** (16-40 cm above WL); or **2 yrs** (10-40 cm above).
Veg Type V	**Emergent marsh (herbaceous)**	*S. pungens, E. perfoliatum, T. ang., C. canadensis*	*Elevations dewatered for*: **2 yrs** (41-80 cm above WL); **3 yrs** (35-70 cm above); **4 yrs** (30-65 cm above); or **5 yrs** (25-50 cm above).
Veg Type VI	**Meadow marsh / grasses**	E. graminifolia, C. canadensis, S. exigua, S.pungens	*Elevations dewatered for*: **3 yrs** (70+ cm above); **4 yrs** (66+ cm above); **5 yrs** (51+ cm above); or **6 yrs** (40+ cm above).
Veg Type VII	Cattail, other species	I. capensis, T. angustifolia, C. canadensis, E. perfol.	***Elevations not flooded.***

Using these relationships, a rules table was developed for assigning vegetation types to heights above water line/water level history (Table 2). Not all cells match available data and predictions required intuitive assessment of vegetation response based on plant life histories. Vegetation types were converted from Roman numerals to Arabic numbers to ease reading. Vegetation types 4 (IV) and 5 (V) are bulrush marsh; vegetation type 6 (VI) is meadow marsh.

Table 2. Rules table for assigning vegetation types to water levels.

Height "Above" Water Line:		*Number of years dewatered:*										
Min	*Max*	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
0	5	2	3	3	4	4	4	4	**4**	**4**	**4**	**4**
6	10	NA	3	3	4	4	4	4	**4**	**4**	**4**	**4**
11	15	NA	3	4	4	5	5	5	**5**	**5**	**5**	**5**
16	20	NA	4	4	4	5	5	5	**5**	**5**	**5**	**5**
21	25	NA	4	4	4	5	5	5	**5**	**5**	**5**	**5**
26	30	NA	4	4	4	5	5	5	**5**	**5**	**5**	**5**
31	35	NA	4	4	5	5	5	6	**6**	**6**	**6**	**6**
36	40	NA	4	4	5	5	5	6	**6**	**6**	**6**	**6**
41	45	NA	**4**	5	5	5	5	6	**6**	**6**	**6**	**6**
46	50	NA	**4**	5	5	5	5	6	**6**	**6**	**6**	**6**
51	55	NA	**4**	5	5	5	6	6	**6**	**6**	**6**	**6**
56	60	NA	**4**	5	5	5	6	6	**6**	**6**	**6**	**6**
61	65	NA	**4**	5	5	5	6	6	**6**	**6**	**6**	**6**
66	70	NA	**4**	5	5	6	6	6	**6**	**6**	**6**	**6**
71	75	NA	**4**	5	6	6	6	6	**6**	**6**	**6**	**6**
76	80	NA	**4**	5	6	6	6	6	**6**	**6**	**6**	**6**
81	85	NA	**NA4**	**5**	6	6	6	6	**6**	**6**	**6**	**6**
86	90	NA	**NA4**	**5**	6	6	6	6	**6**	**6**	**6**	**6**
91	95	NA	**NA4**	**5**	6	6	6	6	**6**	**6**	**6**	**6**
96	100	NA	**NA4**	**5**	6	6	6	6	**6**	**6**	**6**	**6**

Coping Zone Criteria:

The following Coping Zone metrics were developed for Lake Michigan-Huron to identify circumstances where compression of the natural (i.e., pre-project) water level range is expected to have a significant detrimental impact on the abundance and diversity of meadow marsh and emergent marsh vegetative communities in Saginaw Bay and other wetland areas:

- **LMH-01 Metric:**
    - For peak water level events: plan-to-Pre-Project ratio for the maximum peak summertime water level (relative to the 109-year mean) when the Pre-Project peak is greater than 0.65 meter above the 109-year mean water level.

- **LMH-02 Metric:**
    - For post-peak drawdown events: plan-to-Pre-Project ratio of the maximum drawdown of summertime high water levels occurring within 5 years of a 'peak' water level event (only evaluated when the maximum drawdown for Pre-Project is at least 0.75 meter).

For the suite of range compression metrics, performance is evaluated based on how closely the plan mimics Pre-Project behavior for peak water level and post-peak event. For example, if the plan-to-PreProject ratios for a given alternative plan are *closer* to 1.0 than the Plan 77A ratio, this indicates that the alternative plan permits more natural water level range relative to 77A.

Note that analogous metrics related to water level range were developed for Lake Superior (SUP-01 and SUP-02). Those metrics are not associated with a specific vegetation PI, but are instead based on expert opinion that water level range requirements to maintain vegetation in Lake Superior are similar to those for Lakes Michigan-Huron and the other Great Lakes.

Calibration Data: Area of wetland in bulrush and meadow marsh vegetation types was determined by sampling vegetation along transects with known water level history and making comparisons with the extent of those elevations in a topographic/bathymetric model for the site.

Validation Data: Similar procedures have not been conducted at other sites on Lake Michigan-Huron, but other locations in Saginaw Bay could be used for validation following the next extreme high lake level.

Risk and Uncertainty Assessment: Data used in the assessment include six years following a high lake level in 1986. Invasive *Phragmites* has since become much more prominent in Saginaw Bay, suggesting that some responses in the future may differ.

Confidence, Significance and Sensitivity:

Confidence: Spatial accuracy within the study site was high. Translation to a larger area of Saginaw Bay will make that accuracy dependent on the accuracy of topographic/bathymetric maps for the bay. Temporal accuracy for data used in model development was high during the period of data collection. Translation to a larger area of Saginaw Bay in later years could introduce error related to different temporal sequences of lake-level events.

Significance: This and other wetland habitat models are very significant, as many of the other wetland PIs are dependent on the habitat model outputs. The meadow marsh specifically represents vegetation that typically develops between the maximum long-term high water level and the long-term mean. Plant species within this community are intolerant to prolonged flooding; however, occasional flooding is required to prevent woody plant species from expanding downslope into the meadow marsh community. More importantly, periodic low water level cycles are required to stop the expansion of aggressive emergent plants upslope into the meadow community. During the low water period, emergent plant species will die back at higher elevations where the hydrology is no longer suitable. Coincidently, the hydrology does become suitable for meadow marsh plant species, which will expand, and result in the meadow marsh habitat expanding downslope. This low water cycle is of critical importance for maintaining the area of meadow marsh within coastal wetlands. As water levels fluctuate between the high and low water level cycles, the meadow marsh will typically also contain some emergent, shrub, or upland plant species. The relative amount of these species is dictated by the years since the last high or low water level cycle. For this reason, the meadow marsh community supports a diversity of plant species but occurs in a relatively narrow hydrologic range in comparison to the other wetland vegetation communities. There are many species of amphibians, reptiles, birds and fish that specifically require meadow marsh habitats at some point within their life cycle. The emergent bulrush marsh represents vegetation that may persist as rhizomes during high lake levels but is not available as faunal habitat in the water column. As water levels recede, bulrushes become dominant and provide habitat for many invertebrates and small fish. The thin physical structure of bulrushes allows them to withstand waves during subsequent flooding until their depth tolerance is reached or wave energy in deeper waters becomes too great. The outer edges of bulrush stands dampen waves and result in calmer waters with reduced turbidity closer to shore. This provides diversity of habitat for faunal species.

Sensitivity: The model for Fish Point wetland, used for development of this model, suggests high sensitivity.

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Fact Sheet ID: 13

Performance Indicator (PI) Name/Short Description: Macroinvertebrate abundance index and diversity index in Saginaw Bay wetlands (Lake Huron)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Uzarski, Murry, and Cooper

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: This fact sheet describes two PI metrics for Saginaw Bay wetlands: 1) macroinvertebrate density (abundance) index and 2) macroinvertebrate diversity index (based on taxon richness). The PI metrics are based on a comparison of macroinvertebrate communities in emergent vegetation and unvegetated habitats to demonstrate impacts of vegetation zone contraction or vegetation loss.

Ecological Importance/Niche: Great Lakes coastal wetlands are important habitats for fish, amphibians, reptiles, and birds. Macroinvertebrates make up a large portion of the diets of many of these animals and often form critical linkages between primary production (plant growth), detrital (dead plant and animal matter) energy supplies, and higher trophic levels (position an organism occupies on the food chain). Macroinvertebrates are also of interest because they can be used to monitor ecosystem-level anthropogenic impacts that are not always detectable with traditional chemical/physical monitoring (Burton et al. 1999; Uzarski et al. 2004). In Great Lakes coastal wetlands, emergent, floating, and submersed vegetation form the dominant physical habitat where macroinvertebrate communities exist. Therefore, macroinvertebrate abundance and community structure depend largely on the vegetation found at a given location along the Great Lakes coast. Since hydrologic regime has a substantial influence on wetland vegetation communities, macroinvertebrate communities can be affected secondarily by water levels via the effect on vegetation. For example, if unnatural hydrologic regimes cause contraction of emergent vegetation, resulting in a transition to bare substrate, the invertebrate community will likely be very different from the community that existed under the vegetated condition. Consequently, other organisms that depend on macroinvertebrates for food such as fish and/or other vertebrates will likely be affected.

To identify potential consequences of vegetation zone contraction that could occur under certain unnatural hydrologic regimes (e.g., stabilization of lake water levels), we analyzed macroinvertebrate community data from previous studies. Our goal was to identify and quantify differences in macroinvertebrate communities inhabiting naturally-vegetated wetlands and adjacent unvegetated areas. While contraction of vegetation zones would have numerous consequences for fish, amphibian, reptile, and bird communities (e.g., loss of spawning/nesting sites, loss of refuge from predators, etc.), we are specifically addressing macroinvertebrates as a food source for higher trophic levels (e.g., fish). Data presented here were collected in fringing bulrush-dominated coastal wetlands of Saginaw Bay and northern Lake Huron and drowned river mouth wetlands of eastern Lake Michigan.

Temporal Validity: We used data collected in July 2004 and July-August 2005. While some interannual variability can be expected for wetland macroinvertebrate communities, we are confident that our results provide a valid representation of the general differences in macroinvertebrate communities between vegetated and unvegetated habitats. All samples were collected during the summer when communities were fully developed. Data from this period provide the best representation of community structure since the majority of macroinvertebrate taxa inhabiting coastal wetlands reach maturity during the late summer. However, it should be noted that some macroinvertebrate taxa emerge as flying adults in the spring and early summer, before our samples were collected. Additional research would be needed to quantify effects of water level fluctuation and vegetation zone contraction on macroinvertebrate communities at other times of the year.

Spatial Validity: We have reasonably high certainty for the wetlands that were sampled, but data could be extrapolated with some degree of certainty to other fringing wetlands of Saginaw Bay, Lake Michigan and Lake Huron. Extrapolation to other coastal wetland types with low to moderate certainty may be possible, depending on vegetation characteristics and wetland type. We do not recommend extrapolating these results to Lake Superior coastal wetlands, given their different geomorphology and macroinvertebrate communities. Instead, we recommend conducting additional research in coastal wetlands throughout Lake Superior to quantify the effects of vegetation zone contraction on macroinvertebrate communities.

Hydrology Link: There is strong evidence of the link between hydrology and the presence and community structure of wetland vegetation along the Great Lakes coast (Wilcox et al. 1984; Keddy and Reznicek 1986; Hudon et al. 2006; Wilcox and Xie 2007). Generally, stabilization of hydrology leads to encroachment of woody vegetation from the upland (Keddy and Reznicek 1986) and a shift toward dominance by a few highly competitive herbaceous species such as cattail and common reed. Reducing the frequency and magnitude of low water periods over inter- and intraannual periods also leads to contraction of emergent vegetation zones since low water periods are important for vegetation community development. For example, in early spring, as water levels are near annual lows, many coastal wetlands consist of exposed mudflats containing buried seeds, roots, and rhizomes. These areas are then quickly vegetated via seed germination and the production of shoots from buried rhizomes. As water levels increase in the spring, vegetation becomes inundated. Since the low water period is critical for initial shoot development, reducing the frequency or magnitude of seasonal water level fluctuations (i.e., stabilizing lake hydrology) will likely lead to contraction of emergent vegetation communities. Therefore, our analysis of macroinvertebrate community differences between vegetated and unvegetated habitats is representative of potential impacts caused by vegetation zone contraction resulting from stabilization of lake hydrology.

Algorithm: Algorithms were developed for macroinvertebrate density and taxon richness (the number of taxa collected). We also looked for consistent shifts in community structure between vegetated and unvegetated habitats and identified key taxa associated with each habitat type. Metrics may be applicable in the development of submodels associated with larger models that are being used to predict potential changes in emergent vegetation along the Great Lakes coast.

Three Important Caveats to Approach:

1) Any extrapolation should be based only on the areas in each system composed of similar vegetation (i.e., *Schoenoplectus* or *Nuphar advena*), not on changes to total wetland area. For example, in wetlands of Saginaw Bay and northern Lake Huron and Michigan, substantial areas consist of meadow marsh, scrub/shrub, and forested swamp habitats. While macroinvertebrates in these areas would likely be affected by changes to Great Lake hydrology and shifting vegetation, it is unknown whether our results are representative of these other habitats. Similarly, our results for Lake Michigan drowned river mouth wetlands are specific to differences between *Nuphar advena*-dominated habitats and bare sediment.

2) Since the results we report here were derived from studies designed for other purposes (e.g., Uzarski et al. 2009), they should be viewed as potential impacts to macroinvertebrate communities that could be expected with the contraction of emergent vegetation zones due to water level stabilization. Additional experimental research would be necessary to further validate the patterns we report.

3) Studies of living communities are inherently biased by the type of sampling gear used. In this analysis we have included macroinvertebrate data collected using dip nets and quatrefoil light traps. We acknowledge that other sampling techniques may have yielded different results.

Macroinvertebrate Density

Macroinvertebrates were collected from six *Schoenoplectus* zones and six adjacent open water zones in Saginaw Bay (these data were originally published in Uzarski et al. 2009). Water depth was kept consistent between vegetated and unvegetated sampling points. Triplicate samples were collected by pushing hand-held D-nets through the top 3-5 cm of sediment for 3 minutes per sample over an area of approximately 4.25 m^2. Total macroinvertebrate density was significantly higher in vegetated (44.9±12.8 organisms m^{-2}) than unvegetated (14.0±3.9 organisms m^{-2}) habitats (Figure 1). The mean difference between vegetated and unvegetated habitats was 30.9±12.7 organisms m^{-2}. We were unable to compare macroinvertebrate density between vegetated and unvegetated habitats in Lake Michigan drowned river mouth wetlands due to a lack of quantitative and areal-specific data from these systems.

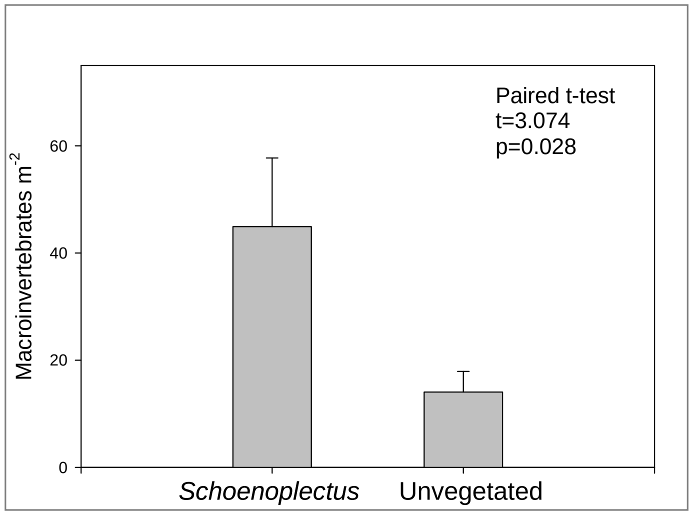

Figure 1. Macroinvertebrate catch m^{-2} (+SE) in six Schoenoplectus (bulrush) dominated habitats and six adjacent unvegetated habitats in Saginaw Bay.

Macroinvertebrate Taxon Richness

Macroinvertebrates were collected from six *Schoenoplectus* zones and six adjacent open water zones in Saginaw Bay (originally published in Uzarski et al. 2009). Water depth was kept consistent between vegetated and unvegetated sampling points. Triplicate samples were collected by pushing hand-held D-nets through the top 3-5 cm of sediment for 3 minutes per sample over an area of approximately 4.25 m^2. Macroinvertebrate taxon richness was significantly higher in vegetated (18.7±1.0) than unvegetated (8.8±1.1) habitats (Figure 2). The mean difference between vegetated and unvegetated habitats was 9.8±1.7 taxa.

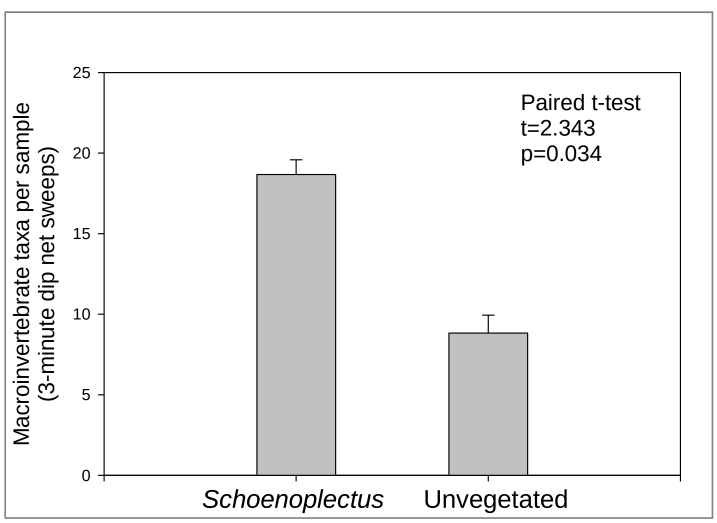

Figure 2. Macroinvertebrate taxon richness (+SE) in six Schoenoplectus (bulrush) dominated habitats and six adjacent unvegetated habitats in Saginaw Bay.

The difference in taxon richness reported above was confirmed by a second study where macroinvertebrates were collected in 15 coastal wetlands of Saginaw Bay and northern Lake Huron using quatrefoil light traps (for information on trap design see Gyekis et al. 2006). Traps were set overnight to collect zooplankton, macroinvertebrates, and larval fish. Traps were set along transects extending from open water into *Schoenoplectus* stands (one transect per wetland). We compared macroinvertebrate taxon richness between traps set at the outer edge of vegetation with traps set 20 m inside of vegetation patches. Sampling points inside the *Schoenoplectus* stands collected an average of 2.1±0.9 more taxa than those set just outside the vegetation. This difference was statistically significant (paired t-test, t=2.446, df=14, p=0.028).

In July 2004 we sampled macroinvertebrates using dip nets in four Lake Michigan drowned river mouth wetlands (Pentwater, White, Muskegon, and Kalamazoo) and compared macroinvertebrate communities in habitats dominated by *Nuphar advena* to those inhabiting unvegetated areas. Sampling was qualitative and followed Burton et al. (1999) and Uzarski et al. (2004). Macroinvertebrate taxon richness was significantly higher in vegetated (16.4±1.0) than unvegetated (8.9±0.2) habitats (Figure 3). The mean difference between vegetated and unvegetated habitats was 7.5±1.1 taxa. *It should be noted that the results summarized in Figure 3 were not used directly as a performance indicator metric; however, these results provide additional support for the Saginaw Bay macroinvertebrate diversity index, which was based on the results summarized in Figure 2.*

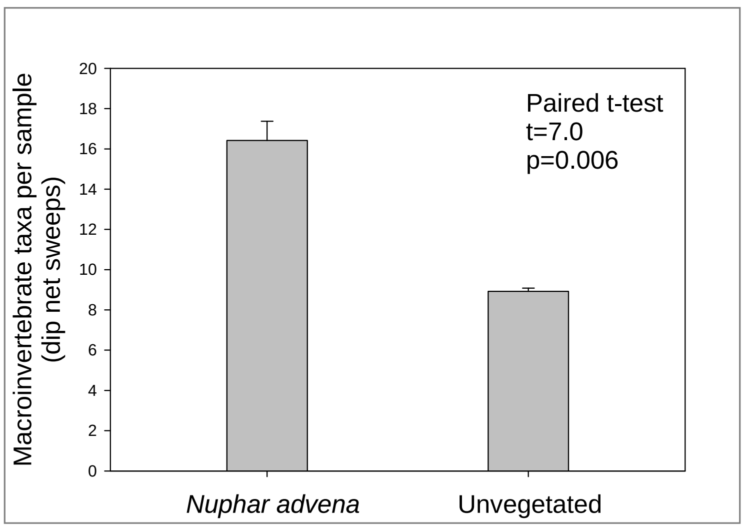

Figure 3. Macroinvertebrate taxon richness (+SE) from Nuphar advena (yellow pond-lily) dominated habitats and adjacent unvegetated habitats in four Lake Michigan drowned river mouth wetlands.

Macroinvertebrate Community Structure

Macroinvertebrate communities from Saginaw Bay (sampled using timed dip net sweeps) were compared between vegetated and unvegetated habitats using a variety of multivariate statistical techniques (e.g., nonmetric multi-dimensional scaling, correspondence analysis, and multi-response permutation procedures). These analyses were used to identify general differences between communities inhabiting each habitat type. Correspondence analysis and nonmetric multi-dimensional scaling revealed that invertebrate communities consistently lost snails (especially *Stagnicola*) and amphipods (especially *Hyallela azteca*) and gained dipterans (especially Chironomini) along a gradient from vegetated habitats to unvegetated habitats.

Coping Zone Criteria:

The hydrologic threshold for this PI is closely associated with that of the ‘bulrush marsh surface area’ PI. Water level regimes that cause a reduction in the areal extent of emergent vegetation will have an appreciable effect on macroinvertebrate abundance as habitat area is reduced. Therefore, the hydrologic threshold for macroinvertebrate abundance and diversity is that which causes any net loss of bulrush habitat.

Departure from natural hydrologic cycles, especially the timing of seasonal highs and lows, will also impact macroinvertebrate communities. For example, if water levels remain at seasonal lows throughout the spring or into the summer, communities will fail to develop because many organisms will remain in diapause due to lack of re-inundation. Therefore, water levels on Lake Michigan and Huron should begin the annual rise by mid-April of each year. Furthermore, midsummer drawdown of water levels, even for short periods (days) would alter macroinvertebrate communities by causing desiccation.

In evaluating coping zone criteria for the macroinvertebrate abundance index and diversity index PIs described in this fact sheet, it was recognized that this PI is well-represented by coping zone criteria developed for other Lake Huron vegetation and fish PIs, including:

- Emergent marsh (i.e., bulrush) vegetation PI in Saginaw Bay (fact sheet #12);
- Macroinvertebrate species composition diversity in Les Cheneaux Islands wetlands (fact sheet #14); and
- Wetland fish abundance and diversity in Saginaw Bay (fact sheet #15).

Please refer to these fact sheets for coping zone criteria that support the specific macroinvertebrate abundance index and diversity index PIs documented in this fact sheet.

Calibration Data: We are not aware of additional calibration data from the Great Lakes.

Validation Data: We are not aware of additional validation data from the Great Lakes.

Risk and Uncertainty Assessment:

This PI metric is based on the following assumptions, which help create the appropriate “story”:

- Vegetation zone contraction, or the loss of emergent vegetation, is a potential consequence of unnatural hydrologic regimes. Low water periods are important for maintaining emergent vegetation communities.
- Macroinvertebrates perform a number of vital roles in coastal ecosystems. For example, they provide a food resource to fish and other vertebrates and are a vital link between detrital material and the rest of the coastal and nearshore food web.
- Vegetation zone contraction will result in a loss of macroinvertebrate diversity and density, which will impact higher trophic levels such as fish.

Confidence, Significance and Sensitivity:

Confidence:
a) Spatial Confidence: high at the sampled sites, moderate at sites with similar vegetation and geomorphology (i.e., other Saginaw Bay and northern Lake Huron and Lake Michigan wetlands, other Lake Michigan drowned river mouth wetlands), and unknown for other wetland types or vegetation types.

b) Temporal (seasonal) Confidence: high for the summer season, when samples were collected. It is unknown how applicable these results are to other times of year. Our sampling was conducted at peak vegetation biomass and when macroinvertebrate communities were fully developed for the year. It is unclear if differences would have been as apparent in the winter or spring when many invertebrate taxa remain in resting stages.

c) Temporal (interannual) Confidence: unknown since data were collected for only two years. However, we are confident that the patterns we report can be generalized across years. Additional research would be required to test this assumption.

Significance: As a secondary impact of vegetation zone contraction or the loss of emergent vegetation, significance is moderate to high. The loss of macroinvertebrate diversity and density that is expected when macrophyte patches contract will impact the productivity of higher trophic levels that rely on invertebrates as a food source.

Sensitivity: Unknown but likely high given that macroinvertebrate communities are generally very sensitive to chemical, physical, and habitat alterations.

Documentation and References:

Burton, T.M., D.G. Uzarski, J.P. Gathman, J.A. Genet, B.E. Keas, and C.A. Stricker. 1999. Development of a preliminary invertebrate index of biotic integrity for Lake Huron coastal wetlands. *Wetlands*, 19:869-882.

Gyekis, K.G., M.J. Cooper, D.G. Uzarski, and T.M. Burton. 2006. A high-intensity LED light source for larval fish and invertebrate floating quatrefoil light traps. *Freshwater Ecology*, 21:621-626.

Hudon, C., D.A. Wilcox, and J.W. Ingram. 2006. Modeling wetland plant community response to assess water-level regulation scenarios in the Lake Ontario-St. Lawrence River basin. *Environmental Monitoring and Assessment*, 113:303-328.

Keddy, P.A. and A.A. Reznicek. 1986. Great Lakes vegetation dynamics: the role of fluctuating water levels and buried seeds. *Journal of Great Lakes Research*, 12:25-36.

Uzarski, D.G., T.M. Burton, R.E. Kolar, and M.J. Cooper. 2009. The ecological impacts of fragmentation and vegetation removal in Lake Huron’s coastal wetlands. *Aquatic Ecosystem Health and Management*, 12(1):1-17.

Uzarski, D.G., T.M. Burton, and J.A. Genet. 2004. Validation and performance of an invertebrate index of biotic integrity for Lakes Huron and Michigan fringing wetlands during a period of lake level decline. *Aquatic Ecosystem Health and Management*, 7:269-288.

Wilcox, D.A., S.I. Apfelbaum, and R.D. Hiebert. 1984. Cattail invasion of sedge meadows following hydrologic disturbance in the Cowles Bog Wetland Complex, Indiana Dunes National Lakeshore. *Wetlands*, 4:115-128.

Wilcox, D.A. and Y. Xie. 2007. Predicting wetland plant community responses to proposed water-level regulation plans for Lake Ontario: GIS-based modeling. *Journal of Great Lakes Research*, 33:751-773.

Fact Sheet ID: 14

Performance Indicator (PI) Name/Short Description: Macroinvertebrates – species composition diversity in bulrush zone (Les Cheneaux Islands, Lake Huron)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Uzarski, Murry, and Cooper

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: Diversity of dominant macroinvertebrate functional feeding group (based on density of Caenidae and Asellidae).

This PI represents the macroinvertebrate response to water level change independent of depth and vegetation type, which demonstrates that water levels impact fauna not only indirectly through changes in vegetation, but also directly by changing energy sources.

Ecological Importance/Niche: The Great Lakes hydrologic regime is paramount to ecosystem structure and function. The $7.5 billion per year commercial and sport fishing industry, along with the coastal wetlands that are worth an order of magnitude more ($69 billion along Canadian shores alone, Krantzberg and de Boer 2008), will be impacted drastically by alterations of water levels and cyclic fluctuations. Over the past 10 to 15 years, scientists have just begun to understand the importance of coastal wetlands to the overall Great Lakes ecosystem. For example, the majority of Great Lakes fishes rely on coastal wetlands for some aspect of their life histories. In addition, coastal wetlands provide habitat for more than 20 mammalian species as well as many amphibians and reptiles (Wilcox 1995, Weeber and Vallianatos 2000). Approximately 80-90 bird species, including 28 species of waterfowl (Prince et al. 1992, Prince and Flegel 1995, Weeber and Vallianatos 2000), also rely on coastal wetlands for habitat.

These systems also support an enormous amount of fish prey in the form of macroinvertebrates. More than 260 taxa of macroinvertebrates utilize coastal wetlands at densities greater than 50,000 per m^2 (Burton et al. 1999, 2002, 2004; Cardinale et al. 1997, 1998; Gathman et al. 1999; Kashian and Burton 2000; Uzarski et al. 2004; Cooper et al. 2006; Cooper et al. 2007; Uzarski et al. 2009; Burton and Uzarski 2009; Cooper et al. 2009). Given the difficulty in identifying immature macroinvertebrates, the 260 taxa documented likely represent 750 to 1,000 species. After losing greater than 50% of our Great Lakes coastal wetlands to development and agriculture, we are just now realizing the importance of these systems to the overall health of the Great Lakes.

Temporal Validity: Relationships between macroinvertebrates and water levels were established using data collected over a six year period. Water levels changed considerably over this time. From 1997 to 2002, water levels of Lakes Michigan/Huron fluctuated approximately 1 m. The very strong relationships with fine, one year, resolution suggest that these metrics will be temporally robust.

Spatial Validity: We feel very confident that our metrics are valid for fringing wetlands of the Les Cheneaux area of Northern Lake Michigan. The metrics are very likely to be valid for all of Northern Lakes Huron and Michigan, but specific data were not available to test this hypothesis.

Hydrology Link: Coastal wetlands serve many critical physical, chemical, and biological functions; water level fluctuations influence these functions in profound ways. Alterations in hydrology, either natural or anthropogenic, shape communities and make community composition dynamic.

Algorithm: We sampled invertebrate communities from wetlands of Lakes Huron and Michigan from 1997to 2002. Water levels fluctuated drastically during that time period. However, our sampling protocols attempted to isolate hydrologic variables. We sampled invertebrate communities within plant zones that migrated towards open water or shoreward depending on the direction of the water level change and the depth of sampling stations was kept relatively constant. We used non-metric multidimensional scaling (NMDS) and Pearson correlation to relate invertebrate community composition to hydrology. With habitat, water quality, and depth variables held relatively constant, Great Lakes water levels still impacted invertebrate communities. Therefore, our results suggest that alterations of natural hydrologic regimes have the potential to impact these ecosystems in ways that have not yet been considered.

Many studies suggest that changes in hydrology produce significant changes in macrophyte community composition. Results of our past published studies relate macroinvertebrate community composition to dominate vegetation types with pronounced differences among vegetation types. However, for this study, we kept vegetation type and depth relatively constant, therefore isolating the effect of annual water level. We determined a shift in macroinvertebrate community composition related to water level change and direction independent of depth and dominant vegetation type.

The relationship between invertebrate community composition and water level was likely driven, in part, by a shift from a detritus (dead plant and animal matter) based food web to an algal (plant) based food web. As water levels rose, more protected areas with denser vegetation were inundated with water. Through time, the deeper water with more hydrologic energy likely reduced vegetation density resulting in an abundance of detritus, favoring shredders and collector/gatherers. As water levels declined, areas of sparse vegetation became benign allowing sunlight to penetrate, gradually favoring algae. During declining water level years, scrapers trended towards becoming more abundant, but there was no significant relationship between their numbers and water levels.

Figure 1 below represents mean annual water levels from 1996 through 2003. While no invertebrate data were collected in 1996, it is noted on the figure because invertebrates are likely responding to the previous year water level.

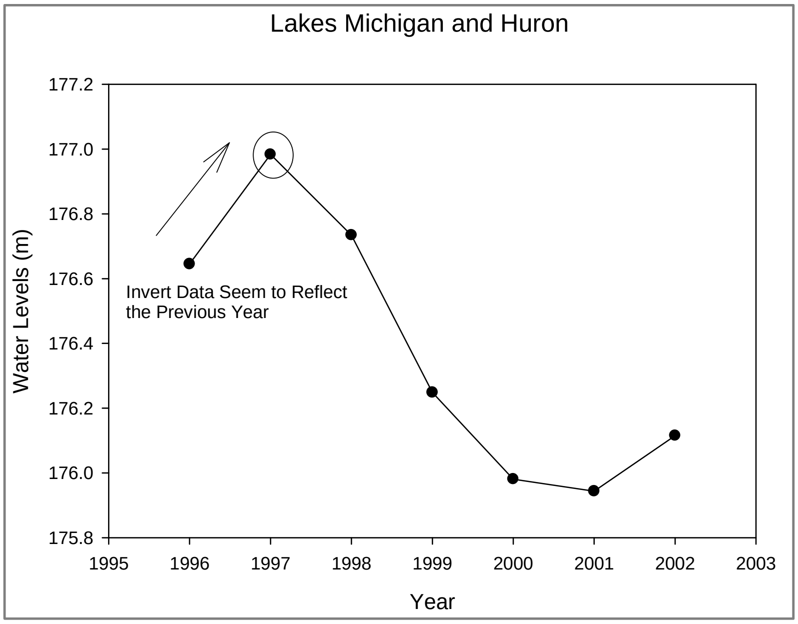

Figure 1. Mean annual water levels from 1996 through 2003. The arrow represents the direction of water level change and the circled point corresponds with the circled point in the subsequent figures.

A significant correlation between invertebrate community composition is shown below in Figure 2. The community shifts from Scrapers (representing an algal based food web) at low water levels to Shredders and Collectors (representing a detrital based food web) at high water levels. NMDS was decomposed to determine the invertebrate families that weighted heaviest in the dimension. While dimension 1 reflects the entire invertebrate community encountered over the entire sampling period, taxon in the family's Caenidae (i.e., mayflies) and Asellidae (i.e., isopod crustaceans) were major drivers.

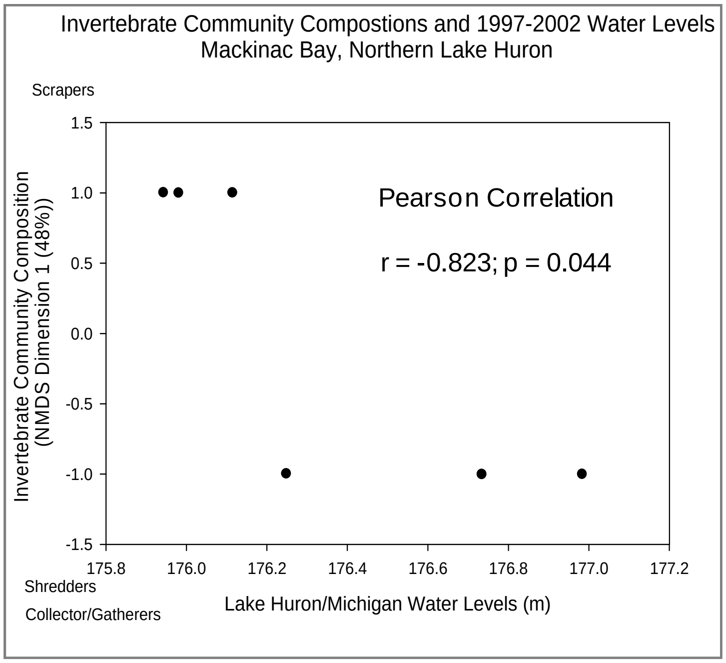

Figure2. Correlation between invertebrate community composition and water levels; represented using NMDS Dimension 1 and water levels over a six year period, keeping plant zone and water depth constant.

Figure 3 below represents mean numbers of mayflies in the family Caenidae. Regardless of whether data are collected from one site (left) or averaged from 10 (right), the figure represents the mirror image of water levels alone, suggesting a one year lag in Caenidae response. While the relationship between mean Caenidae numbers and water levels was significant ($p < 0.05$) without incorporating a one year lag, the relationship is much improved with a lag (Figure 4).

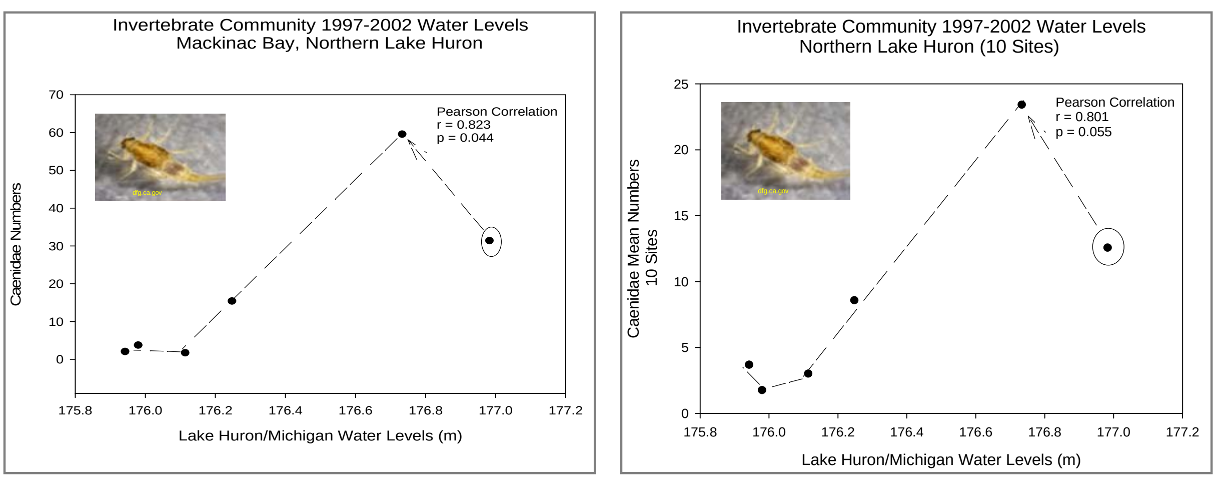

Figure 3. Mean numbers of mayflies in the family Caenidae. Left panel represents data collected from one site and the panel on the right represents data averaged from 10 sites.

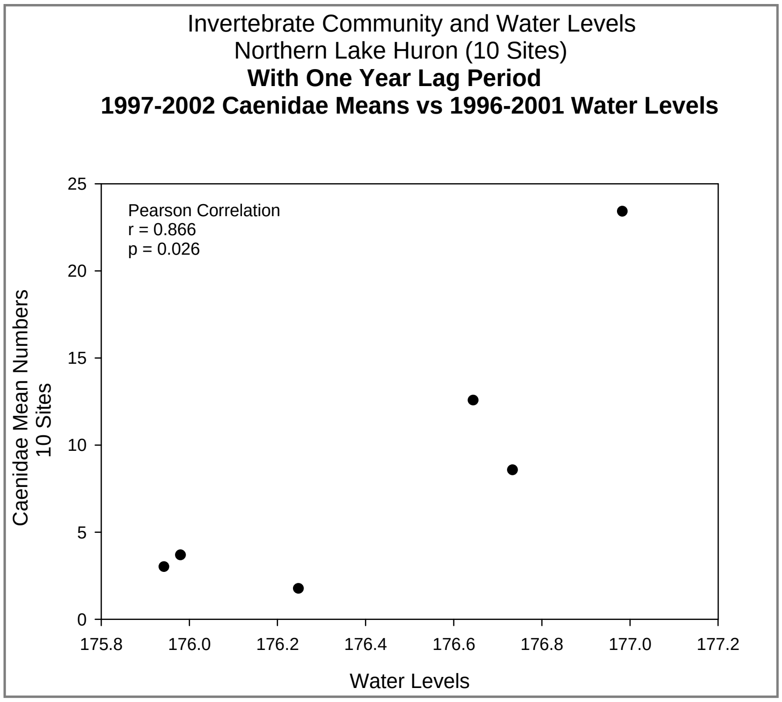

Figure 4. Mean Caenidae numbers in relation to the previous year's water levels. When a lag period is incorporated, r=0.866 and p=0.026.

While the relationship between the mean Asellidae numbers and water levels is not significant at $p < 0.05$, the points do follow the trend of water levels plotted by year suggesting a one year lag period (Figure 5).

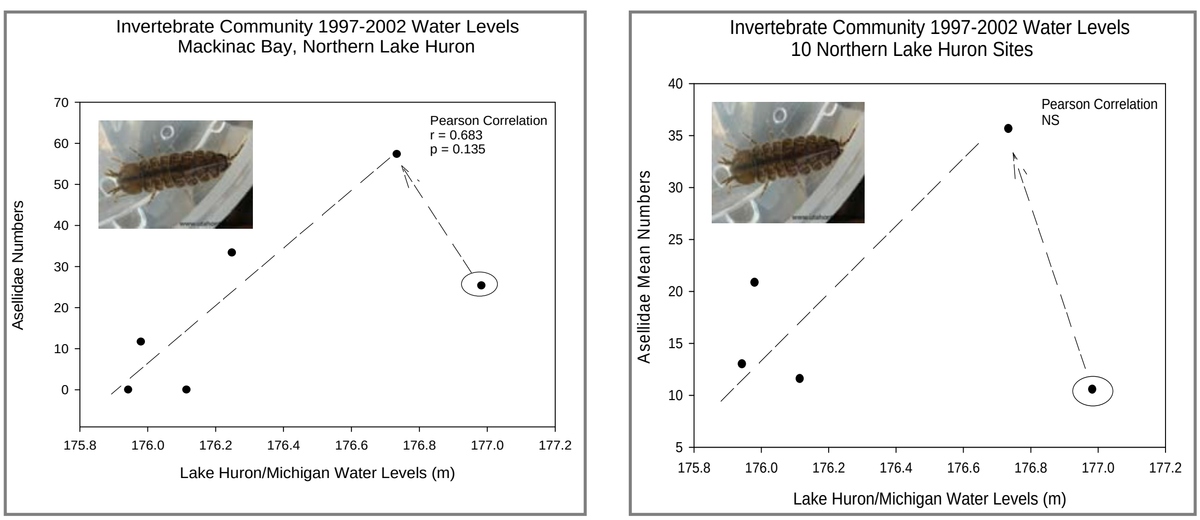

Figure 5. Mean numbers of crustaceans in the family Asellidae. Left panel represents data collected from one site and the panel on the right represents data averaged from 10 sites.

When Pearson correlation was conducted using the previous year's water levels (Figure 6), the relationship was still not significant at $p < 0.05$, but was significant at $p < 0.10$; an alpha value of

0.10 is often used with invertebrate data because the data are inherently variable. In addition, the relationship is surprisingly strong if a single outlier is removed from the dataset. However, until we can determine whether or not there may be error associated with the outlier, or any other data point, we cannot justify removing data points from the dataset. We do, however, believe that this is a valid metric of water level change.

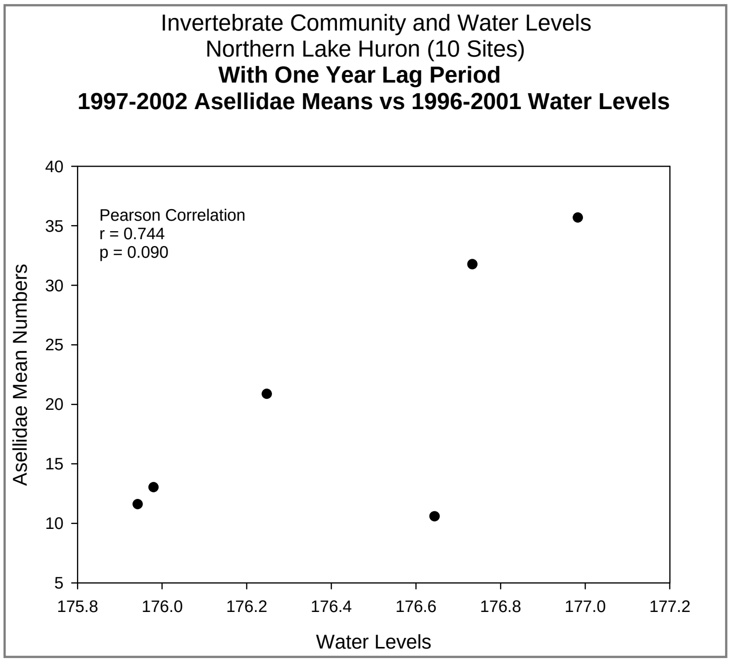

Figure 6. Mean Asellidae numbers in relation to the previous year's water levels. Pearson correlation conducted using a one year lag period in water levels. The relationship was not significant at $p < 0.05$ due to one outlier, but was significant at $p < 0.10$.

Coping Zone Criteria:
Multi-year trends in mean annual water level are important for structuring macroinvertebrate communities. Since trends in mean annual water level tend to oscillate between 'rising' and 'falling' every 3-5 years, we recommend that a 7-10 year trend in a given direction, either falling or rising, be considered a threshold not to be exceeded. The "Zone B" and "Zone C" rules for this criterion are defined as follows:

- **LMH-03 Criterion**:
    - Zone B: Annual peak water level monotonically increases or decreases for any 7 years within a 10-year window.
    - Zone C: Annual peak water level monotonically increases or decreases for 10 consecutive years.

Calibration Data: We are not aware of additional calibration data from the region, but we do have similar data from other regions. However, due to fewer years, power of detection will be reduced.

Validation Data: Gathman and Burton (submitted) have similar data with comparable results.

Risk and Uncertainty Assessment: This PI metric is based on six years of data from 10 sites within one region (Les Cheneaux Islands) of northern Lake Huron. While we feel confident in the results of these analyses and these are consistent with one other study within the region, more data are needed to extend the PI metric to other regions.

Confidence, Significance and Sensitivity:

Confidence:
a) Spatial Confidence: high at the sampled sites, moderate at sites with similar vegetation and geomorphology and unknown for other wetland types or vegetation types.

b) Temporal (seasonal) Confidence: high for July and August only.

c) Temporal (interannual) Confidence: high as these data were analyzed on an annual basis.

Significance: Not only are these invertebrates key food sources for fishes, they serve a function to indirectly transfer energy up the food web by processing detrital material that is much less labile than algae. This PI likely reflects a shift from an algal based food web during low water years to a detritus based food web during high water years. The PI reflects the natural dynamics of the system that directly promotes the overall diversity of the biota above and beyond the invertebrates. The base of the food web is paramount to the structure and the function of the system. If the system is maintained at either an algal base or a detritus base, it will become relatively static and competition for resources will favor those organisms specifically adapted to those conditions and diversity will decrease.

Sensitivity: These data suggest a very high sensitivity.

Documentation and References:

Burton, T.M., D.G. Uzarski, J.P. Gathman, J.A. Genet, B.E. Keas, and C.A. Stricker. 1999. Development of a preliminary invertebrate index of biotic integrity for Lake Huron coastal wetlands. *Wetlands*, 19:869-882.

Gyekis, K.G., M.J. Cooper, D.G. Uzarski, and T.M. Burton. 2006. A high-intensity LED light source for larval fish and invertebrate floating quatrefoil light traps. *Freshwater Ecology*, 21:621-626.

Hudon, C., D.A. Wilcox, and J.W. Ingram. 2006. Modeling wetland plant community response to assess water-level regulation scenarios in the Lake Ontario-St. Lawrence River basin. *Environmental Monitoring and Assessment*, 113:303-328.

Keddy, P.A. and A.A. Reznicek. 1986. Great Lakes vegetation dynamics: the role of fluctuating water levels and buried seeds. *Journal of Great Lakes Research*, 12:25-36.

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Uzarski, D.G., T.M. Burton, and J.A. Genet. 2004. Validation and performance of an invertebrate index of biotic integrity for Lakes Huron and Michigan fringing wetlands during a period of lake level decline. *Aquatic Ecosystem Health and Management*, 7:269-288.

Wilcox, D.A., S.I. Apfelbaum, and R.D. Hiebert. 1984. Cattail invasion of sedge meadows following hydrologic disturbance in the Cowles Bog Wetland Complex, Indiana Dunes National Lakeshore. *Wetlands*, 4:115-128.

Wilcox, D.A. and Y. Xie. 2007. Predicting wetland plant community responses to proposed water-level regulation plans for Lake Ontario: GIS-based modeling. *Journal of Great Lakes Research*, 33:751-773.

Fact Sheet ID: 15

Performance Indicator (PI) Name/Short Description: Wetland Fish - abundance and diversity indices in the inner and outer bulrush zone (Saginaw Bay, Lake Huron)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Uzarski, Murry, and Cooper

Modeled by: LimnoTech (Redder, DePinto)

PI Metrics: This fact sheet addresses a suite of PI metrics that can be used to assess changes in total fish abundance, fish species richness, and fish species evenness (as indexed by standardized trap-net catches) relative to changes in water level in the inner and outer *Schoenoplectus* (i.e., bulrush) zones of Great Lake coastal wetlands. The four PI metrics incorporated into the IERM2 model are:

1. Fish species richness in outer bulrush zone;
2. Fish assemblage evenness in outer bulrush zone;
3. Fish total abundance in inner bulrush zone; and
4. Fish species richness in inner bulrush zone.

We examined these fish assemblage responses (abundance, richness, and evenness) to several unique components of the natural hydrologic regime (Poff et al. 1997) modified for lake water levels. Specifically, we examined how the magnitude and timing of water levels (indicated by monthly mean, minimum, maximum water levels as well as monthly water level range and standard deviation) and rates of water level change (spring equinox to summer solstice and winter to summer) affected the fish assemblage. Fish assemblages were sampled in July and August, at the peak of vegetation development, and the height of the nursery period of most fishes. We have assessed the role of spring and summer water level regimes on the fish assemblage.

Ecological Importance/Niche: Fish are the most visible and easily recognizable connection between people and the Great Lakes ecosystem. Fish typically hold the highest trophic (place on the food chain) positions; therefore, fish may serve as important (though potentially overly-conservative) indicators of integrated ecosystem health. Fish populations and assemblages (collection of many species) respond to many different features of their environment, including physical and chemical habitat, prey availability, predator abundance, and disturbance regimes, all of which may be influenced by daily, seasonal, annual, and long-term water levels. Great Lake coastal wetland fish assemblages consist largely of young-of-the-year (YOY) fish using the highly productive coastal wetlands as nursery habitats. Approximately 90% of Great Lakes fishes utilize coastal wetlands for some aspect of their life cycle and the most common stages include the spawning and nursery periods, collectively termed ‘early life stages’. The nursery period, or the first growing season of a fish’s life, is a critical period for year class development and individual survival and is often dependent on habitat quality. High quality spawning and nursery habitat will be defined uniquely for each species of fish, but will generally consist of a species-specific range of water temperature, water chemistry (e.g., dissolved oxygen and pH), water depth, vegetation and substrate characteristics (cover from predators and source for prey), and of course ample prey to maximize growth.

The water level regime can be broken down into component parts that can collectively influence local water depth, wave energy, substrate composition, water chemistry, nutrient cycling, and metabolism, which in turn influences vegetation composition and ultimately habitat quality for invertebrates and fish. Components of the water level regime include: magnitude of levels, timing of highs and lows, temporal variation, rates of change, frequency of water level changes, and durations of particular levels (e.g., highs, lows, or average levels). Each of these components acts uniquely to indirectly influence fish populations by altering habitat conditions.

Components of the ambient water level regime, such as timing, magnitude, and rates of change, can also affect fish directly by acting as important cues that initiate changes in life history. For example, spawning runs are initiated during high water levels. Water levels are likely a secondary cue behind primary cues such as photoperiod and water temperature, but will work in concert with other cues to initiate spawning activities, hatching, swim-up, and post-larval habitat movements. The spring equinox (March 21^{st}, the day of equal light and dark) and the summer solstice (June 21^{st}, longest day of the year) are important photoperiod cues and may interact with seasonal water levels to influence aspects of life history. Similarly, high variability or rapid rates of change in monthly or seasonal water levels might influence egg and YOY success of individual species and/or habitat use patterns. Thus, we hypothesize that monthly differences in mean, high, and low water levels, monthly ranges and variation in water levels, and rates of change relative to key photoperiod cues will affect the abundance, species richness and evenness of fish in Great Lake coastal wetlands.

Temporal Validity: Data used in development of these PI metrics were gathered from 2000 to 2008 and consist of mean monthly spring and summer water levels ranging from 175.469 m in April 2001 (lowest studied mean monthly water level) to 176.529 m in July 2004 (highest mean monthly water level studied). We have high confidence in the algorithms (described below) within this range of water levels and decreasing confidence beyond this range. Appendix 1 contains specific years and sites that were sampled and used in developing this set of PIs.

Spatial Validity: Suitable data were available for three upper lake ecoregions: Saginaw Bay, northern Lake Huron, and northern Lake Michigan (Appendix 1). We treated each ecoregion separately, developing unique functional relationships between fish and water levels for each region. The spatial coverage of representative sites gives us moderate to high certainty for those entire regions, but not for extrapolation to other ecoregions or wetland types.

Hydrology Link: It is hypothesized that components of the water level regime (e.g., magnitude of levels, rate of change, and variation in levels), serving as secondary environmental cues, will interact with primary cues, namely water temperature and photoperiod, to influence fish habitat use. Monthly water level factors during spring may differentially influence the spawning behavior of fish species which will impact summer wetland fish assemblages, resulting in changes in abundance, richness, and evenness depending on which species benefitted or were deterred by a given spring water level regime. Late spring and summer water levels could influence nursery habitat quality on a species-specific basis, influencing total fish abundance, species richness, and/or evenness.

Algorithm: Twenty-six different measures of spring and summer water level were related to fish abundance, species richness, and assemblage evenness. The water level metrics included: monthly mean, minimum, and maximum water levels from March to August (18 metrics); monthly standard deviation of water levels March to August (6 metrics); the rate of water level change (increase) from January to July and the rate of water level change (increase) from the spring equinox to the summer solstice. Clearly, there is significant multicollinearity (in multivariate analyses, some of the independent variables or predictors may be correlated with each other) among these metrics, so we first utilized simple Pearson correlation between each water level metric and each fish response to identify those factors having the strongest univariate (single) relationship. We then methodologically selected factors showing strong univariate ties to each response variable and low collinearity to other water level factors and used these hand selected water level components in a stepwise multiple regression analysis. Regression models were developed in SAS (Statistical Analysis Software) and assessed for multicollinearity using variance inflation, collinearity, and condition indices. Ultimately, model selection was based on the strongest predictive power (r^2), overall simplicity (univariate models were selected over multivariate), and biological meaning. Sample year is the experimental unit and individual sampling sites were pooled with each year and ecoregion. Though samples were collected between 2000 and 2008, not all ecoregions were sampled in all years, thus sample size was less than nine years in all ecoregions (Appendix 1).

Here we present three PIs: 1) mean total fish abundance, 2) fish species richness, and 3) fish species evenness for both the inner and outer bulrush (*Schoenoplectus*) zones and in each of three ecoregions: Saginaw Bay, northern Lake Huron, and northern Lake Michigan. Observed water level data are presented in Appendix 2 for all identified metrics.

Saginaw Bay outer bulrush zone –mean total abundance of fish

Mean total abundance of fish (trapnet catch per unit effort, CPUE) in Saginaw Bay was influenced by the degree of April and May water level variation and the rate of change from the spring equinox to the summer solstice. The final model is (r^2 = 0.9999, $F_{3,4}$ = 5900.80, P = 0.0096) :

Mean total fish abundance = 1,158.28401 + 5,433.58723 * (April WL STDEV) – 16,542.0 * (May WL STDEV) – 16,871.0 * (Rate of change equinox to solstice)

Where:

WL STDEV = monthly water level standard deviation calculated based on daily mean water level.

Rate of change equinox to solstice = (mean June WL – mean March WL) / 92 days; 92 days is the number of days between the spring equinox (March 21) and the summer solstice (June 21).

All model parameters are significant ($p < 0.05$) with the exception of the rate of change from equinox to solstice (p = 0.1065), which was retained because its inclusion greatly improved model performance. Complete model specifics are presented in Appendix 3.

Saginaw Bay outer bulrush zone – Fish species richness

Fish species richness was best described by the rate of water level change (increase) from the spring equinox to the summer solstice. The final univariate model showing a decline in fish species richness as the rate of water level change increases described 82% of the total annual variance in fish species richness ($F_{1,4}$ = 13.48, P = 0.0350; Figure 1). Complete model details are presented in Appendix 3.

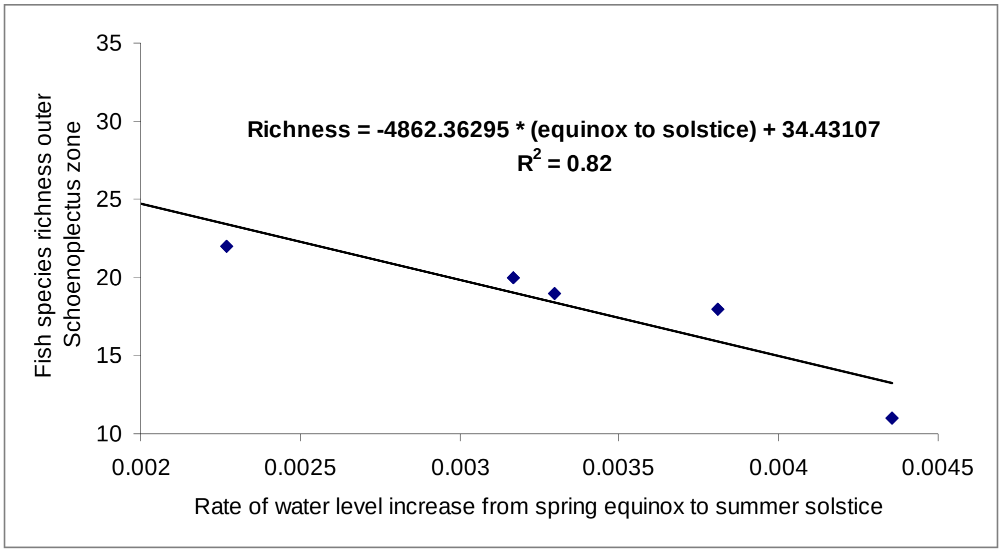

Figure 1. Declining fish species richness with increasing rate of water level change from the spring equinox to the summer solstice.

Saginaw Bay outer bulrush zone –fish assemblage evenness

The final model for fish species evenness in the outer bulrush zone of Saginaw Bay was marginally non-significant ($F_{1,4}$ = 9.22, P = 0.0560), but described 75% of the variance in fish assemblage evenness (Figure 2). Complete model details are presented in Appendix 3.

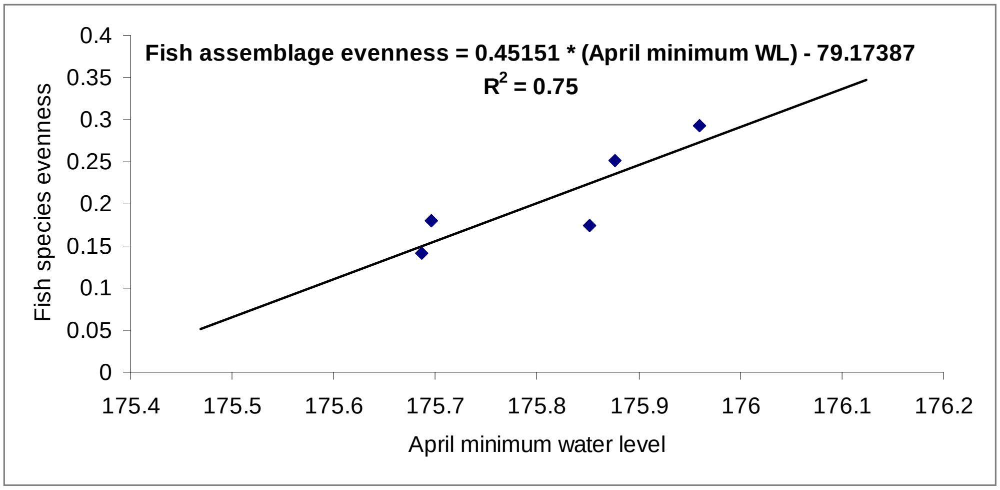

Figure 2. Increasing fish assemblage evenness with increasing April minimum water levels.

Saginaw Bay inner bulrush zone –mean total abundance of fish

Mean total fish abundance (trapnet CPUE) was best described by the rate of water level change (increase) from January to July. The final univariate model showing an increase in fish abundance with increasing rate of water level change described 78% of the total annual variance in fish abundance ($F_{1,4}$ = 10.67, P = 0.0469; Figure 3). Complete model details are presented in Appendix 3.

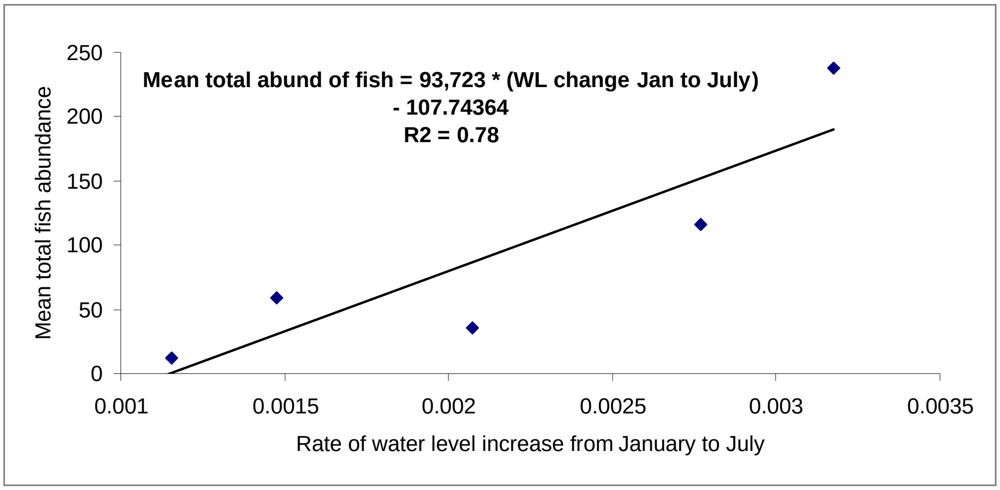

Figure 3. Increasing mean total fish abundance (trapnet CPUE) with increasing rate of water level change from January to July.

Saginaw Bay inner bulrush zone – fish species richness

Ninety-eight percent of the variation in fish species richness in the inner bulrush zone was described by maximum May water levels. As May water levels increased fish species richness increased. ($F_{1,4}$ = 151.37, P = 0.0012; Figure 4). Complete model details are presented in Appendix 3.

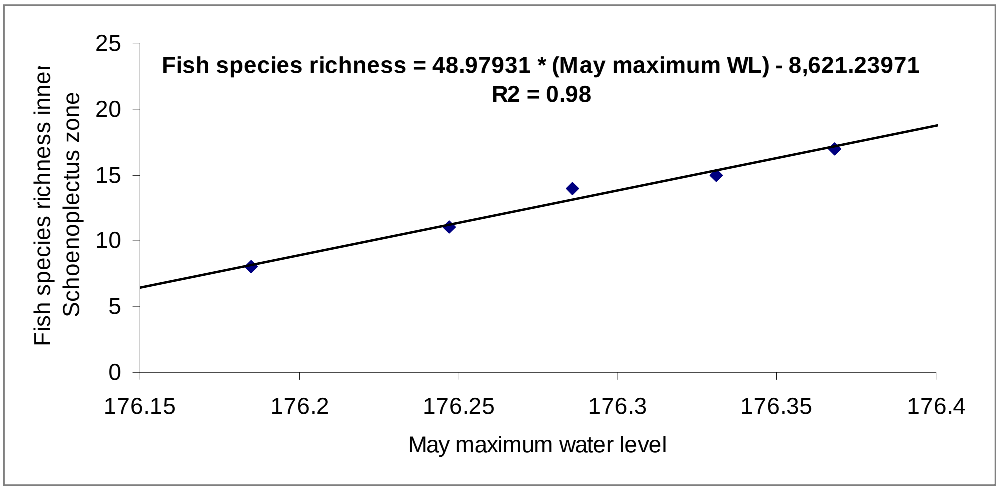

Figure 4. Fish species richness increased with increasing May maximum water levels.

Saginaw Bay inner bulrush zone – fish assemblage evenness

Two models were developed to describe fish assemblage evenness. The variance (standard deviation) of May water levels and the rate of water change from January to July described 95% of the variance in fish assemblage evenness (although adjusted $r^2 = 0.90$) and was marginally significant ($F_{2,4} = 19.99$, $P = 0.0477$), although all parameters were found to be non-significant (Appendix 3). The univariate model illustrated below (Figure 5), consisting only of the variance in May water levels, was highly significant and described a similar amount of variation ($r^2 = 0.88$, $F_{1,4} = 22.08$, $P = 0.0182$). Therefore, we advocate the use of the univariate model (Figure 5).

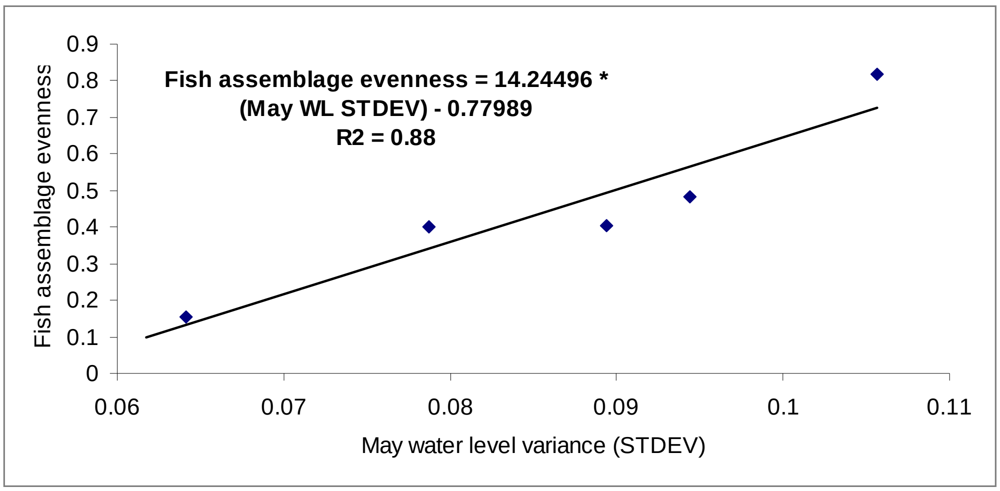

Figure 5. The univariate model of fish assemblage evenness in the inner bulrush zone of Saginaw Bay predicted by the variance in May water levels.

It should be noted that it was not possible to incorporate this relationship as a PI in the IERM2 model because it requires daily water level information in order to compute the standard deviation for water level during the month of May.

Coping Zone Criteria:

Coping zone criteria developed separately for the four individual PI metrics described in this fact sheet:

PI #1: Fish species richness in outer bulrush zone:

To maintain fish species richness at or above 15 sp, water level must not increase more than 4 mm/day between the spring equinox and summer solstice. The threshold for this PI should be 3 consecutive years in which this rate of increase is exceeded. Based on the life history traits (e.g., generation times) of common wetland fish species, exceeding 3 consecutive years of rapid water level increase may lead to dominance by a limited number of species that are able to out compete other species for habitat and resources in newly-inundated habitats. If dominance is achieved by

a limited number of species, the system will not be able to recover easily even if conditions return to normal.
The "Zone B" and "Zone C" rules for this criterion are defined as follows:

- **LMH-09 Criterion:**
    - Zone B: Water level increases by more than 0.36 meter between March and June for any year.
    - Zone C: Water level increases by more than 0.36 meter between March and June for 3 consecutive years.

PI #2: Fish assemblage evenness in outer bulrush zone:
To maintain fish species evenness above 20% (avoid dominance), April minimum water level must not be less than 175.80 m. We acknowledge that wetland vegetation zones may migrate given sufficient time and appropriate geomorphic conditions as long as anthropogenic structures (e.g., roads, seawalls) do not impede the migration. Therefore, this threshold may vary with long term changes in Great Lakes water levels and should be tied to the long-term. Because this evaluation would require an assessment of daily water levels, this coping zone criterion was not incorporated into the IERM2 model or the IERM2-based "Coping Zone Calculator".

PI #3: Fish total abundance in inner bulrush zone:
To maintain **total fish abundance** above 50 fish per trap-net night (3 net mean) daily water level change must be at least 1.68 mm/day between January and July. The threshold for this PI should be 9 consecutive years in which the rate of increase is insufficient. Based on the life history traits (e.g., generation times) of common wetland fish species, exceeding 9 consecutive years of insufficient water level increase may reduce overall fish production. If abundance is reduced for many consecutive years, the system may not be able to recover easily when conditions return to normal.

The "Zone B" and "Zone C" rules for this criterion are defined as follows:

- **LMH-04 Criterion:**
    - Zone B: Water level increases by less than 0.30 meter between January and July for any 7 years in a 9-year window.
    - Zone C: Water level increases by less than 0.30 meter between January and July for 9 consecutive years.

PI #4: Fish species richness in inner bulrush zone:
To maintain **fish species richness** at or above 10 sp in inner wetlands, May maximum water levels must remain above 176.22 m. We acknowledge that wetland vegetation zones may migrate given sufficient time and appropriate geomorphic conditions as long as anthropogenic structures (e.g., roads, seawalls) do not impede the migration. Because this evaluation would require an assessment of daily water levels, this coping zone criterion was not incorporated into the IERM2 model or the IERM2-based "Coping Zone Calculator".

Calibration Data: We are not aware of additional time series data that would be appropriate for calibration purposes.

Validation Data: We are not aware of additional independent data for validation purposes. We spent considerable time trying to divide our existing data into calibration and validation sets, but ran into issues of non-independence and excessive variation among sites (e.g., habitat) that we believe strongly would mask water level effects. What is needed is a series of sites that could be consolidated to overcome the inter-site variance and be comparable to the developed models.

Risk and Uncertainty Assessment: Not available.

Confidence, Significance and Sensitivity: Not available.

Documentation and References:

Poff, N.L., J.D. Allen, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, R.E. J.C. and Stromberg. 1997. The Natural Flow Regime. *BioScience,* 47: 769-784.

Appendix 1. Sites sampled annually in the inner and outer zone across ecoregions.

			# nets fished	
Ecoregion	**Year**	**Site name**	**Inner zone**	**Outer zone**
Saginaw Bay	2002	Bradleyville Rd	0	3
		Pinnconning	3	3
		Vanderbilt Park	3	3
		Wigwam Bay	3	3
		Wildfowl Bay	2	0
	2003	Almeda Beach	0	3
		Nyanquing	0	3
		Vanderbilt Park	0	3
		Wigwam Bay	3	3
	2004	Bayport Rd	4	0
		Linwood Beach	1	2
		Nyanquing	1	2
		White's Beach	3	0
		Wigwam Bay	0	3
	2006	Pinnconning	3	3
		Vanderbilt Park	3	3
		Wigwam Bay	3	3
		Sebawing	3	3
	2008	Pinnconning	3	3
		Vanderbilt Park	0	3
		Wigwam Bay	3	3

Appendix 2. Annual water level metrics of identified important variables to fish abundance, richness, and evenness. Water level metrics for Saginaw Bay were derived from the NOAA buoy in Essexville, MI and the northern Lakes Huron and Michigan water level metrics were derived from the NOAA buoy in Mackinaw, MI.

Saginaw Bay	April WL STDEV	May WL STDEV	Rate WL change equinox-solstice	April min. WL	Rate WL change Jan. - July	May max. WL
2000	0.131192	0.09978	0.001861	175.814	0.001347	176.285
2001	0.110303	0.078112	0.002637	175.469	0.001796	176.11
2002	0.099392	0.094365	0.003298	175.877	0.002073	176.368
2003	0.137818	0.105619	0.003168	175.696	0.001155	176.185
2004	0.090332	0.089406	0.004354	175.852	0.00277	176.331
2005	0.087219	0.061763	0.001067	176.124	0.000567	176.468
2006	0.061514	0.078717	0.002268	175.96	0.001477	176.247
2007	0.091127	0.071387	0.001578	175.794	0.00051	176.273
2008	0.123946	0.064161	0.003808	175.686	0.003176	176.286

Appendix 3. Complete regression model details.

Mean Total Abundance = outer zone Saginaw Bay

Number of Observations Read	9
Number of Observations Used	5
Number of Observations with Missing Values	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	287768	95923	5900.80	0.0096
Error	1	16.25585	16.25585		
Corrected Total	4	287784			

Root MSE	4.03185	R-Square	0.9999
Dependent Mean	228.68516	Adj R-Sq	0.9998
Coeff Var	1.76306		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value
Intercept	Intercept	1	1158.28401	14.62474	79.20
WLSTDEV4	WLSTDEV4	1	5433.58723	76.60558	70.93
WLSTDEV5	WLSTDEV5	1	-16542	133.60423	-123.81
RateChangeEquinoxSolstice	RateChangeEquinoxSolstice	1	-16871	2847.98121	-5.92

Parameter Estimates

Variable	Label	DF	Pr > |t|	Variance Inflation
Intercept	Intercept	1	0.0080	0
WLSTDEV4	WLSTDEV4	1	0.0090	1.27970
WLSTDEV5	WLSTDEV5	1	0.0051	1.09307
RateChangeEquinoxSolstice	RateChangeEquinoxSolstice	1	0.1065	1.20833

Collinearity Diagnostics

			-----------------Proportion of Variation----------------			
Number	Eigenvalue	Condition Index	Intercept	WLSTDEV4	WLSTDEV5	RateChange Equinox Solstice
1	3.91595	1.00000	0.00097963	0.00312	0.00152	0.00215
2	0.04092	9.78255	0.05055	0.60263	0.18144	0.04199
3	0.03345	10.81942	0.00484	0.36186	0.10372	0.60161

4	0.00968	20.11332	0.94363	0.03239	0.71332	0.35425

Test of First and Second
Moment Specification

DF	Chi-Square	Pr > ChiSq
4	1.81	0.7710

SPECIES RICHNESS = outer zone Saginaw Bay

The REG Procedure

Model: MODEL1

Dependent Variable: SpR SpR

Number of Observations Read	9
Number of Observations Used	5
Number of Observations with Missing Values	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	57.25552	57.25552	13.48	0.0350
Error	3	12.74448	4.24816		
Corrected Total	4	70.00000			

Root MSE	2.06111	R-Square	0.8179
Dependent Mean	18.00000	Adj R-Sq	0.7572
Coeff Var	11.45059		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value
Intercept	Intercept	1	34.43107	4.56960	7.53
RateChangeEquinoxSolstice	RateChangeEquinoxSolstice	1	-4862.36295	1324.46103	-3.67

Parameter Estimates

Variable	Label	DF	Pr > |t|
Intercept	Intercept	1	0.0048
RateChangeEquinoxSolstice	RateChangeEquinoxSolstice	1	0.0350

SPECIES EVENNESS = outer zone Saginaw Bay

Number of Observations Read	9
Number of Observations Used	5
Number of Observations with Missing Values	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.01163	0.01163	9.22	0.0560
Error	3	0.00378	0.00126		
Corrected Total	4	0.01541			

Root MSE	0.03551	R-Square	0.7546
Dependent Mean	0.20789	Adj R-Sq	0.6727
Coeff Var	17.07947		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-79.17387	26.13901	-3.03	0.0564
MinWL4	MinWL4	1	0.45151	0.14867	3.04	0.0560

Species Richness = inner zone Saginaw Bay

Number of Observations Read	20
Number of Observations Used	5
Number of Observations with Missing Values	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	49.02829	49.02829	151.37	0.0012
Error	3	0.97171	0.32390		
Corrected Total	4	50.00000			

Root MSE	0.56912	R-Square	0.9806
Dependent Mean	13.00000	Adj R-Sq	0.9741
Coeff Var	4.37788		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-8621.23971	701.79147	-12.28	0.0012
MaxWL5	MaxWL5	1	48.97931	3.98104	12.30	0.0012

Mean total abundance = inner zone Saginaw Bay

Dependent Variable: meantotabund meantotabund

Number of Observations Read	20
Number of Observations Used	5
Number of Observations with Missing Values	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	25339	25339	10.67	0.0469
Error	3	7127.42262	2375.80754		
Corrected Total	4	32466			

Root MSE	48.74226	R-Square	0.7805
Dependent Mean	91.92131	Adj R-Sq	0.7073
Coeff Var	53.02607		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-107.74364	64.90824	-1.66	0.1955
WLRateJanJuly	WLRateJanJuly	1	93723	28698	3.27	0.0469

Evenness = Inner zone Saginaw Bay model 1

Dependent Variable: even even

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.21850	0.10925	19.99	0.0477
Error	2	0.01093	0.00547		
Corrected Total	4	0.22944			

Root MSE	0.07394	R-Square	0.9523
Dependent Mean	0.45164	Adj R-Sq	0.9047
Coeff Var	16.37053		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-0.25317	0.36607	-0.69	0.5607	0
WLSTDEV5	WLSTDEV5	1	10.64160	3.12908	3.40	0.0767	1.78296
WLRateJanJuly	WLRateJanJuly	1	-101.01168	58.12720	-1.74	0.2244	1.78296

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	---------Proportion of Variation--------- Intercept	WLSTDEV5	WLRateJan July
1	2.88227	1.00000	0.00097474	0.00168	0.00707
2	0.11267	5.05773	0.00279	0.04327	0.35166
3	0.00505	23.88171	0.99623	0.95504	0.64126

Evenness = Inner zone Saginaw Bay model 2

Dependent Variable: even even

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.20199	0.20199	22.08	0.0182
Error	3	0.02744	0.00915		
Corrected Total	4	0.22944			

Root MSE	0.09564	R-Square	0.8804
Dependent Mean	0.45164	Adj R-Sq	0.8405
Coeff Var	21.17616		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-0.77989	0.26554	-2.94	0.0607
WLSTDEV5	WLSTDEV5	1	14.24496	3.03132	4.70	0.0182

Fact Sheet ID: 16

Performance Indicator (PI) Name/Short Description: Fish Habitat – percentage of wetland area accessible by fish (Lake St. Clair)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: S.D. Mackey

Modeled by: LimnoTech (Redder, DePinto)

PI Metrics: The metric for the Lake St. Clair fish habitat is percent area of available (or accessible) fish habitat as a function of mean annual water level calculated from monthly means over the period of spawning activity from March to October.

Ecological Importance/Niche: Coastal wetlands and shallow water nearshore embayments serve as important spawning grounds, nurseries and feeding areas for many Great Lakes fishes (Jude and Pappas 1992; Tanner et al. 2004). Important sport fish species such as northern pike, yellow perch, walleye, black crappie and smallmouth and largemouth bass, along with forage species such as minnows, suckers, darters and bullheads use coastal wetlands during some part of their life history (Stephenson 1990; Brazner and Beals 1997). Highly productive shallow coastal embayments and coastal wetlands in Lake St. Clair provide spawning and nursery habitat for numerous fish species that not only populate Lake St. Clair and the connecting channels, but Lake Erie and Lakes Michigan-Huron as well. Recent fish tracking data show widespread dispersal of walleye and other species of interest throughout Lake St. Clair and the connecting channels and both Lakes Michigan–Huron and Lake Erie as well (Robert Haas, Michigan Department of Natural Resources and Environment (MDNRE), personal communication).

Temporal Validity: The data used to identify spawning and nursery sites are based on historical data and observations as reported in Goodyear et al. (1982). This report summarizes data and observations described in the peer review and gray literature from decades of fisheries research. Multiple observations for different species may be recorded at the same location as species habitat utilization will vary as function of season. Moreover, the reported data and observations have been collected over an extended time period (i.e., multiple years). The comprehensive datasets incorporated into the Goodyear et al. (1982) report were collected over a sufficient period of time and during different seasons to be representative of the temporal distribution of fish spawning habitats in Lake St. Clair and the St. Clair Delta.

Spatial Validity: The Great Lakes Fishery Commission (GLFC), working with the MDNRE Institute for Fisheries Research and the University of Michigan, has incorporated coordinates and location descriptions from the Goodyear et al. (1982) report into the Lake Erie Geographic Information System (LEGIS). The LEGIS contains location shapefiles derived from coordinates provided in the Goodyear et al. (1982) report. These locations may not represent individual sampling sites, but are representative of the general area where samples were collected or observations made with respect to fish spawning and nursery habitat. Multiple observations for different species may be recorded at the same location as species habitat utilization will vary as function of season. The locations provided in the Goodyear et al (1982) are representative of spawning locations in shallow water areas of Lake St. Clair and the St. Clair Delta.

Hydrology Link: Fish are highly mobile and can move in response to changing water levels. However, many fish also respond to water level fluctuations indirectly via response to changes in habitat structure and aquatic vegetation. In Lake St. Clair, changing water levels may reduce access to or eliminate historical spawning sites. Figure 1 illustrates a broad shelf associated with the St. Clair Delta. Approximately 22,000 ha (54,000 ac) of lake bed will become exposed with a 1 meter drop in Lake St. Clair water levels below chart datum (see Figures 1 and 2). Fish spawning sites within that area will be eliminated. Associated with these changes is a loss of connectivity between the Lake and existing coastal marshes and wetlands. Coastal marshes and wetlands serve as spawning and nursery habitat for many important Great Lakes fish species (Stephenson 1990; Brazner and Beals 1997).

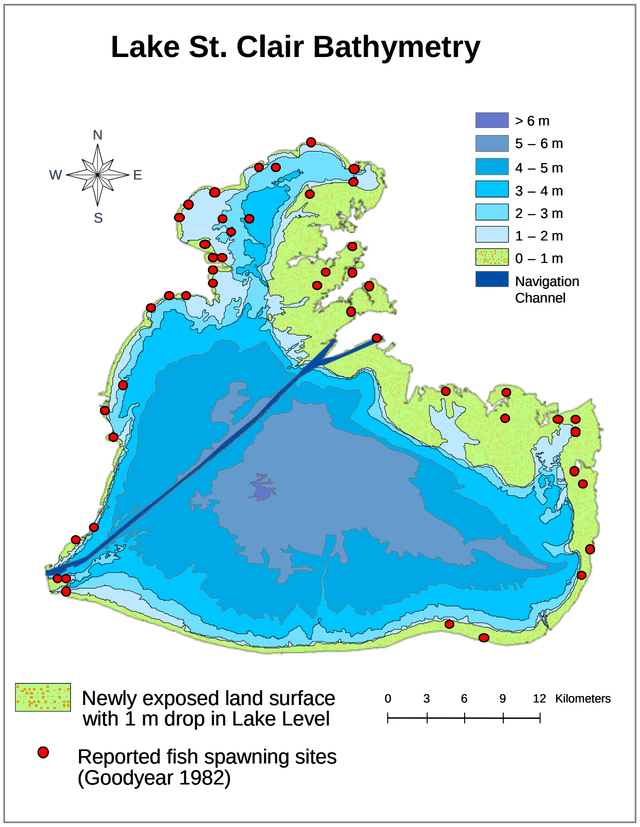

Figure 1. Map illustrating newly exposed land surface with a 1 meter drop below chart datum of Lake St. Clair water levels. Red dots represent locations of reported fish spawning sites from Goodyear (1982). 43 spawning sites used by 33 fish species will be directly impacted by a 1 meter lowering of Lake St. Clair water levels (Mackey et al. 2006).

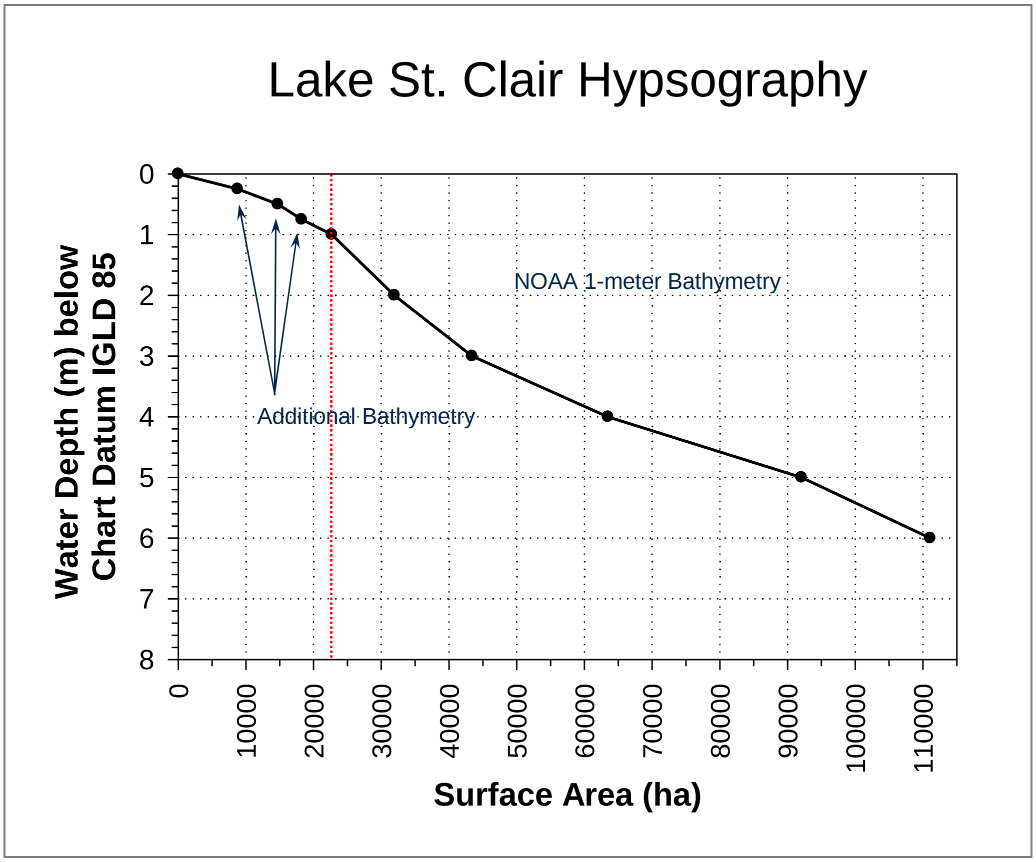

Figure 2. Lake St. Clair hypsography (relationship between water depth and surface area). Bathymetric data from National Geophysical Data Center (NGDC, 1998). Additional bathymetry for this PI derived from National Oceanic and Atmospheric Administration (NOAA) digital navigation chart 14850_1.

Algorithm:

Data for indicator development**:** Bathymetric data were obtained from the NGDC (1998) Marine Geology and Geophysics Report #MGG-13. This report collected available raw historical bathymetric data for Lake St. Clair, converted the data to a common datum, and contoured the data at a 1 meter contour interval (see Figure 1). The Lake St. Clair datum is 174.4 meters (572.3 feet) IGLD 1985. An overview of the report, methods used to generate the new NOAA 1-meter bathymetric maps, vector files, and raw data are available for download from the NGDC at: http://www.ngdc.noaa.gov/mgg/greatlakes/lakeerie_cdrom/html/e_gmorph.htm. For this PI, additional shallow-water bathymetric data was digitized from NOAA navigation chart 14850_1 to augment detailed bathymetry between 0 and 1 meter water depths. The bathymetric contours were converted to polygons and areas for each polygon were calculated. A hypsographic curve was then generated from the digital bathymetric data to illustrate the relationship between water depth and surface area.

The data used to identify spawning and nursery sites are based on historical data and observations as reported in Goodyear et al. (1982). This spawning atlas summarizes data and observations described in the peer review and gray literature resulting from decades of fisheries research. The GLFC has incorporated the Goodyear et al. (1982) report into the LEGIS. The LEGIS tool contains location shapefiles derived from coordinates and fish spawning data provided in the Goodyear et al. (1982) report. A query was performed on the Goodyear dataset to identify spawning locations that are spatially located within individual bathymetric polygons. Spawning locations that are within areas anticipated to be exposed during low water levels are eliminated as active fish spawning habitat. A similar query was performed to calculate the number of spawning sites (for each species) anticipated to be exposed during low water levels in order to assess individual species impacts.

Coping Zone Criteria:

Summary:

The following coping zone criteria were developed to identify circumstances where extended low-water or high-water conditions are expected to cause significant harm to the St. Clair fishery:

- **LSC-02:**
    - Zone B: Mean water level for March-October maintained at or below 174.3 meters for any 3 years in a 5-year window.
    - Zone C: Mean water level for Mar-Oct maintained at or below 174.3 meters for 5 consecutive years.
- **LSC-03:**
    - Zone B: Mean water level for March-October maintained above 176.5 meters for any 3 years in a 5-year window.
    - Zone C: Mean water level for Mar-Oct maintained at or below 176.5 meters for 5 consecutive years.

Detailed Discussion:

For this PI, additional shallow-water bathymetric data was digitized from NOAA navigation chart 14850_1 to augment detailed bathymetry between 0 and 1 meter water depths. The bathymetric contours were converted to polygons and areas for each polygon were calculated. A hypsographic curve was then generated from the digital bathymetric data to illustrate the relationship between water depth and surface area.

The Goodyear et al. (1982) spawning atlas summarizes data and observations described in the peer review and gray literature resulting from decades of fisheries research. The GLFC has incorporated the Goodyear et al. (1982) report into the LEGIS tool. The LEGIS contains location shapefiles derived from coordinates and fish spawning data provided in the Goodyear et al. (1982) report. A query was performed on the Goodyear dataset to identify spawning locations that are spatially located within individual bathymetric polygons (i.e., water depth intervals). Spawning locations that are within areas anticipated to be exposed during extended low water periods are eliminated as active fish spawning habitat (Figure 3). A similar query was performed to calculate the number of coastal wetland spawning sites anticipated to be lost during extended high water periods (Figure 3). Progressive changes in habitat loss are plotted relative to water elevation in meters (IGLD 1985) along with the historic lows and highs for the time period March through October. A similar query was performed to calculate individual species impacts. This is the percent loss of the total number of species (species occurrence loss) that would normally use those spawning sites within historical water level ranges for the time period March through October (Figure 4).

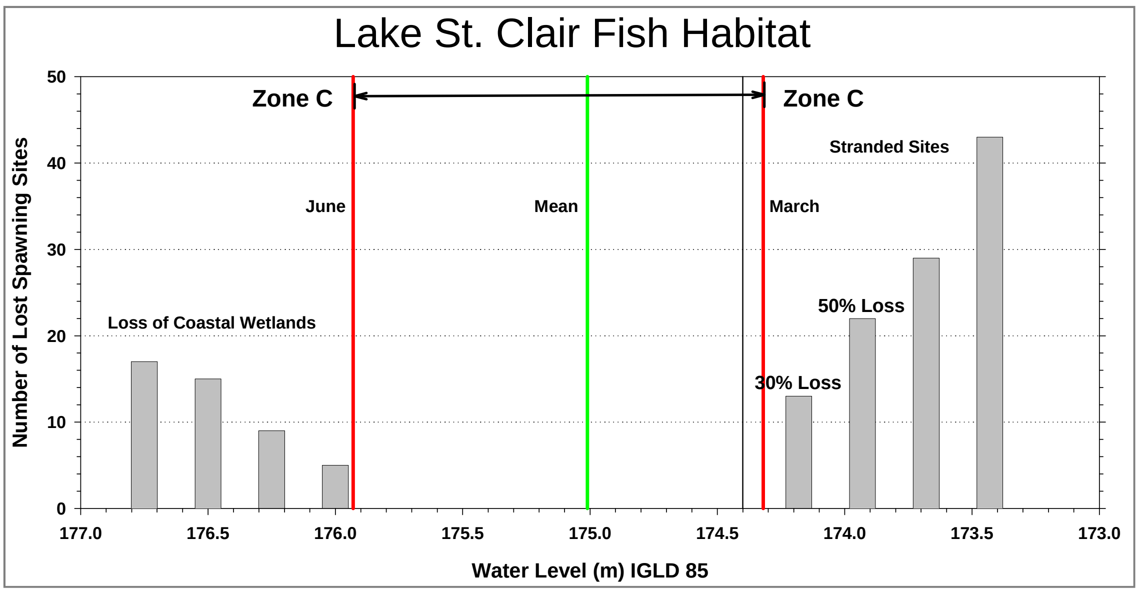

Figure 3. Number of lost spawning sites versus water level in meters IGLD 1985. Red lines represent the historic low in March and the historic high in June. Spawning activity occurs between March and October. Chart datum is 174.4 meters IGLD 1985.

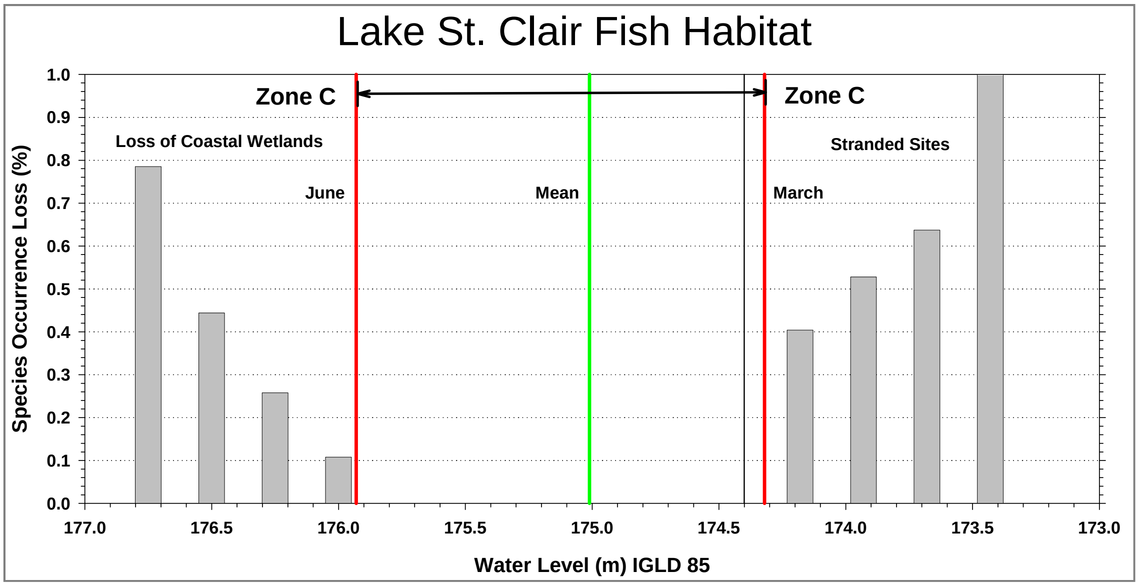

Figure 4. Percent species occurrence loss due to loss of spawning sites versus water level in meters IGLD 1985. Red lines represent the historic low in March and the historic high in June. Spawning activity occurs between March and October. Chart datum is 174.4 meters IGLD 1985.

Discussions with MDNRE fisheries staff indicate that a 40% loss of spawning habitat for a time period greater than three years would significantly impair the Lake St. Clair fish community. Integrating the effects of lost spawning sites and water level, illustrated in Figures 3 and 4, yields a water level response curve that links percent fish spawning habitat available to change in Lake St. Clair water levels in meters IGLD 1985 (see Figure 5). A threshold of 60% fish habitat availability is used to determine the threshold Lake St. Clair water elevations. When these elevations (both high and low) are reached or exceeded for period of at least three years, significant damage to the Lake St. Clair fish community will occur – equivalent to coping zone "C".

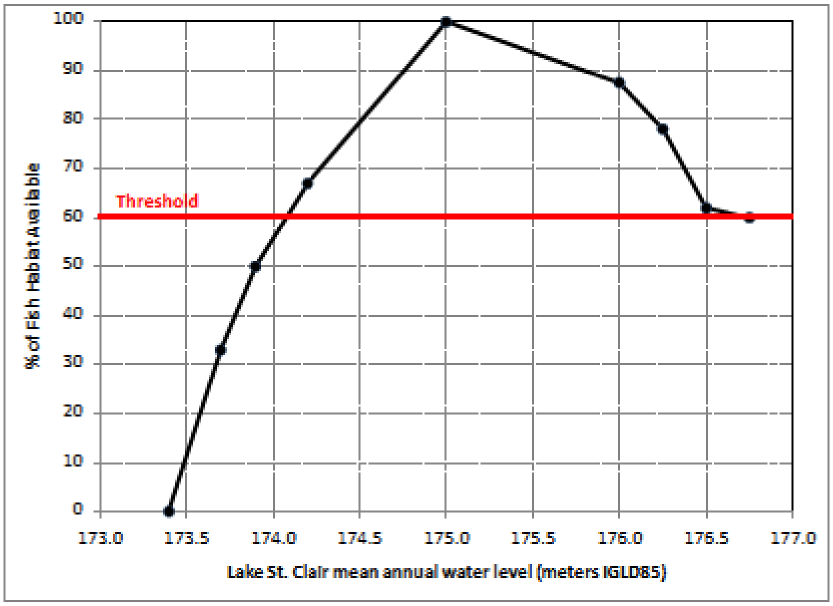

Figure 5. Water level response curve linking percent fish spawning habitat available to changes in Lake St. Clair water level in meters IGLD 1985. Threshold is defined when 40% of available fish habitat is lost for a period greater than three years. This will occur when mean water levels are less than 174.1 meters or greater than 176.5 meters IGLD 1985 for a period of at least three years.

Using the 107-year water supply sequence, the Integrated Ecological Response Model (IERM2) model calculates the aggregate threshold value (percent fish habitat available) using a three year moving average across the entire time period. For Lake St. Clair, Zone "C" is identified when less than 60% of available fish habitat is available.

Calibration Data: High resolution bathymetry and detailed information on fish habitat utilization in nearshore areas of Lake St. Clair are not available. Additional high resolution bathymetric and fish habitat utilization data would need to be collected to calibrate the indicator.

Validation Data: High resolution bathymetry and detailed information on fish habitat utilization in nearshore areas of Lake St. Clair are not available. Historical datasets and existing bathymetric information and data were used to develop this general indicator. Additional high resolution bathymetric and fish habitat utilization data would need to be collected to validate the indicator.

Risk and Uncertainty Assessment: The data used to derive these indicators were not collected for the purpose of investigating fish response to changes in water level regime. The risk of spawning habitat loss is high during extended periods of low water. However, there is uncertainty in the position of the actual shoreline due to a lack of high resolution bathymetry. Compaction, dewatering of exposed lakebed sediments, and wave erosion may alter the elevation and configuration of the Lake St. Clair coastline. Moreover, the actual loss of coastal wetlands due to extended periods of high water is uncertain due to a lack of information on nearshore coastal topography, shoreline hardening, and the ability of coastal wetlands to adapt to high water events within the St. Clair Delta.

Confidence, Significance and Sensitivity:

Confidence:

a*) Spatial Confidence:* The locations provided in the Goodyear et al (1982) are representative of spawning locations in shallow water areas of Lake St. Clair and the St. Clair Delta. Geospatial data were extracted from the GLFC LEGIS database maintained by the MDNRE Institute for Fisheries Research at the University of Michigan. The NGDC NOAA 1meter regional dataset is the highest resolution bathymetric dataset currently available for Lake St. Clair. Additional fine scale bathymetry was digitally obtained from NOAA navigation chart 14850_1 to augment water depth information between 0 and 1 meter in the area of the St. Clair delta. Additional bathymetric data collection would be desirable, but would not significantly alter the Lake St. Clair fish habitat indicator.

b) Temporal (seasonal) Confidence: The comprehensive datasets incorporated into the Goodyear et al. (1982) report were collected over a sufficient period of time and during different seasons to be representative of the temporal distribution of fish spawning habitats in Lake St. Clair and the St. Clair delta.

c) Temporal (duration) Confidence: The comprehensive datasets incorporated into the Goodyear et al. (1982) report were collected over a sufficient period of time and during different seasons to be representative of the temporal distribution of fish spawning habitats in Lake St. Clair and the St. Clair delta.

Significance: Highly productive shallow coastal embayments and coastal wetlands in Lake St. Clair provide spawning and nursery habitat for numerous fish species that not only populate Lake St. Clair and the connecting channels, but Lake Erie and Lakes Michigan-Huron as well. Recent fish tracking data show widespread dispersal of walleye and other species of interest throughout Lake St. Clair and the connecting channels and both Lakes Michigan–Huron and Lake Erie as well (Robert Haas, MDNRE, personal communication). Figure 5 illustrates the importance of Lake St. Clair and the Detroit River to the State of Michigan fishery. Total economic value of the fishery was estimated to be $50 million U.S. dollars per year in 2002 (Gary Towns, MDNRE, personal communication).

Lake St. Clair and Detroit River Fishing Effort

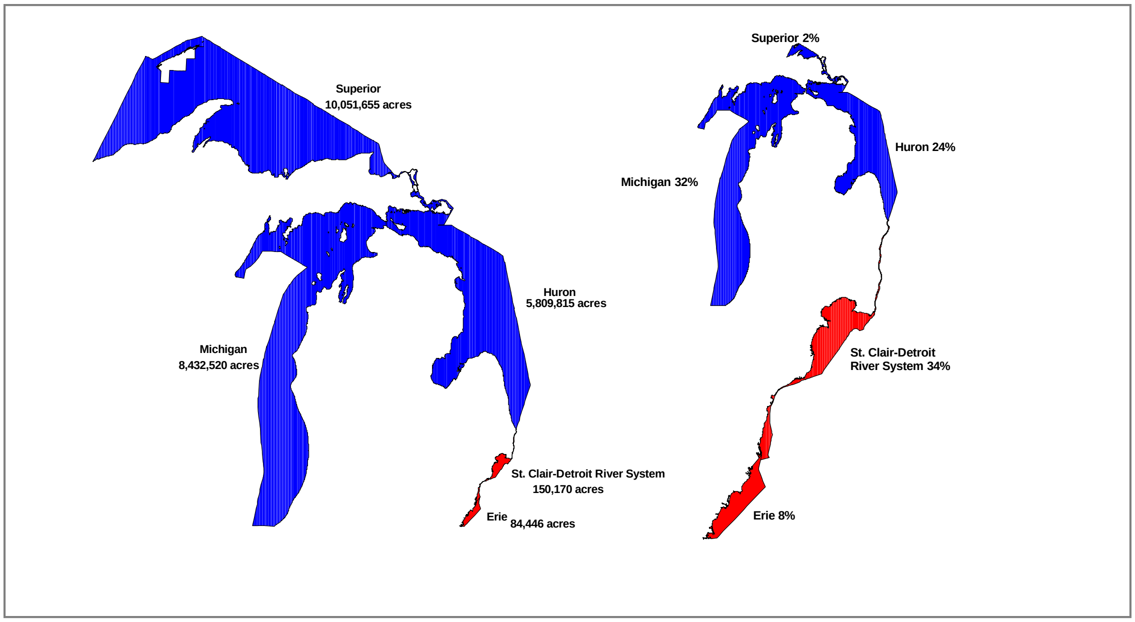

Figure 5. Lake St. Clair and the Detroit River represent 1% of Michigan's Great Lakes fishing waters but 46% of the fishing effort. Estimated economic value of the combined Lake St. Clair-Detroit River fishery was $50 million U.S. dollars per year in 2002 (Gary Towns, MDNRE, personal communication).

Sensitivity: Fish species are linked to individual spawning sites as part of this indicator. It is possible to assess which species will be most significantly affected by changing water level regimes and potential loss of fish spawning habitat. Table 1 provides a summary list of species potentially impacted by changes in Lake St. Clair water level regimes. Entries are ordered by the number of sites used as spawning habitat by each species. Individual sites may be utilized by multiple species during different times of the year. Species highlighted in gray may be more sensitive to changes in water level regime and temperature than other species.

Table 1. Summary list of species that use spawning and/or nursery sites potentially affected by long-term reductions in Lake St. Clair water levels (Mackey et al. 2006). Fish spawning locations from Goodyear et al. 1982.

Species	*Sites*	*Environment*	*Temperature*	*Country*
Smallmouth bass	24	Intermediate	warm	US, Canada
Muskellunge	17	Intermediate	warm	US, Canada
Yellow perch	15	Intermediate	cool	US, Canada
Northern pike	14	Intermediate	cool	US, Canada
Largemouth bass	13	Coastal wetland	warm	US, Canada
Bluegill	11	Coastal wetland	warm	US, Canada
Carp	7	Intermediate	warm	US, Canada
Channel catfish	7	Intermediate	warm	US, Canada
Emerald shiner	7	Intermediate	cool	US, Canada

Species	***Sites***	***Environment***	***Temperature***	***Country***
Rock bass	7	Coastal wetland	cool	US, Canada
Walleye	7	Intermediate	cool	US, Canada
Lake sturgeon	6	Open water	cool/cold	US, Canada
Pumpkinseed	6	Coastal wetland	warm	US, Canada
Spottail shiner	6	Intermediate	cold/cool	US, Canada
Common shiner	5	Coastal wetland	cool	US, Canada
Spotfin shiner	5	Coastal wetland	warm	US, Canada
Black crappie	4	Intermediate	cool	US, Canada
Golden shiner	4	Coastal wetland	cool	US, Canada
Longnose gar	4	Coastal wetland	warm	US, Canada
Alewife	3	Intermediate	cold	US, Canada
Goldfish	3	Coastal wetland	warm	US, Canada
White crappie	3	Coastal wetland	cool	US, Canada
Brown bullhead	2	Coastal wetland	warm	US, Canada
Lake whitefish	2	Open water	cold	US, Canada
Rainbow smelt	2	Intermediate	cold	US, Canada
Sea lamprey	2	Open water	cold	US, Canada
White bass	2	Coastal wetland	warm	US, Canada
Bowfin	1	Coastal wetland	warm	Canada
Gizzard shad	1	Coastal wetland	cool	Canada
Logperch	1	Coastal wetland	cool/warm	Canada
Trout-perch	1	Intermediate	cold	Canada
White sucker	1	Intermediate	cool	Canada

Documentation and References:

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Fact Sheet ID: 17

Performance Indicator (PI) Name/Short Description: Wetland Vegetation Communities – emergent vegetation and open water surface area (Long Point, Turkey Point and Inner Bay, Lake Erie)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Linda Mortsch, Susan Doka, Peter Deadman and Raymond Cabrera

Modeled by: University of Waterloo (Cabrera) and LimnoTech (Redder, DePinto)

PI Metric: The PI metrics are based on annual estimates of 1) emergent wetland vegetation surface area, and 2) open water surface area. These metrics are calculated for each individual year based on current/hypothetical and historical water depths at Long Point, Turkey Point and Inner Bay, which are located on the north shore of Lake Erie in Ontario, Canada.

Ecological Importance/Niche: Water level fluctuations keep coastal wetlands in a constant state of adaptation. The presence of specific wetland communities are a result of current and recent environmental conditions. The tolerance thresholds of particular communities vary; communities may disappear if tolerance thresholds have been surpassed. In addition, shifts along the water level and soil moisture continuum may occur landward or lakeward (in the direction of the water level change), and is dependent upon available seed banks, suitable substrate, the slope of the wetland and other natural or artificial (anthropogenic) barriers.

Low water years result in the displacement or die back of submergents (plants completely beneath the surface of water) and emergents (plants partially in water and air), and their replacement by species tolerant of dry conditions. These include trees, shrubs, grasses and sedges (Mortsch 1998). High water years result in the opposite process.

The study area for wetland vegetation focuses on Inner Long Point Bay and explores the impact of water level change on the Long Point and Turkey Point wetlands (see Figure 1). This study examines six key wetland vegetation communities (transitioning from wettest to driest conditions) including open water, exposed substrate, mixed emergent and floating vegetation, emergent vegetation, meadow marsh, and areas of trees and/or shrub. The coping zones were defined by using a rule-based wetland vegetation model to assess wetland community changes (e.g., open water to emergent vegetation resulting from a decline in water levels) and associate them with critical water level thresholds. The focus of this analysis is on the open water and emergent vegetation classes. Water level conditions are defined by the IUGLS water level scenarios and used in the IERM2 model. Performance indicators are defined in terms of total area of open water and total area of emergent vegetation. Coping zone thresholds are identified based on the percentage decrease or increase in area of emergent vegetation or open water. Access between Inner Bay and Lake Erie is analyzed based on visual interpretation of flooding or increased dense vegetation cover.

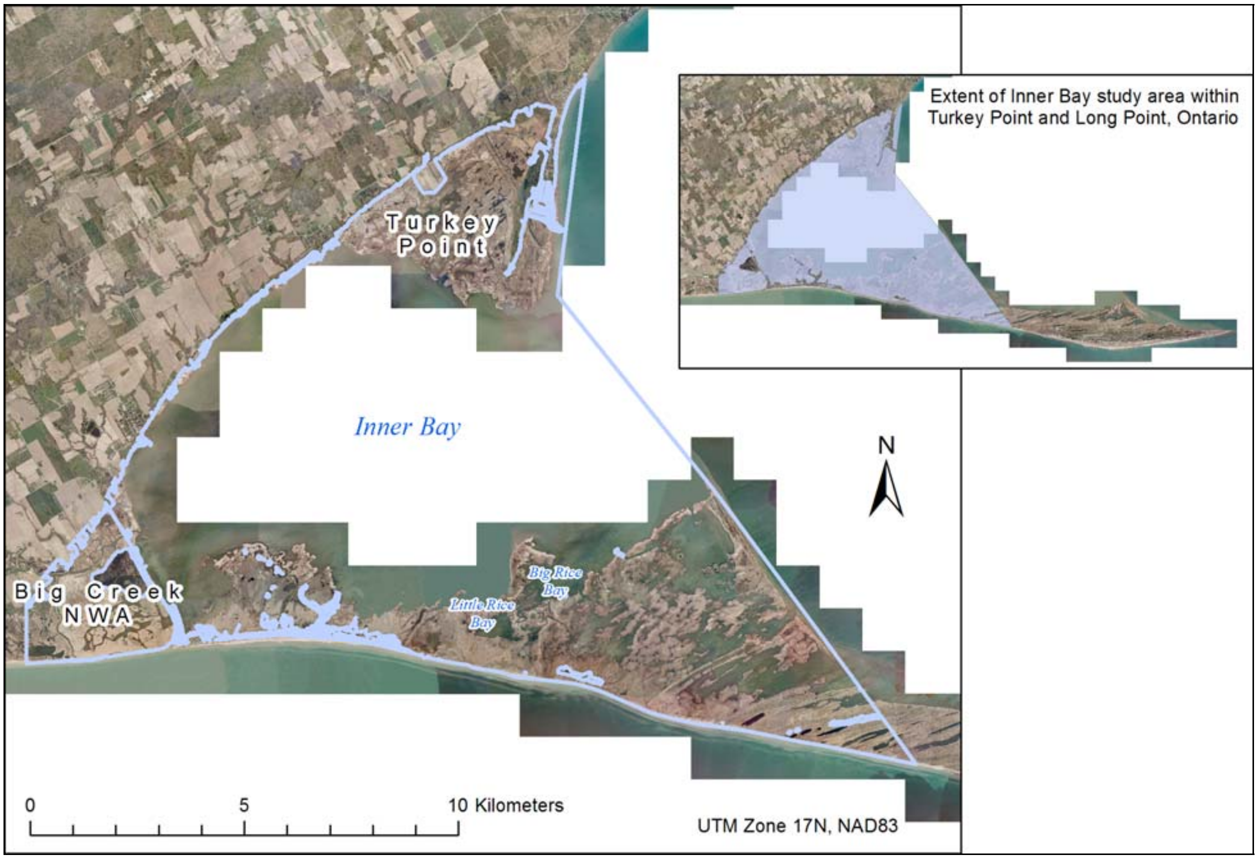

Figure 1. Study area including Turkey Point and Long Point, with modelling domain of Inner Bay delineated in light blue.

Temporal Validity: Expected vegetation communities are derived for each 10-meter model cell in each simulation year. Model outputs are summarized in terms of a seasonal or annual average, and do not account for inter-seasonal variation. Shorter-term variations, such as storm surges and seiches, are not expected to result in long-term ecological change (Mortsch 1998; Whillans 1985). Monthly water levels during the growing season (March-October) are averaged to derive an annual growing season mean water level. Simulation years have been chosen to allow for validation against interpreted air photos (1945, 1955, 1964, 1968, 1972, 1978, 1985, 1995, and 1999). These air photos, with the exception of 1999, have been interpreted by Snell and Cecile Environmental Research (2001). The 1999 air photo interpretation data was provided by Bird Studies Canada as part of a data exchange.

Spatial Validity: Total surface areas and percent cover for each wetland community are derived from wetland plant community and elevation models. Digital elevation models (DEMs) have been produced from a variety of sources. DEMs were developed from Triangular Irregular Networks (TINs, vector-based representations of the physical land surface or sea bottom) and were interpolated to a cell size of 10 meters (Mortsch et. al 2006). Air photos have been interpreted by Snell and Cecile Environmental Research (2001). Using elevation and water levels (assumed to be uniform lake-wide), a wetland community is predicted at each cell, based on the algorithm detailed below. Air photos are used for validation only.

Hydrology Link: Wetland vegetation in this area influenced by the current water depth and the duration of hydrological condition (flooded vs. dewatered) (Mortsch 1998). Seasonal fluctuations do not exert as strong an influence, since vegetation responses to seasonal variation are shown only by annual plants. Wetland vegetation has been shown to shift lakeward or landward due to changes in water level and soil moisture.

Algorithm:

Wetland vegetation data

A range of wetland vegetation communities were delineated by air photo interpretation for 9 years in the period of 1945 to 1999 and digitized into digital data sets for use in a Geographic Information System (GIS) [1,2]. This suite of communities was combined into six key wetland classes. Each year of air photo analysis is associated with an average annual water-level condition (e.g., high, low, average, rising, falling). A spatio-temporal analysis was conducted in GIS to determine landscape attributes such as total wetland area and vegetation community distribution and area. These metrics were then related to current and antecedent water level conditions to develop an understanding of the response of the wetland communities to changes in water levels.

Digital Elevation Model (Long Point topography and bathymetry)

A 10m-cell digital elevation model (DEM) was developed for the Inner Bay for modelling and spatio-temporal analysis. A number of digital data sources were used to construct the DEM consisting of:

- Natural Resources Values and Information System (NRVIS): topography, interpolated from contour lines to 10m cells;
- Great Lakes Information Network (GLIN): bathymetry, 2m contour lines;
- Canadian Hydrographic Service (CHS): bathymetry, point samples;
- Southwestern Ontario Orthoimagery Project (SWOOP 2006) orthographic air photos and Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) soil maps: delineating shoreline and water edge;
- CanVec (version 1.1), provided through GeoGratis (Natural Resources Canada) and a successor to the National Topographic Data Base (NTDB): identify and delineate dykes.

The DEM was masked to exclude upland and dyked areas. Upland areas that were masked were those cells which would be unaffected by all water level scenarios; specifically, these were cells with elevations 2m or more above the highest water level encountered in the IUGLS scenarios. Dykes were identified digitally using the CanVec product. In order to assess the vulnerability of the dykes to overtopping, a 10m buffer was drawn around each dyke to estimate their maximum elevation and thus, establish the high water level threshold. In addition, developed, urban and cultivated areas were also masked out using 2006 Ecological Land Classification (ELC) interpreted data from Snell & Cecile (Paul Watton, Environment Canada, pers com). As provided, ELC data were interpreted from SWOOP 2006 orthoimagery by Snell & Cecile. ELC data were then classified into the six vegetation communities based on a translation table developed for a 2006 study (Mortsch et al. 2006).

Wetland Vegetation Community Modelling

The model is designed to classify wetland vegetation communities based on depth below water or height above water, as well as the duration of hydrologic condition (flooding or exposed). (It requires an input of 40 sequential years of annual average water levels prior to the year under investigation. For model validation, historical monthly mean water levels are averaged to produce annual average water levels for the entirety of Lake Erie. Average, whole lake water levels for Lake Erie are assumed to apply to Inner Bay. Modelled outputs provided for this study use the IUGLS water level scenarios provided by LimnoTech.) Water depths are calculated within each cell to determine the cell's water depth or height above water, as well as the duration of its current hydrological condition (i.e., flooded vs. exposed). The duration of hydrological condition is determined by calculating the water depth for each cell for the forty years prior to the years under study. A set of rules, developed for a 2006 study (Mortsch et al. 2006) and revised for the IUGL study, determine assignment between a depth/height and duration pair and its associated vegetation community.

Performance Indicators

Two performance indicators (PIs) were chosen, open water and emergent vegetation. Based on model validation against interpreted air photos, open water was found to be the most amenable to classification based on the rules developed for the 2006 study (Mortsch et al. 2006). Furthermore, open water can be used as a measure of total area that is not covered by vegetation. Among the wetland vegetation community classes, emergent vegetation is the dominant vegetation community. In addition, the rule-based model performed the best in correctly classifying the location and abundance of emergent vegetation.

PI#1: Open Water

The open water classification is not a vegetation community per se but delineates areas within a wetland complex that has no vegetation. The absence of vegetation in standing water is due to factors that limit vegetation colonization and growth including: water depth, fetch and hence wave energy, erosion, and substrate characteristics.

Open water is an important metric as it documents accessibility – from Inner Bay, Long Point Bay to Lake Erie and vice versa (i.e., circulation of water, fish movement and recreational boating access). The Inner Bay is relatively shallow with a maximum water depth of 4.5m at its deepest point (see Figure 1). At present, Turkey Point and Long Point are not connected but there is an underwater sand spit that runs between Turkey Point and Long Point that could become an exposed land bridge in extreme low water level scenarios. This low water level scenario was modelled and the sand spit emerged when water levels were approximately 1.5 m below the minimum water level observed since 1942.

Fetch length plays an important role in limiting vegetation growth in areas of high wave exposure and dynamic coastal erosion. In an extreme high water level scenario (a 50cm water level increase from a historical modelled scenario [IERM2 scenario PrePlan + 0.50m]), flooding and an increase in open water area in Long Point Inner Bay, results in a breach across the south shore of Inner Bay toward Lake Erie, and results in longer fetches across Lake Erie and into Long Point Bay. The south shore of Inner Bay was breached in all years of this scenario, with a water level threshold equal to or greater than 174.33m. A small (20-40m) breach occurred across Hastings Drive with IERM2 scenario PP+0.25m at a water level of 173.97m. This could increase storm, wave and erosion exposure in vegetation communities that are currently in a protected, low energy environment in Inner Long Point Bay. It can also change the substrate environment in which the wetland vegetation can/cannot grow.

PI#2: Emergent Vegetation

The emergent vegetation community, which includes species such as typha and bulrush, is commonly found around Long Point, Turkey Point and the Inner Bay area. Many of these emergents provide valuable habitat for fish and birds (e.g., nesting, nursery, feeding).

In the spatio-temporal analysis of the historical air photo data in GIS, the emergent vegetation community displayed/demonstrated a clear response to water level changes [3,4]. Area of emergent vegetation increased with higher water levels and decreased with lower water levels. Of the five vegetation communities modelled for the Long Point study, emergent vegetation demonstrated the most robust relationship with water level time series. Specifically, this relationship was demonstrated when rules based on depth and duration criteria were applied. The classification accuracy of emergent vegetation is the highest and most reliable of all the vegetation communities, such as emergent/floating mixed and treed/shrub.

Coping Zone Criteria:

Analyzing interpreted air photos against historical water levels, extreme (short-term) high and low water level events were removed from historical scenarios to produce long-term Zone A water level ranges. The water level ranges for Zone A were selected from historical modelled years that exhibited “typical” vegetation cover. The “extremes”, which were excluded from Zone A, were defined as years which displayed atypical, yet temporary changes in wetland cover. While these wetland community changes were temporary due to the short-term nature of the extremes, long-term shifts in water level averages to these levels are likely to cause significant (greater than 15% deviation from normal) changes in total wetland area and emergent vegetation area. Zone B thresholds were interpreted from model outputs, where clear thresholds could be observed, such as:

- Significant losses (greater than 15% loss from typical area) of emergent wetland area;
- A loss in connectivity between Inner Bay and Lake Erie, preventing fish migration and isolating boating facilities; and
- An increase in fetch due to flooding across Long Point.

Zone C includes all scenarios outside Zones A and B. The wetland community model tends to overestimate the area of emergent and upland vegetation and underestimate the area of mixed (sparse) emergent/floating vegetation, meadow marsh and treed/shrub. Therefore, modelled decreases in emergent wetlands associated with higher water level or tighter range compression scenarios are likely conservative. Dyked areas are masked from the modelling environment since the enclosed wetland does not respond to natural lake level fluctuation. Yet, these dykes are vulnerable to overtopping under high water level conditions, and operation and maintenance issues with low water level conditions. The analysis indicates that dyked areas would be flooded with water levels above approximately 175.1m (IGLD85). At present, the wetland community model does not incorporate increases in fetch and its impact on submergent and emergent wetland vegetation occurrence. The assessment is limited to visually interpreting whether there is more flooding and potential breaching of the Long Point spit or due to low water levels the emergence of a spit east of Inner Bay. Invasive species such as Phragmites have not been incorporated into the model; Phragmites and its response to water level changes may pose a threat even within Zone A water level thresholds.

The specific coping zone rules developed for the emergent vegetation and open water PIs for Long Point are as follows:

- **ERI-01a Criterion:**
  - Zone B: Mean water level for March-October maintained below 173.91 meters for any 3 years in a 5-year window.
  - Zone C: Mean water level for March-October maintained below 173.66 meters for 5 consecutive years.
- **ERI-01b Criterion:**
  - Zone B: Mean water level for March-October maintained above 174.59 meters for any 3 years in a 5-year window.
  - Zone C: Mean water level for March-October maintained above 175.2 meters for 5 consecutive years.
- **ERI-02 Criterion:**
  - Zone B: Variance in March-October mean water levels for 30-year rolling period is less than or equal to 0.045 m^2.
  - Zone C: Variance in March-October mean water levels for 30-year rolling period is less than or equal to 0.0095 m^2.

Calibration Data: Transition rules have been synthesized from available literature (Mortsch et al. 2006, Section 3.1; Wilcox et al. 2005). See above discussion in the "Algorithm" section regarding vegetation and physical datasets used to support the modeling analysis.

Validation Data: Wetland historical data from interpreted historical air photos are used to validate model predictions. For each simulation year (1945, 1955, 1964, 1968, 1978, 1986, 1995, 1999), air photos have been interpreted by Snell & Cecile Environmental Research (2001), with the exception of 1999, which was provided by Bird Studies Canada.

Risk and Uncertainty Assessment: See discussion in preceding sections.

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

Documentation and References:

Fay, D. and Dahl. 2008. *Fencepost Plans*. Report for the Upper Great Lakes Water Levels Study. March 2008.

Hebb, A.J. 2003. *Implementation of a GIS to assess the effects of water level fluctuations on the wetland complex at Long Point, Ontario.* Master's thesis. University of Waterloo. Waterloo, Ontario.

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Wilcox, K. L., Petrie, S. A., Maynard, L. A., Meyer, S.W., 2003. *Historical distribution and abundance of Phragmites australis at Long Point, Lake Erie, Ontario.* J. Great Lakes Res. 29, 664–680.

Wilcox, D.A., J.W. Ingram, K.P. Kowalski, J.E. Meeker, M.L. Carlson, Y. Xie, G.P. Grabas, K.L. Holmes, and N.J. Patterson. 2005. *Evaluation of Water-Level-Regulation Influences on Lake Ontario and Upper St. Lawrence River Coastal Wetland Plant Communities*. Final report. International Joint Commission, Washington, DC and Ottawa, Ontario. 67 p.

Fact Sheet ID: 18

Performance Indicator (PI) Name/Short Description: Submerged Aquatic Vegetation (SAV) Community – surface area (Inner Bay of Long Point, Lake Erie)

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Doka, Gertzen, (Mortsch, Deadman, and Cabrera)

Modeled by: Fisheries and Oceans Canada (Gertzen, Doka), LimnoTech (Redder, DePinto)

PI Metric: The PI metric is surface area of SAV community changes as a result of current/hypothetical and historical water depths at Inner Bay of Long Point, which is located on the north shore of Lake Erie in Ontario, Canada.

Ecological Importance/Niche: SAV provides important habitat to fishes, and habitat and food for other aquatic-associated biota (e.g., benthos, or organisms that live on, in, or near the bottom of the waterbody, birds, and mammals).

Temporal Validity: The surface area of SAV is derived for each 10-meter cell within a spatially explicit model for each simulation year, from 1900 to 2008. The data are collapsed/lumped for use in the Integrated Ecological Response Model (IERM2). The model/look-up tables are valid for the time period referenced above but may be extended where important factors, such as soil/substrate deposition, do not change significantly. For example, a change in soils/substrate deposition is an important factor that does not change significantly. The model uses seasonal (March-October) average water level for each year in the scenarios provided. The intra-annual cycle of vegetation growth and senescence (biological aging) are not modeled here.

Spatial Validity: The SAV model is valid for Long Point Bay and may be extended to other areas with similar attributes, especially areas with similar geology (i.e., Lake St. Clair, Lake Erie, Lake Ontario, and possibly Lake Huron but not shield areas without validation).

Hydrology Link: Surface area of SAV is influenced by the average water depth in a growing season among other variables. The distribution and percent cover of SAV are affected by the presence of existing emergent (partially in water and air) wetland vegetation, water clarity, fetch (area in which waves and currents are formed by wind exposure) and substrate (e.g., soft sediments or local geology like bedrock) composition. Seasonal fluctuations in these variables do not exert as strong an influence on annual SAV extent; intra-annual water elevation changes will only determine the area of SAV that is wetted or exposed. Annual maximum SAV coverage is considered an adequate representation of habitat availability without making the models too complex.

Algorithm: SAV cover is dependent on water depth, fetch (as a measure of exposure) and substrate composition. A digital elevation model (DEM) of Long Point Bay was prepared, with a raster cell size of 10 m x 10 m (Cabrera, Deadman, and Mortsch). For each year evaluated, average growing season water depth is computed for each cell in Long Point Bay using the DEM or derived look-up table, and the average March to October water level elevations that were derived from monthly water level data. The effective fetch at each cell, or group of cells within an elevation range, was calculated using the United States Geological Survey (USGS) fetch model (Rohweder et al. 2008), weighted across 18 compass directions based on the amount of time wind blew from each direction. Weights were determined using fifteen years of wind direction data from the Long Point automated weather station (1994-2009; 42°34'00 N, 80°03'00 W; Environment Canada). The "shoreline" or boundary condition for fetch calculations was modified at 10cm increments between a specified elevation range: currently, from highest historical water level plus 1 m to lowest historical water level minus 2 m. Using the appropriate fetch value for a given annual growing season water level, a binary condition is specified for a cell or group of similar cells; SAV does not establish when fetch is greater than 7 km (this threshold value has been specifically calibrated for Long Point).

SAV grows less densely in areas with a high proportion of sand. Substrate information was derived from several sources:

1) Geomatics International Inc. 1997. Discrimination of substrate, submerged vegetation density and species assemblages and wetland species assemblages using airborne remotely sensed imagery. Long Point, Lake Erie, Ontario. Final Report. Burlington, Canada.
2) Minns, CK, SE Doka, CN Bakelaar, PCE Brunette, and WM Schertzer. 1999. Identifying habitats essential for pike Esox lucius L. in the Long Point Region of Lake Erie: a suitable supply approach. American Fisheries Society Symposium 22:363-382.
3) Present, EW, and CJ Acton. 1984. Soils of the Regional Municipality of Haldimand-Norfolk. Volumes I and II. Report No. 57. Agriculture and Agri-Foods Canada. (http://sis.agr.gc.ca/cansis/publications/on/on57/intro.html) and associated GIS layers (http://sis.agr.gc.ca/cansis/nsdb/detailed/on/zipfiles.html)
4) Rukavina, NA. 1976. Nearshore sediments of Lakes Ontario and Erie. Geoscience Canada 3:185-190.
5) Thomas, RL, J-M Jaquet, ALW Kemp, and CFM Lewis. 1976. Surficial sediments of Lake Erie. Journal of the Fisheries Research Board of Canada 33:385-403.

Substrate data were used to derive a percentage sand assignment for each cell (Long Point calibration; to be validated for other sites/substrate types).

In areas where fetch and substrate conditions are suitable for SAV establishment, a percent cover – depth function is used to predict cover by cell or cell group. This function is specifically calibrated to the water transparency of the area, in this case Long Point. Surface area of SAV is derived from the number of cells, percent cover of each cell, and the area of each cell.

Coping Zone Criteria:

The coping zone criteria within the Coping Zone Calculator apply to wet vegetated area, and not exclusively submerged aquatic vegetation. Within the calculator, in the absence of knowledge of the area of wet emergent vegetation, we are unable to differentiate between wet emergent and submergent vegetation. We assumed that wet vegetation, regardless of the type of vegetation, will be useful to fishes that prefer vegetated areas.

Criteria for Low Water Level Conditions:

The lower coping zone water level thresholds were assigned based on the bathymetry of the Inner Bay; "Zone B" is where area decreases below 75% of the maximum wetted area and "Zone C" is where area decreases below 50% of the maximum wetted area. Additionally, a 'maximum difference between two consecutive months' criterion was added to these coping zone definitions to reflect the fact that major changes in water levels over a short period of time will be detrimental to vegetation communities. This difference was set as changes no greater than those that would be predicted to occur naturally given the current flow rates.

- **ERI-03a Criteria:**
    - Zone B: Mean growing season (March-October) water level is between 172.8 and 173.55 meters for 3 out of 5 years, or less than 172.8 meters in any given year; or the maximum difference in water levels for consecutive months is greater than 0.33 meter in any given year.
    - Zone C: Mean growing season (March-October) water level is less than 172.8 meters for 5 consecutive years.

Criteria for High Water Level Conditions:

Based on bathymetry data, little additional wetted area is gained in the Inner Bay above an elevation of 174 m ASL. Above 174 m, however, parts of the Long Point spit become flooded and portions of the Inner Bay become exposed to currents from the larger eastern basin of Lake Erie. Vegetation is likely not sustained in areas that are highly exposed. Thus, to define upper coping zones, we used exposure (fetch). Two inflection points exist where there are major increases in the portion of the spit flooded; these were used to assign "Zone B" and "Zone C". However, it is important to note that because both bathymetry and the presence and depth of emergent vegetation will determine at what point water level flooding of the spit becomes detrimental to SAV growth, we modified these inflection points to take into account the buffering effect of emergent vegetation under 'natural' and variance compression conditions, using the same cut-offs as ERI-02 (emergent vegetation coping zones for variance regime), rounded to the nearest cm. Under historical water level regime, average emergent vegetation depth is 0.53 m; under major variance compression scenarios (80%), average emergent vegetation depth decreases to 0.1 m.

- **ERI-03b Criteria:**
    - Zone B:
        - *If the 30-year (rolling) variance in growing season (March-October) water levels is < 0.01 m*: mean growing season (March-October) water level is 174.2-174.6 meters for 3 out of 5 years or greater than 174.6 meters for a given year.
        - *If the 30-year rolling variance in growing season (March-October) water levels >= 0.01 m:* mean growing season (March-October) water level is

174.63-175.03 meters for 3 out of 5 years or greater than 175.03 meters for a given year.

- Zone C:
  - *If the 30-year (rolling) variance in growing season (March-October) water levels is < 0.01 m*: mean growing season (March-October) water level is greater than 174.6 meters for 5 consecutive years.
  - *If the 30-year rolling variance in March-October water levels >= 0.01 m:* mean growing season (March-October) water level is greater than 175.03 meters for 5 consecutive years.

It is important to note that the rules for ERI-03a and ERI-03b should always be considered together when assessing the condition of the wet vegetated area (i.e., a "Zone C" for either the low or high water case for a given year constitutes an overall "Zone C" condition).

Calibration Data: Binary rules and functions have been synthesized from available literature and field data specific to Long Point (Minns et al. 1999; Leisti (Seifried) 2002; Doka 2004; Doka et al. 2005; Doka et al. 2006; Doolittle et al. in review).

Validation Data: The SAV model has been validated using the above references. It will be further validated using recently collected field data for Long Point Inner Bay in 2010.

Risk and Uncertainty Assessment: See the following section.

Confidence, Significance and Sensitivity:

Confidence: In general confidence is high. Models have been calibrated with real data, and predictions of SAV cover are good.

Significance: Significance is moderate to high. SAV cover in this area will be able to migrate downslope. Changes in SAV surface area will be dependent on local slope and substrate composition and will be determined once full scenario testing has taken place.

Sensitivity: Regulation of Lake Superior does not significantly affect Lake Erie water levels (Fay and Dahl 2008). However, the impact of long term variability remains of interest with respect to adaptive management under a changing climate. SAV cover in this area will be able to migrate downslope; therefore, the overall sensitivity, even under low water conditions, may be low. This is dependent on local slope and substrate composition and will be determined once full scenario testing has taken place.

Documentation and References:

Doka, S. 2004. Spatially-explicit habitat characterization, suitability analysis, verification, and modeling of the yellow perch *Perca flavescens* (Mitchell 1814) population in Long Point Bay, Lake Erie. PhD thesis, McMaster University. 344 p.

Doka, S., C.K. Minns, C. Bakelaar, C. Chu, K. Leisti, and J.E. Moore. 2005. Year 4 Final Report for Burlington Fish Habitat & Modeling Group. Lake Ontario-St. Lawrence River Study.

Doka, S., C. Bakelaar and L. Bouvier. 2006. Coastal wetland fish community assessment of climate change in the Lower Great Lakes. *In:* Mortsch, L., J. Ingram, A. Hebb and S. Doka (eds.) 2006. Great Lakes Coastal Wetland Communities: Vulnerabilities to Climate Change and Response to Adaptation Strategies. Final report submitted to the Climate change Impacts and Adaptation Program, Natural Resources Canada. Environment Canada and the Department of Fisheries and Oceans, Toronto, Ontario. 251 p. + Appendices.

Doolittle, A.G., C.N. Bakelaar and S.E. Doka. 2010 (In review). Spatial framework for storage and analyses of fish habitat data in Great Lakes' Areas of Concern: Hamilton Harbour geodatabase case study. *Canadian Technical Report of Fisheries and Aquatic Sciences*, 2879: xi + 68 p.

Minns, C.K, S.E. Doka, C.N Bakelaar, P.C.E. Brunette and W.M. Schertzer. 1999. Identifying habitats essential for pike *Esox lucius L.* in the Long Point Region of Lake Erie: a suitable supply approach. *In:* L. Benaka (ed.), Fish Habitat: Essential Fish Habitat and Rehabilitation. American Fisheries Society, Symposium 22, Bethesda, Maryland. p. 363-382.

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Seifried, K.E. 2002. Submerged macrophytes in the Bay of Quinte: 1972 to 2000. Unpublished M.Sc. Thesis, Department of Zoology, University of Toronto, 132 p.

Fact Sheet ID: 19

Performance Indicator (PI) Name/Short Description: Spawning habitat supply (area) for 4 fish guilds in Inner Long Point Bay, Lake Erie:

1. High vegetation - 10°C guild (HV10);
2. High vegetation - 14°C guild (HV14);
3. High vegetation - 18°C guild (HV18); and
4. High vegetation - 24°C guild (HV24).

Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: Doka, Gertzen, Minns, (Mortsch, Deadman, Cabrera)

Modeled by: Doka, Gertzen, Moore, LimnoTech (Redder, DePinto)

PI Metric: This suite of PIs represents the annual habitat supply (weighted suitable area (WSA), hectares) for the HV10, HV14, HV18, and HV24 spawning guilds (groups of species found in the same place that share the same resources) in Long Point Bay, Lake Erie. Emergent vegetation, submergent vegetation, substrate composition, water level and land elevations (used to calculate water depths) were used to compute habitat suitability and supply for these guilds in the Long Point Bay study area based on habitat associations for each guild. Temperature was used to calculate the appropriate time window for spawning in the annual calculations.

Ecological Importance/Niche: The members of the HV10, HV14, HV18, and HV24 spawning guilds occupy shallow water (<20 m) during their life histories and prefer spawning in high vegetation and in water temperatures 8-12°C, 12-16°C, 16-20°C, and 20-28°C, respectively. The species that comprise each of the guilds have been recorded in the Lake Erie system and their species-specific habitat requirements have been used to calculate WSAs in the appropriate part of the system. Specific habitat requirements used for calculations are available in other references (Lane et al. 1996, Minns et al. 2001, Cudmore-Vokey and Minns 2002).

Temporal Validity: Spawning habitat supply is computed seasonally for each guild over an appropriate thermal window to generate annual habitat supply results (in units of hectares). Habitat supply is computed across the 109-year simulation period for different water level scenarios for comparison (a baseline condition for comparison could be pre-project or current regulation).

Spatial Validity: This guild-specific spawning habitat supply PIs are valid for the entire Inner Bay of Long Point Bay, Lake Erie between the minimum and maximum elevations specified in the model. The WSA for different fish spawning guilds, based on thermal and vegetation preference during spawning, are calculated for the entire area of Long Point Inner Bay.

Hydrology Link: Habitat suitabilities for each spawning guild, which are used to compute WSA in hectares, depend on the interaction between emergent vegetation, submergent vegetation, substrate composition, temperature and water depth in the Long Point Bay, Lake Erie study area. Water depth inputs for the habitat suitability model are calculated seasonally across the appropriate time window for spawning, by guild (see coping zone criteria section for details) and are based on monthly water levels provided by the study. A digital elevation model (DEM) (Cabrera, Deadman and Mortsch) and average spawning season water level elevation are used to derive area by water depth. WSAs over time are used to assess habitat availability for different water level scenarios to determine how it is affected by regulation or water supply. WSAs can be combined across life stages, where appropriate, based on weightings determined by each stage's responsiveness to habitat variables.

Algorithm: Algorithms used in previous research in Long Point and in the Lake Ontario-Upper St. Lawrence River Study provide the basis for the current Long Point study (Chu et al. 2005; Doka 2004; Doka et al. 2005; Minns et al 1999). Specific equations and algorithms used in submodels for the calculation of WSAs are too extensive to list here and will be documented elsewhere.

Coping Zone Criteria:

A set of rules for "low water level" and "high water level" coping zones are defined below for the four high vegetation spawning guilds. It is assumed that all wet vegetation (emergent and submergent) is equally useful to fishes that prefer vegetated areas. It is also assumed that spawning occurs during the same dates in each year, where spawning windows are defined by the average annual historical or climate scenario temperatures; however, we acknowledge that inter-annual differences in spring and summer temperatures may be important. While spawning habitat is not necessarily the limiting habitat type in Long Point Inner Bay, processes affecting nursery habitat for young fish are complex and would likely not be captured within the coping zone calculator.

Water levels used (4 – one for each guild): *SWWL* – weighted mean monthly water level for the months during with spawning occurs, for each guild. These spawning windows are defined below.
Water regime variable also used: variance in growing season water level (March to October) over last 30 years

The spawning windows for each guild for the historical temperature regime are defined in Table 1 below.

Table 1. Guild-Specific Spawning Windows for Historical Temperature Regime

Guild	TemperaturePref (°C)	HistoricalSpawnWindow	SWWL – Historical Climate
HV10	8-12	May 14-May 18	MayWLevel
HV14	12-16	May 19-May 23	MayWLevel
HV18	16-20	May 24-June 1	[(8*MayWLevel)+(1*JunWLev)]/9
HV24	22-26	June 8-July 16	[(23*JunWLevel)+(16*JulWLev)]/39

Under climate change scenarios, for each guild:

- If mean scenario/annual surface water temperature is 2-3°C above historical mean (1950-2000; mean = 10.64°C), shift spawning window earlier in year by 16 days; use SWWL corresponding to new spawning window; and

- If mean scenario/annual surface water temperature is 3-4°C above historical mean (1950-2000; mean = 10.64°C), shift spawning window earlier in year by 21 days; use SWWL corresponding to new spawning window.

Criteria for Low Water Level Conditions:

Based on the spawning windows described in Table 1, the lower water level coping zones were assigned based on the 'health' of vegetated area and the bathymetry of the Inner Bay. If vegetated area is in Zone C, spawning habitat is in Zone C. If vegetated area is in Zone B, spawning habitat is either in Zone B or C, depending on spawning period water level and bathymetrically designated zone thresholds (see vegetated area lower coping zone for description). If vegetated area is in Zone A, spawning habitat can be in Zone A, B or C, depending on water level and thresholds.

- **ERI-04a Criteria:**
    - If the "wet vegetation area" lower coping zone (ERI-03a, see fact sheet #18) condition is "Zone A" for a given year, then the following rules are applied:
        - Zone B: Mean water level during the guild-specific spawning season is less than 172.8 meters in any given year, or between 172.8 and 173.55 meters, for 3 years in a 5-year window.
        - Zone C: Mean water level during the guild-specific spawning season is less than 172.8 meters for five consecutive years.
    - If the "wet vegetation area" lower coping zone (ERI-03a, see fact sheet #18) condition is "Zone B" for a given year, then the default coping zone is also "B" for the spawning habitat supply criterion. The following rule is then applied to determine whether a "Zone C" condition applies:
        - Zone C: Mean water level during the guild-specific spawning season is less than 172.8 meters for five consecutive years.
    - If the "wet vegetation area" lower coping zone (ERI-03a, see fact sheet #18) condition is "Zone C" for a given year, then the spawning habitat supply coping zone is also assigned as "Zone C".

Criteria for High Water Level Conditions:

Based on the spawning windows described in Table 1, the coping zones associated with higher water levels were assigned based on the 'health' of vegetated area (see spawning habitat area lower zone for description) and water level thresholds based on the proportion of the Long Point spit that is flooded and water level variance regime (see vegetated area upper coping zone for description).

- **<u>ERI-04b Criteria:</u>**

  <u>**Case #1**</u>**: Variance of mean growing season (March-October) water level over a rolling 30-year period is less than 0.01 meter:**

  - If the "wet vegetation area" upper coping zone (ERI-03b, see fact sheet #18) condition is "Zone A" for a given year, then the following rules are applied:
    - <u>Zone B</u>: Mean water level during the guild-specific spawning season is greater than 174.6 meters in any given year, or between 174.2 and 174.6 meters for 3 years in a 5-year window.
    - <u>Zone C</u>: Mean water level during the guild-specific spawning season is greater than 174.6 meters for five consecutive years.
  - If the "wet vegetation area" upper coping zone (ERI-03b, see fact sheet #18) condition is "Zone B" for a given year, then the default coping zone is also "B" for the spawning habitat supply criterion. The following rule is then applied to determine whether a "Zone C" condition applies:
    - <u>Zone C</u>: Mean water level during the guild-specific spawning season is greater than 174.6 meters for five consecutive years.
  - If the "wet vegetation area" upper coping zone (ERI-03b, see fact sheet #18) condition is "Zone C" for a given year, then the spawning habitat supply upper coping zone is also assigned as "Zone C".

  <u>**Case #2**</u>**: Variance of mean growing season (March-October) water level over a rolling 30-year period is greater than or equal to 0.01 meter:**

  - If the "wet vegetation area" upper coping zone (ERI-03b, see fact sheet #18) condition is "Zone A" for a given year, then the following rules are applied:
    - <u>Zone B</u>: Mean water level during the guild-specific spawning season is greater than 175.03 meters in any given year, or between 174.63 and 175.03 meters for 3 years in a 5-year window.
    - <u>Zone C</u>: Mean water level during the guild-specific spawning season is greater than 175.03 meters for five consecutive years.
  - If the "wet vegetation area" upper coping zone (ERI-03b, see fact sheet #18) condition is "Zone B" for a given year, then the default coping zone is also "B" for the spawning habitat supply criterion. The following rule is then applied to determine whether a "Zone C" condition applies:
    - <u>Zone C</u>: Mean water level during the guild-specific spawning season is greater than 175.03 meters for five consecutive years.
  - If the "wet vegetation area" upper coping zone (ERI-03b, see fact sheet #18) condition is "Zone C" for a given year, then the spawning habitat supply upper coping zone is also assigned as "Zone C".

It is important to note that the rules for ERI-04a and ERI-04b should always be considered together when assessing impacts to guild-specific spawning habitat supply for Long Point (i.e., a "Zone C" for either the low or high water case for a given year constitutes an overall "Zone C" condition).

Calibration Data: No specific calibration data are available for habitat associations, but relationships between habitat suitability and emergent vegetation, submergent vegetation, substrate composition, depth, and temperature are based on a large body of literature and information available on the habitat requirements for the four individual spawning guilds. Individual habitat components, such as vegetation cover, substrate type and temperatures, have been calibrated with different sources of information.

Validation Data: No specific validation datasets are available for WSAs. Temperatures used in the habitat supply calculations have been validated using simulated data from different thermal models for Long Point Bay or empirical datasets specific to the Long Point Bay/Lake Erie study area, when available.

Risk and Uncertainty Assessment: See discussion in the following section.

Confidence, Significance and Sensitivity: See discussion in the following section.

***Confidence*:** Currently cumulative uncertainties have not been estimated but errors and uncertainties exist at three levels of the habitat supply analysis: spatial habitat information, habitat models, WSA calculations based on their suitability and thermal windows. The scenarios should be equally affected by these cumulative uncertainties and also the relative differences used for comparisons. Therefore, we are confident in the relative habitat supply effects and predictions.

Significance:

Sensitivity: Regulation of Lake Superior does not significantly affect Lake Erie water levels (Fay and Dahl 2008). However, the impact of long-term variability remains of interest, with respect to adaptive management under a changing climate. The response of habitat availability will be determined once full scenario testing has taken place.

Documentation and References:

Chu, C., J. E. Moore, C.N. Bakelaar, S.E. Doka and C.K. Minns. 2005. Supporting data for the habitat-based population models developed for northern pike, smallmouth bass, largemouth bass and yellow perch. *Canadian Data Report of Fisheries and Aquatic Sciences,* 1160:iv+31p.

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Fact Sheet ID: 20

Performance Indicator (PI) Name/Short Description: Wetland Birds - ecological condition index (ECI) (Saginaw Bay, Lake Huron and Long Point and Turkey Point, Lake Erie)
Technical Workgroup: Ecosystem Technical Working Group (ETWG)

Researched by: G. Niemi and R. Howe

Modeled by: LimnoTech (Redder, DePinto)

PI Metric: The PI metric is an ecological condition index (ECI) based on the change in habitat area for 13 wetland-associated bird species, including four species at risk*:* least bittern, black tern, king rail, and yellow rail.

The basic hypothesis for the analysis of this PI metric is based on the direct relationship between the amount of available wetland habitat and viable population levels of a species. Because each of these species at risk are rare, population estimates are low (e.g., < 1 breeding pair per 100 ha of wetland habitat), and each species are not always present in a particular wetland complex. For example, in the Upper Great Lakes (UGL) region, the king rail has been extirpated from most of the wetlands of the region and the yellow rail has been rarely been recorded from any of the UGL coastal wetlands. To simplify the analysis and the interpretation in multiple responses by these 13 wetland species, we combine them into an ECI (Howe et al. 2007a). This index can be calculated based on the area of wetland habitat and the relative density of each wetland species within the area of interest. Since the ECI represents a gradient from degraded to pristine conditions, it parallels the “Descriptive Framework of Biological Condition” for adaptive management. The ECI values range from 0 (degraded) to 10 (pristine).

The PI metric represents an assessment of the amount of available breeding habitat for a combination of the 13 wetland species listed and to be evaluated under different water level scenarios. Estimates were made of breeding populations in different wetland habitats on the basis of wetlands sampled within the Great Lakes (Hanowski et al. 2007; Howe et al. 2007b, Niemi et al. 2007) or from expert judgment. In contrast to studies of water level regulation in Lake Ontario – St. Lawrence River (DesGranges et al. 2005), little information on nesting success is available in the UGL on the four species of primary concern, which includes the least bittern *(Ixobrychus exilis)*, black tern (*Chlidonas niger*), king rail (*Rallus elegans*), and yellow rail (*Coturnicops noveboracensis)*. Therefore, there is no basis to support an evaluation of nesting success for any of the 13 species included here.

Specific habitat data were not available for the study sites in the UGL; hence, populations for each of the species were estimated from general habitat types available under the base water level conditions and under different water level scenarios. Generally, the acreage of habitat was only available for grass-sedge wetlands or for emergent vegetation (e.g., cattail) mosaics in the areas studied. However, these are the primary habitats where each of the 13 wetland species primarily occurs, and in particular, the four species of primary concern. For example, the least bittern, black tern, and king rail are primarily found in wetland complexes dominated by emergent vegetation, often with patches of shallow open water. In contrast, yellow rails are primarily found in grass-sedge wetlands, especially those dominated by *Carex lasiocarpa*. The remaining nine species considered in this analysis are all species representative of important wetland habitats in the UGL coastal region and serve as important ecological indicators of conditions in the coastal region (Howe et al. 2007b). In contrast to the four breeding bird species that are at risk, there is considerable information on the breeding density of these other nine species within Great Lakes wetland complexes; hence, they are representative of the wetland ecological conditions for different water level scenarios.

Ecological Importance/Niche: The least bittern is listed as threatened in Canada, endangered in Indiana, and threatened in Michigan, Illinois, and Ontario. The king rail is listed as endangered in Canada, Illinois, Indiana, Michigan, Minnesota, and Ohio. The yellow rail is listed as threatened in Michigan and Wisconsin and it is a species of special concern in Minnesota. The black tern is listed as endangered in Illinois and New York and of special concern in Canada and Michigan. Status of these species has been previously described by Albert et al. (2008).

Temporal Validity: The data considered here are valid, primarily, for the entire breeding period for those species represented here. This pertains to the period from mid-April to late September.

Spatial Validity: This general ECI was designed to be spatially relevant to any wetland complex within the UGL region because density estimates and their variances were derived from data throughout the UGL region.

Hydrology Link: All 13 species included here nest within wetland complexes of the UGL. Their nest placement varies from close to the water level (e.g., black tern, blue-winged teal, common moorhen, pied-billed grebe, and sora, Virginia, yellow, and king rails) to emergent vegetation within 1 m of the prevailing water level (e.g., American and least bittern). All of the included species, with the exception of the yellow warbler, are obligate wetland species that are dependent on long-term water supplies. Hydrological changes in water levels (e.g., > 15 cm) during the breeding season can drown nests, eggs, and/or chicks. Decreases in water level during the breeding season can increase access of nest sites to predators.

Algorithm: A suite of obligate wetland bird species were selected to be representative across the range of habitats in Great Lakes coastal wetlands and to include several species at risk. A total of thirteen species were selected, including five species at risk:

- American Bittern;
- Black Tern (species at risk);
- Blue-Winged Teal;
- Common Moorhen;
- Least Bittern (species at risk);
- Marsh Wren;
- Pied-billed Grebe;
- Sedge Wren;
- Sora;
- Virginia Rail (species at risk);

- Yellow Warbler;
- Yellow Rail (species at risk); and
- King Rail (species at risk).

Species densities (# per hectare) were estimated for each major habitat type from the GLEI datasets. Table 1 below includes the basic mean density and standard deviation (SD) of relative abundance estimates (per 1.57 ha) used in the determination of ECI values under base water level conditions and various water level scenarios.

Table 1. Species code, species name, and mean plus standard deviation (SD) of number of breeding individuals recorded in point count samples (per 1.57 ha) in over 200 wetland complexes in the Great Lakes. Estimates of yellow rail and king rail were never counted during these surveys; therefore, they were determined by expert opinion and reflect very low relative abundance estimates.

Species Code	Species Name	Sedge/Grass		Emergent	
		Mean	SD	Mean	SD
AMBI	American Bittern	0.000	0.000	0.028	0.166
BLTE	Black Tern	0.000	0.000	0.009	0.097
BWTE	Blue-winged Teal	0.098	0.300	0.057	0.251
COMO	Common Moorhen	0.000	0.000	0.038	0.235
LEBI	Least Bittern	0.000	0.000	0.047	0.213
MAWR	Marsh Wren	0.146	0.422	0.524	0.857
PBGR	Pied-billed Grebe	0.024	0.156	0.019	0.136
SEWR	Sedge Wren	0.439	0.896	0.259	0.663
SORA	Sora	0.049	0.312	0.099	0.383
VIRA	Virginia Rail	0.024	0.156	0.104	0.321
YWAR	Yellow Warbler	0.756	1.044	1.019	1.002
YEAR	Yellow Rail	0.010	0.156	0.000	0.000
KIRA	King Rail	0.000	0.000	0.010	0.097

The densities provided in Table 1 can be integrated with predictions of the surface area of major habitat types (i.e., meadow marsh, emergent) in a wetland for a given year to estimate the total number of individuals that could be supported by that wetland area.

The “ecological condition index” (ECI) approach is used to integrate population estimates for the 13 species into a single indicator representing overall wetland bird community health. The ECI is developed by relating the number of individuals for a given species to an index ranging from 1 to 10, with 1 representing a very poor overall condition and 10 representing an optimal condition. For example, Figure 1 plots the population size for Sedge Wren as a function of the ECI. An optimal condition (ECI = 10) occurs when the Sedge Wren population is approximately 160 individuals. A very poor condition (ECI = 0) occurs when only 10 individuals are expected to be found at a given wetland location.

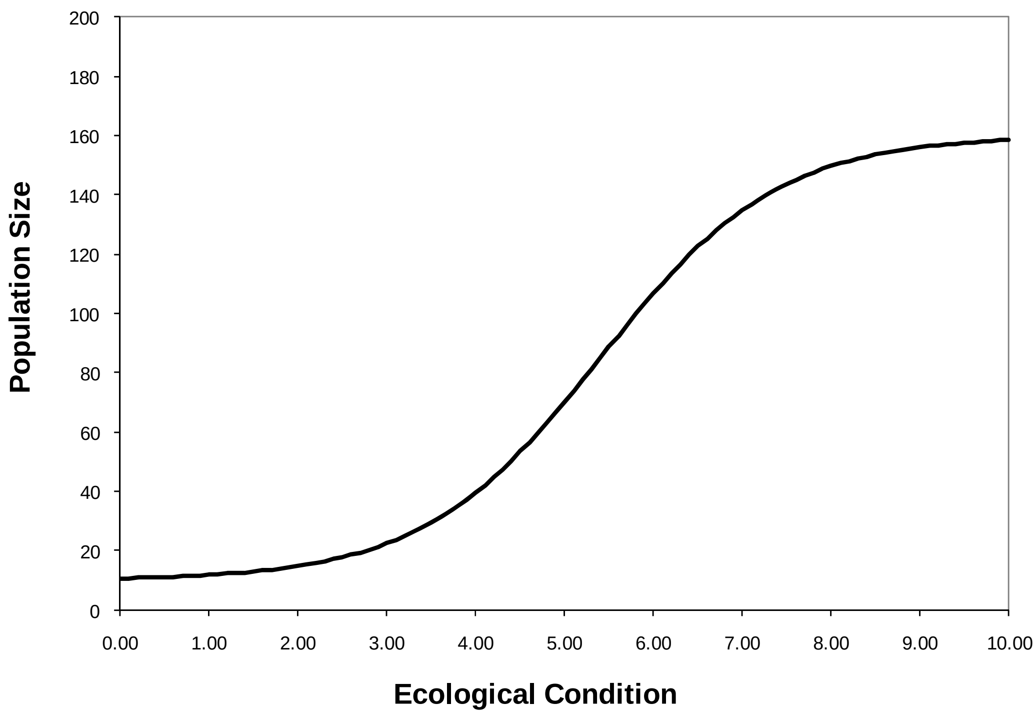

Figure 1. Sedge Wren Population Size vs. "Ecological Condition Index" (ECI)

The species-specific relationship between the ECI and population size is described by the following probability function:

$$P_i(C) = \beta_1 + \beta_2 * \frac{e^{\beta_4 * (C - \beta_3)}}{1 + e^{\beta_4 * (C - \beta_3)}} \quad (1)$$

where *C* represents the ECI (1-10 scale), $P_i(C)$ is the estimated population for species *i*, β_1 is the species population at C=0, β_2 is the optimal species population at C=10, β_3 is the ECI at which the average of β_1 and β_2 occurs, and β_4 is a slope coefficient. The coefficients developed for each of the 13 species are listed in Table 2.

Table 2. Wetland Bird Species Coefficients for ECI Function

Species Name	Species Code	β_1	β_2	β_3	β_4
American Bittern	AMBI	0.0	40.0	10.0	0.300
Black Tern	BLTE	0.0	50.0	8.0	1.0
Blue-winged Teal	BWTE	0.0	60.0	6.0	1.0
Common Moorhen	COMO	0.0	30.0	7.0	1.0
King Rail	KIRA	0.0	20.0	10.0	1.0
Least Bittern	LEBI	0.0	50.0	9.0	1.0
Marsh Wren	MAWR	20.0	150.0	3.0	1.0
Pie-billed Grebe	PBGR	0.0	50.0	6.0	1.0
Sedge Wren	SEWR	0.0	50.0	8.0	1.0
Sora	SORA	0.0	80.0	6.0	1.0
Virginia Rail	VIRA	0.0	40.0	7.0	1.0
Yellow Rail	YERA	0.0	20.0	10.0	1.0
Yellow Warbler	YWAR	10.0	150.0	4.0	1.0

Given the ECI functions for each of the 13 species and estimates of species populations for a given wetland in a given year, an overall ECI is calculated by performing a least squares optimization on the 13 functions. In general, water level scenarios that allow for short- and long-term inter-annual variability in water levels will maintain the greatest diversity in wetland bird habitats (i.e., for all 13 species). Therefore, these conditions will typically produce the highest "index of ecological condition" scores. In contrast, a water level scenario that compresses the range of water levels will result in the meadow marsh and/or emergent marsh zones being contracted, thus reducing overall wetland bird community health. This condition will result in a lower ECI being calculated for a given wetland site.

Coping Zone Criteria:

The "ecological condition index" (ECI) calculated for the wetland bird community is driven by the availability of two critical emergent vegetation types: meadow marsh and emergent marsh (i.e., bulrushes and other emergent species). Therefore, successful breeding and long-term sustainability of the wetland bird community requires the long-term sustainability of meadow marsh and emergent marsh in Upper Great Lakes wetlands. Instead of developing specific Coping Zone criteria for the wetland bird "ecological condition index", this PI has been linked with the following Coping Zone criteria developed for maintaining emergent vegetation for Lakes Michigan-Huron and Lake Erie:

- LMH-01 and LMH-02 (see fact sheet #12); and
- ERI-01a, ERI-01b, and ERI-02 (see fact sheet #17).

Calibration Data: Calibration data are not available.

Validation Data: No external or internal validation was performed. The results were reviewed based on knowledge of the scientific literature and empirical knowledge of these species and wetland complexes.

Risk and Uncertainty Assessment: This PI metric is based on the following assumptions: 1) breeding habitat supply is a critical factor in the perpetuation of viable breeding populations for each of the 13 species included here; 2) breeding habitat supply is fundamentally related with the reproductive success for each of these species, which is the ultimate determination of the survival of a species; 3) the estimates of relative abundance were based on the most accepted scientific method available for a vast area the size of the UGL region; 4) the wetland habitat and assumed variation within the wetland habitats are related with the relative abundance estimates for the wetland bird species considered here; and 5) the hydrological data and subsequent modeling of wetland habitat available are assumed representative of potential conditions within the UGL region.

Confidence, Significance and Sensitivity:

Confidence: Given the assumptions above, we are confident that this assessment will provide an approximation on the relative effects of water level fluctuation on wetland bird assemblages in the UGL region. Our confidence is reduced by the lack of better information on bathymetry, which would provide better estimates of wetland vegetation and their spatial distribution. In addition, there clearly needs to be more data gathered on nesting productivity within these wetland complexes. These are very difficult and expensive studies to complete.

Significance: There is substantial public interest and concern with the status of breeding bird populations in UGL study region. Many species have already had major declines (e.g., waterfowl and black tern) or have been extirpated from the region probably due to the loss of wetland habitat quality and quantity over the past 200 plus years (e.g., king rail). Birds also contribute to the healthy function of the UGL ecosystem via predator-prey interactions and via recreation such as wildlife viewing and tourism.

Sensitivity: The status of bird species populations is one of the easiest and cheapest to measure relative to other organisms; hence, they often serve as early-warning systems for larger scale problems.

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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.

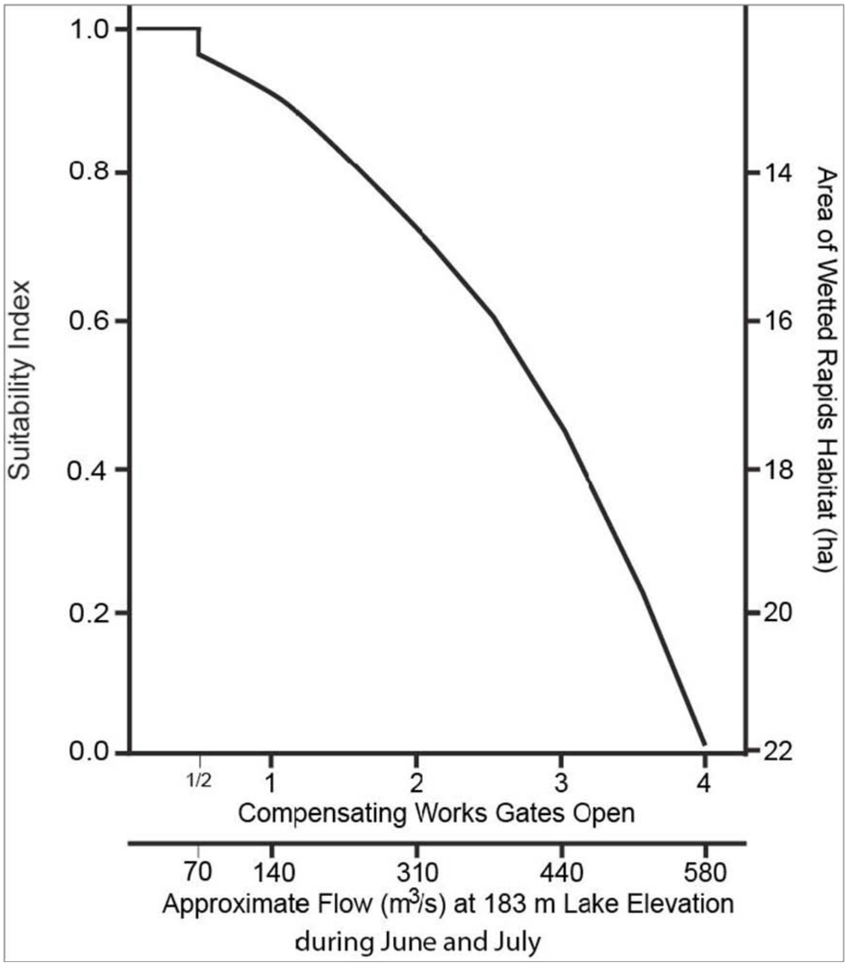

Figure 1. Relationship between flow and habitat area to determine a suitability index value for sea lamprey spawning habitat.

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 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”:

- **<u>SMG-01</u>**:
    - <u>Zone B</u>: 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.

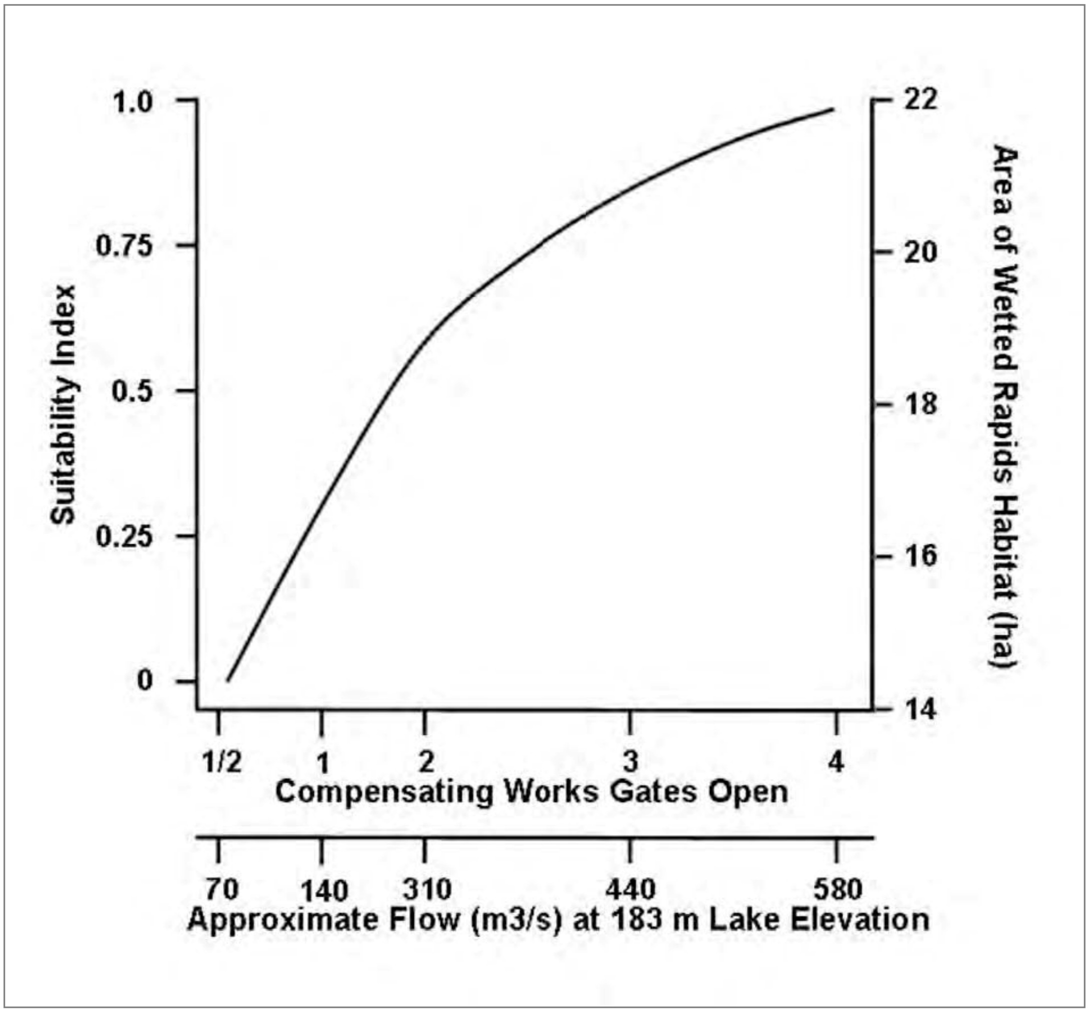

Figure 1: Relationship between flow and area of wetted rapids to determine a suitability index for native fish habitat area.

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.

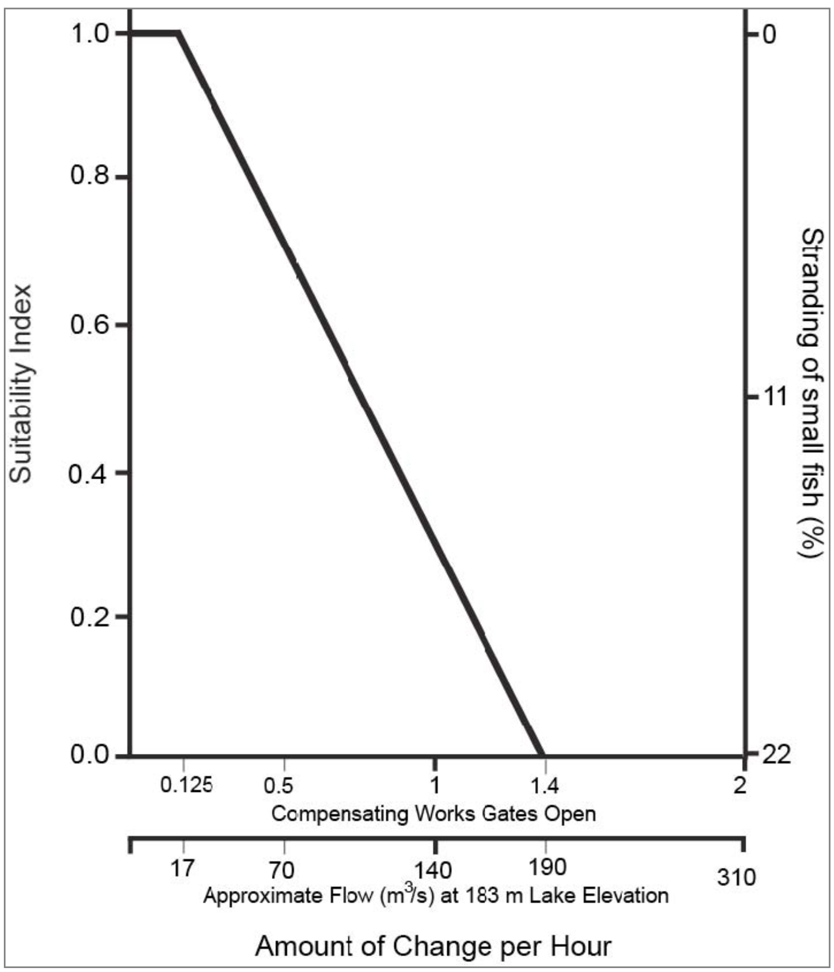

Figure 1. Relationship between flow and stranding of small fish to determine a suitability index for ramping rates.

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:

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

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:

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

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.

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).

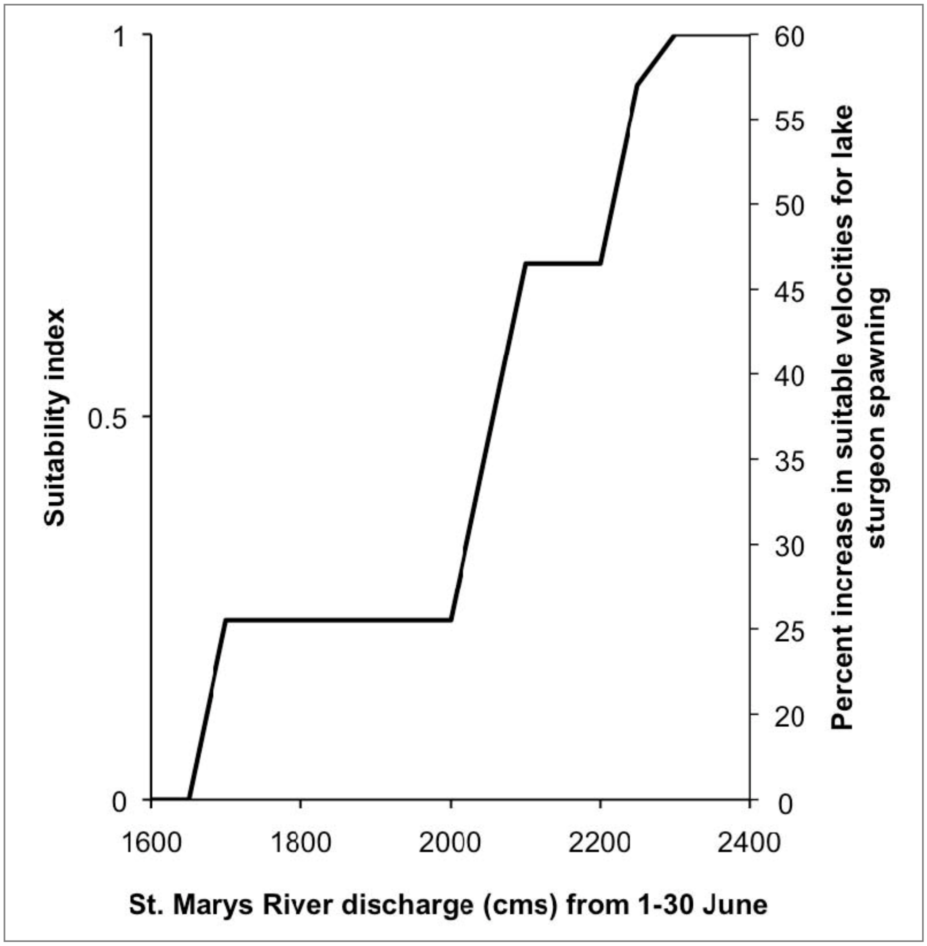

Figure 1. Relationship between St. Marys River discharge flow and suitable velocities for lake sturgeon spawning to determine a suitability index value.

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).

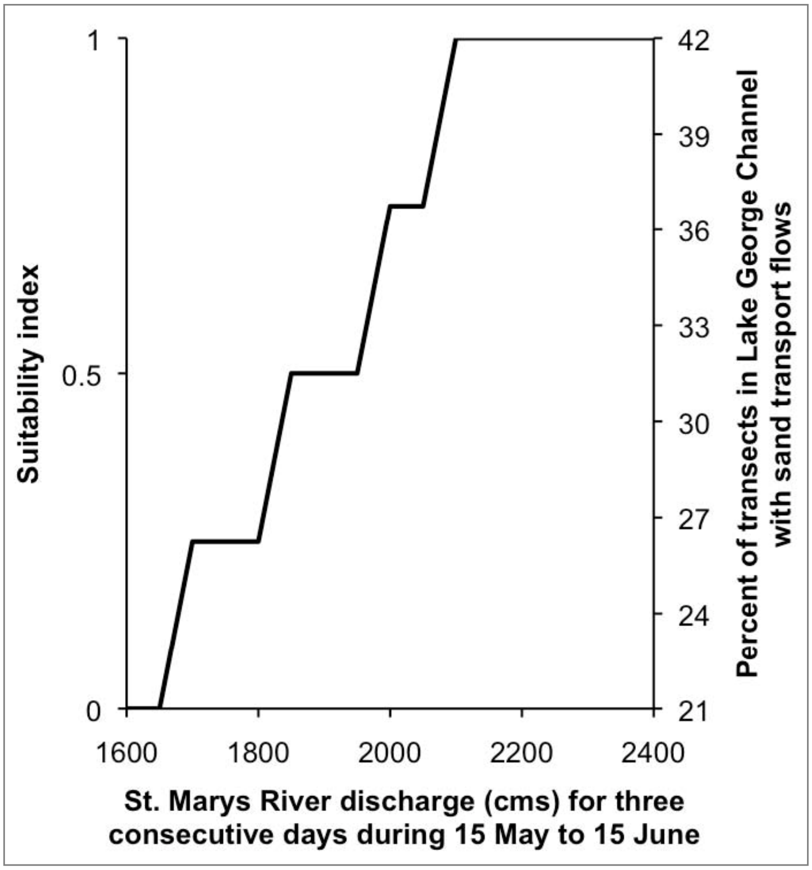

Figure 1. Relationship between St. Marys River discharge and the percent of transects in the Lake George Channel with sand transport flow to determine a suitability index.

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.

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.

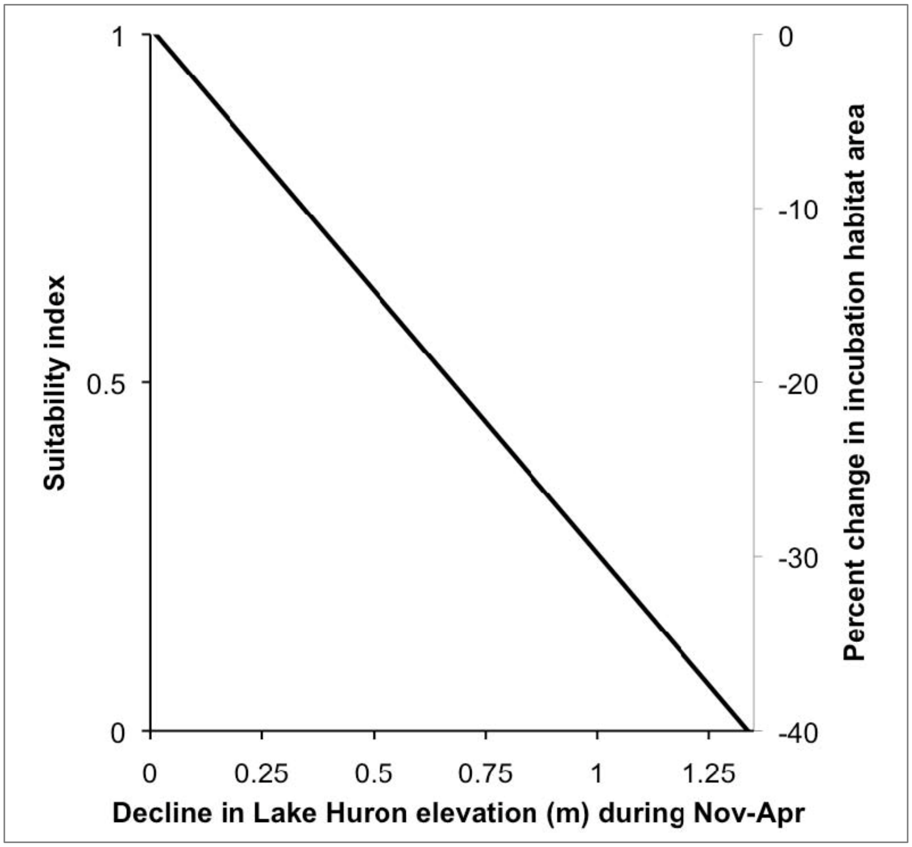

Figure 1. Relationship between Lake Huron water elevation and the percent change in cisco habitat area to determine a suitability index value.

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.

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.

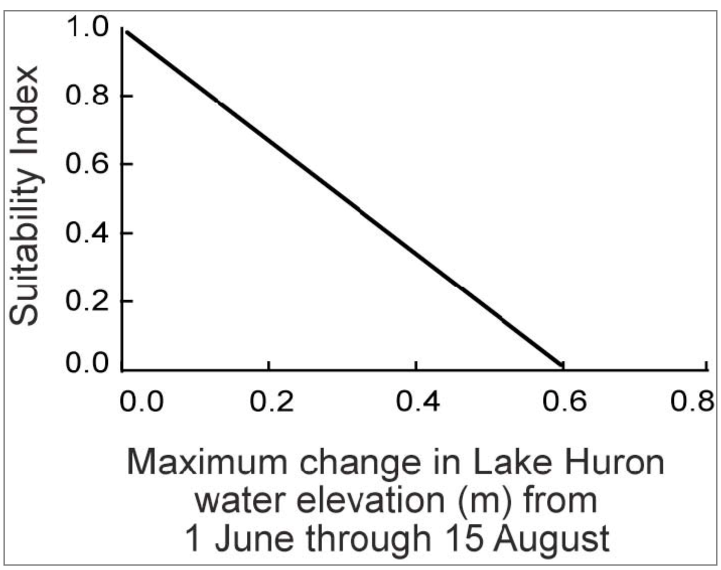

Figure 1. Suitability index for black tern nesting success based on Lake Huron water level.

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.

Documentation and References:

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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.

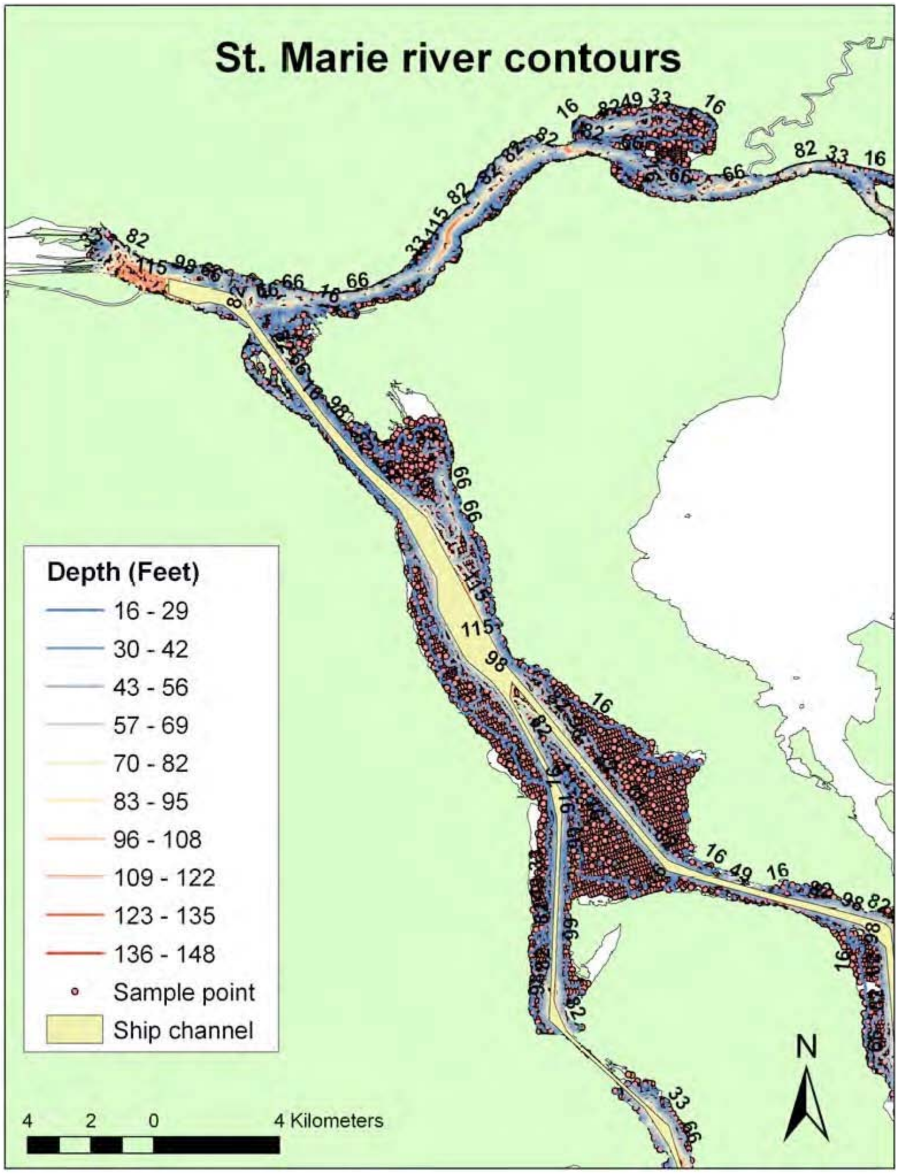

***Figure 1. Spatial extent of the St. Marys River analyzed; dots represent depth sampling points, colored lines represent depth intervals (ft), and the shipping channel is indicated in yellow*.**

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).

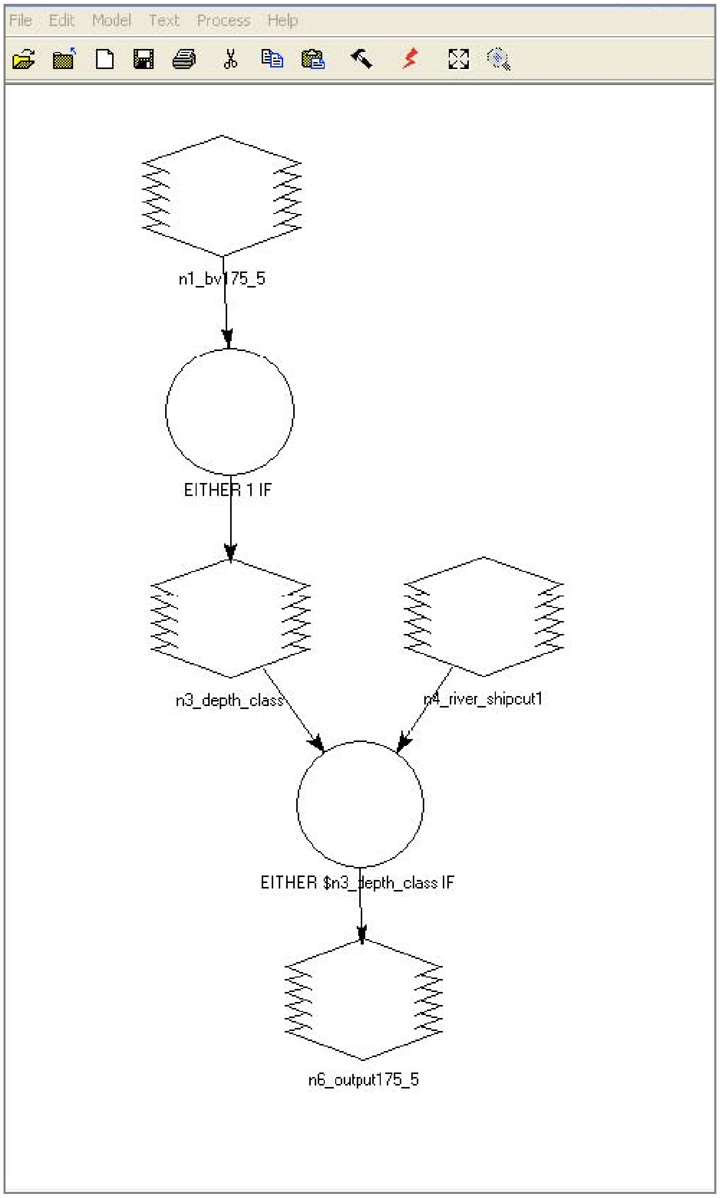

Figure 2. Process structure in the ERDAS Model Maker tool.

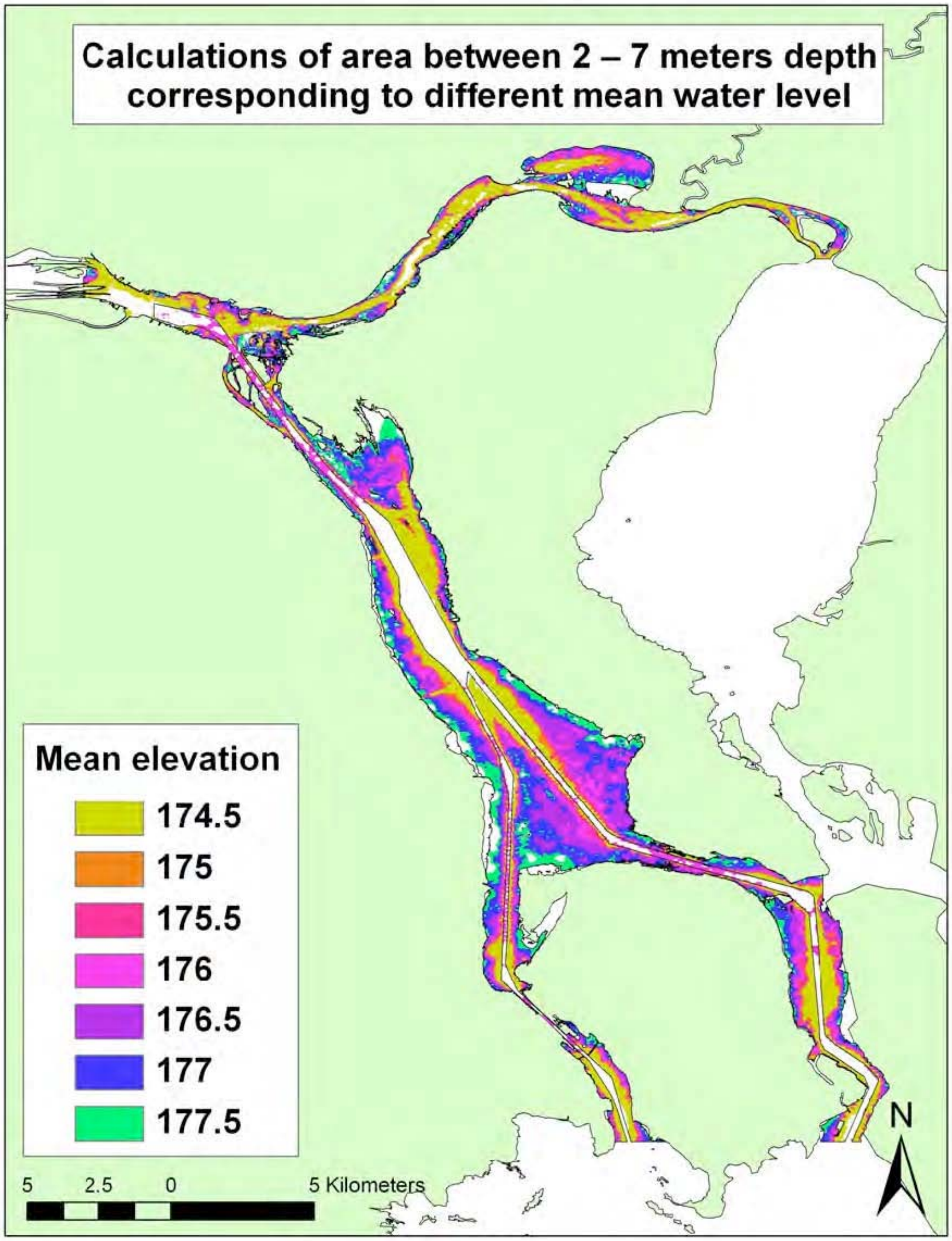

Figure 3. Area of the 2 to 7 meter depth range for each 0.5 m water elevation interval.

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

(area at 0.5 m inteval – area at 176.5 m) / (area at 176.5 m)

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.

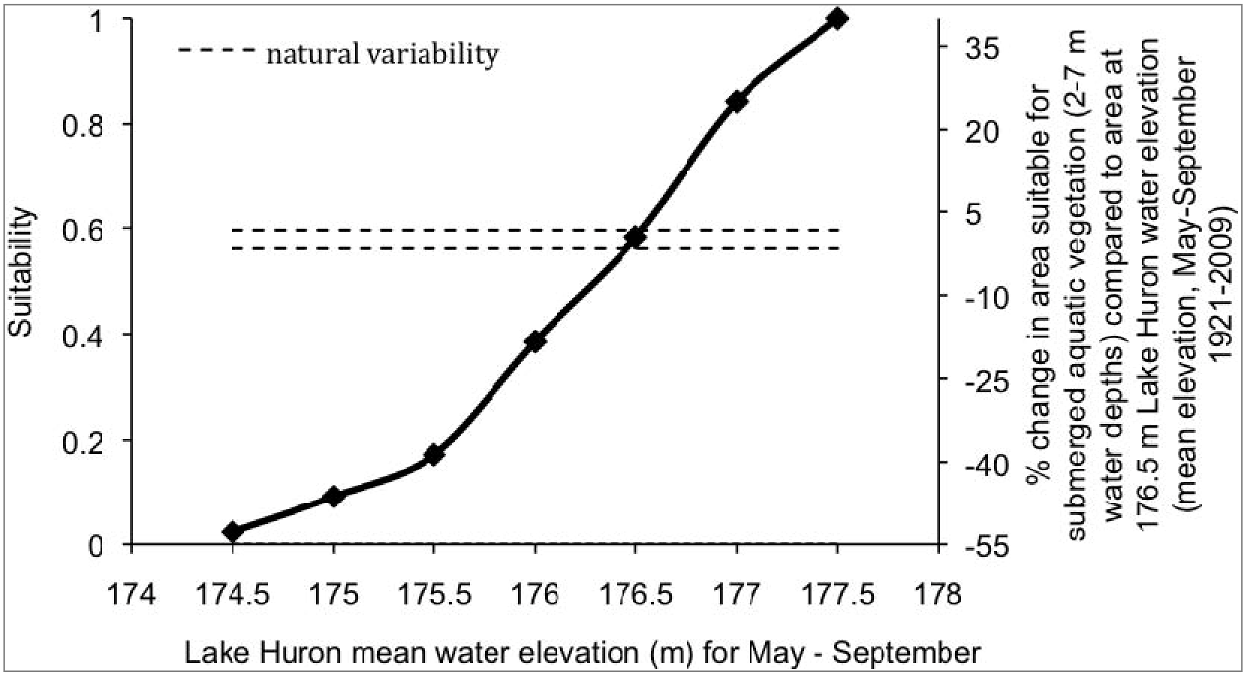

Figure 4. Relationship between Lake Huron water levels and the percent change in area suitable for SAV growth to determine a suitability index for SAV habitat.

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 ±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.

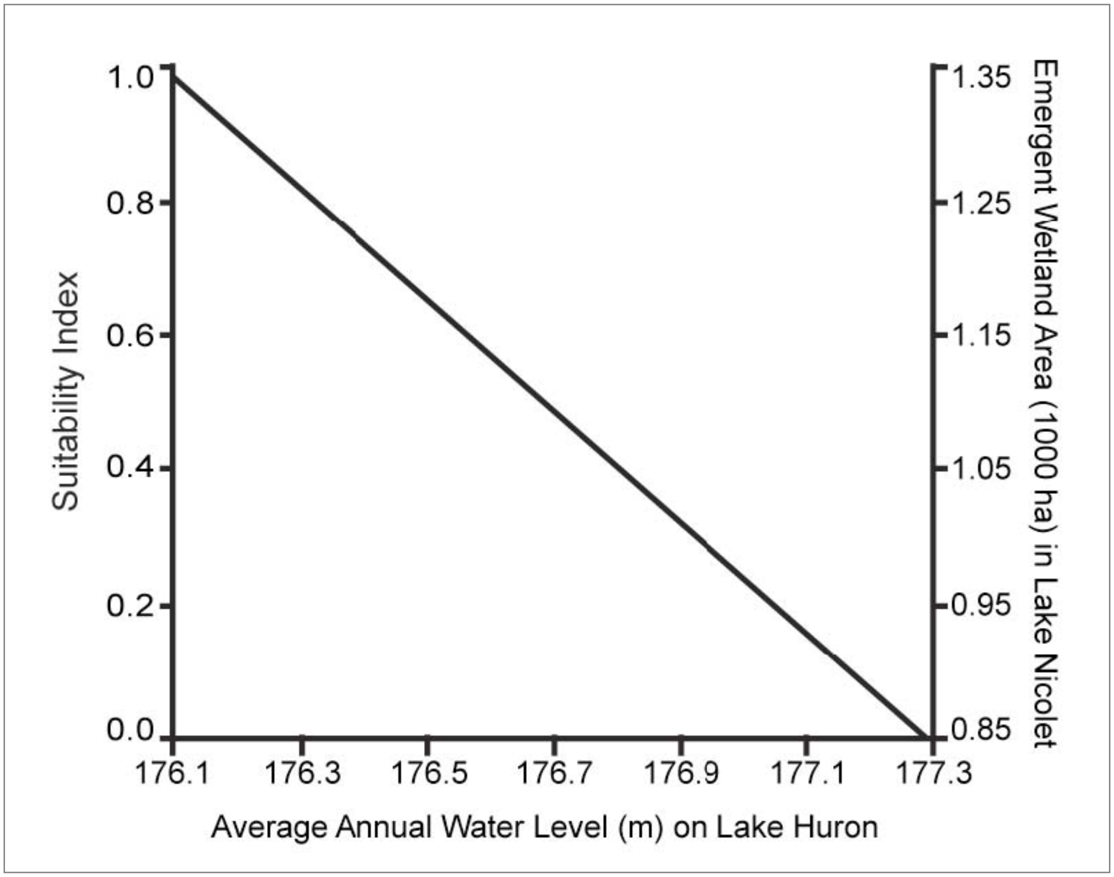

Figure 1. Relationship between Lake Huron water levels and emergent wetland area in Lake Nicolet to determine a suitability index for habitat.

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.

Documentation and References:

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Liston, C.R. and C.D. McNabb. 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 14-16-0009-79-013 by Michigan State University to the US Fish and Wildlife Service, Office of Biological Services, Twin Cities, Minnesota, USA.

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Spence, D.H.N. 1982. The zonation of plants in freshwater lakes. *Advances in Ecological Research*, 12: 37-126.

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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.

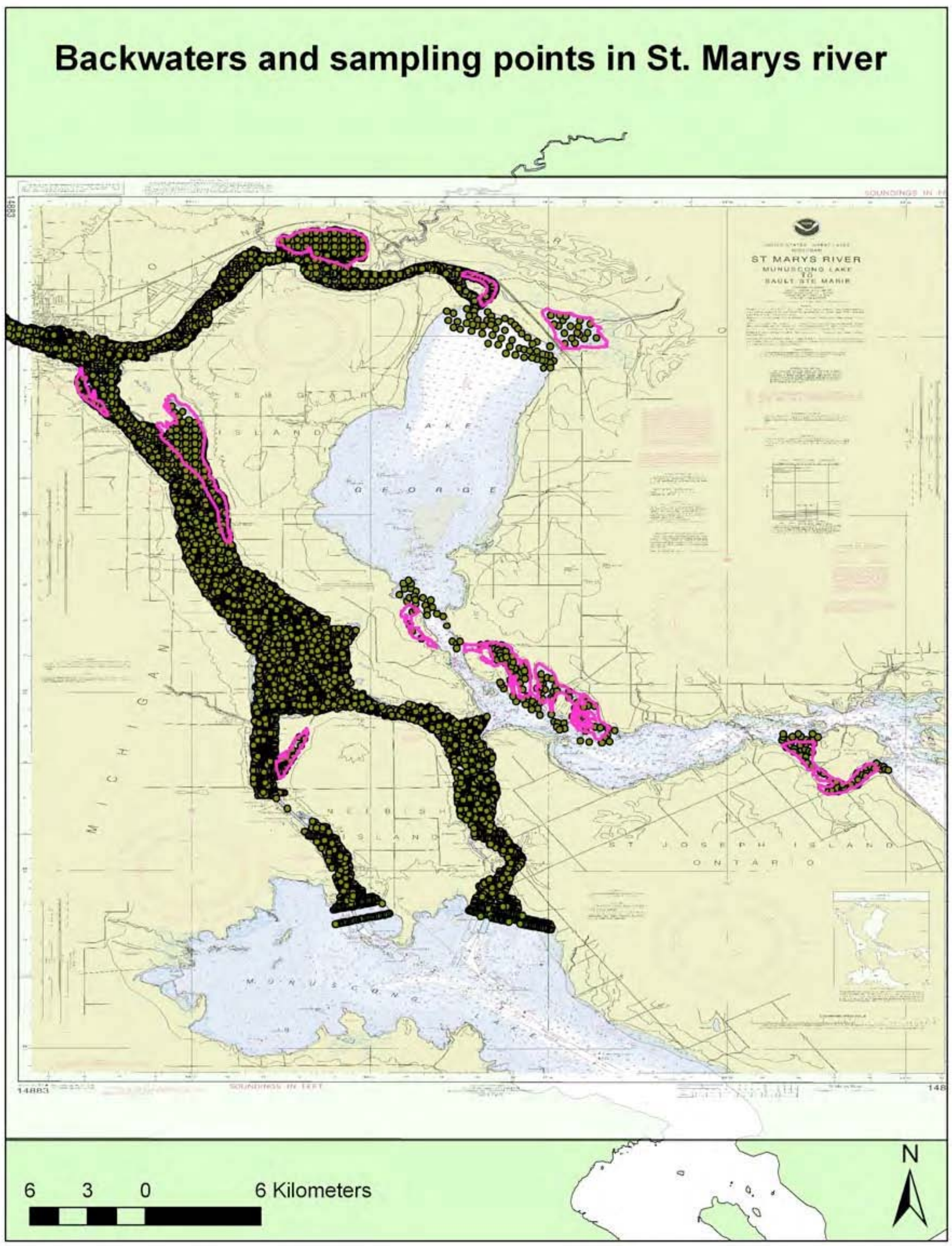

Figure 1. Spatial extent of the St. Marys River analyzed; dots represent depth sampling points; pink lines outline the backwater habitats considered.

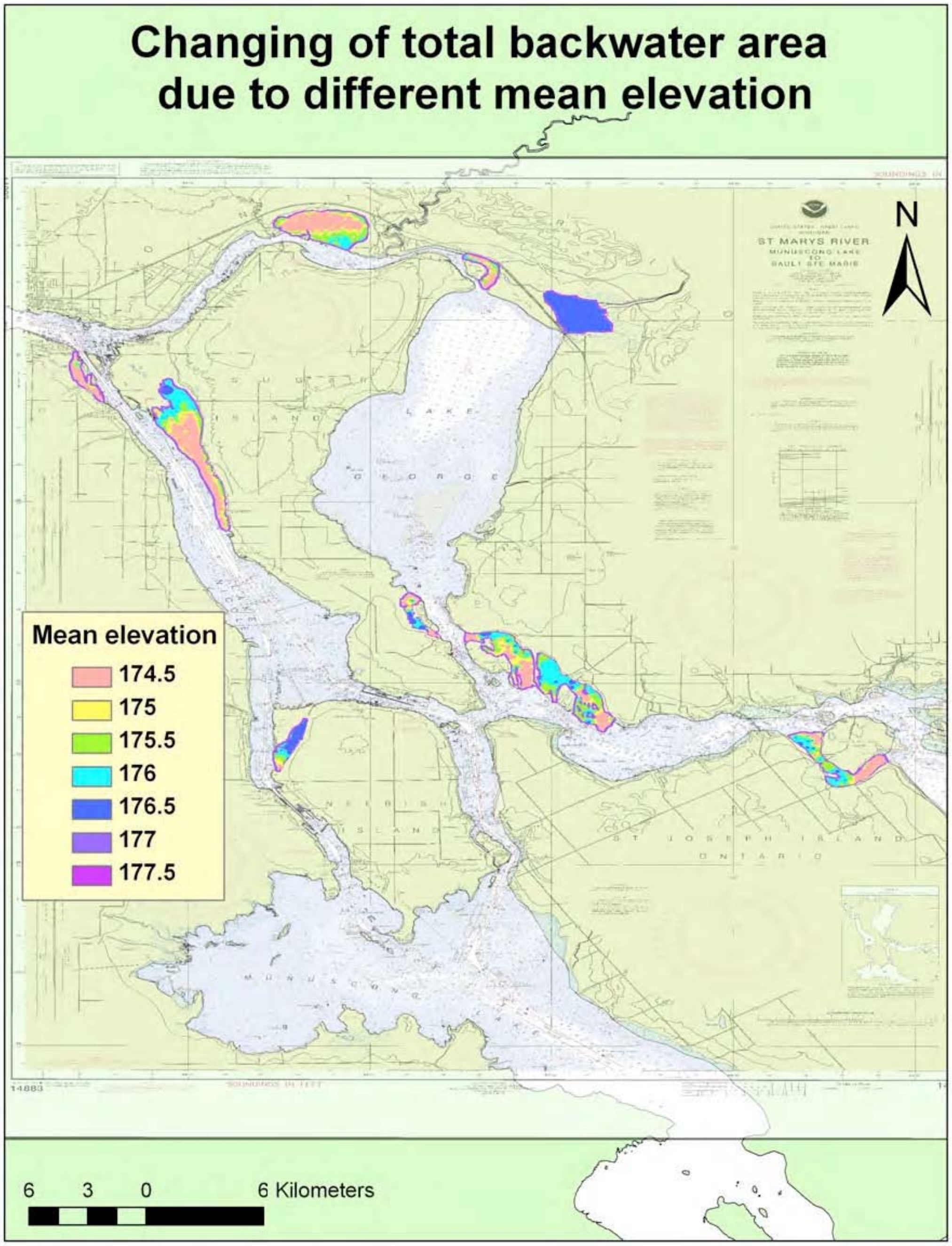

Figure 2. Total backwater habitat area at each 0.5 m water elevation interval ranging from 174.5 m to 177.5 m.

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.

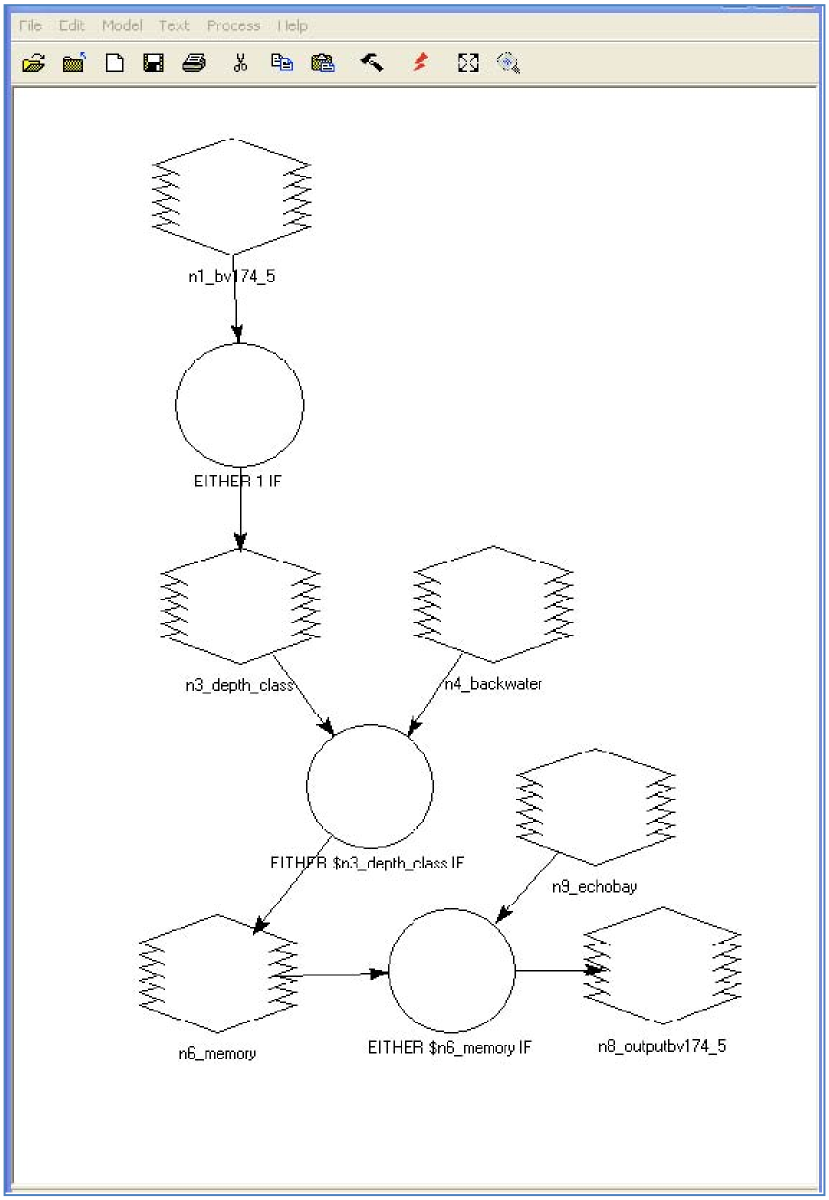

Figure 3a. Model structure used to calculate backwater habitat area at each 0.5 m water elevation interval from 174.5 to 176.5 m.

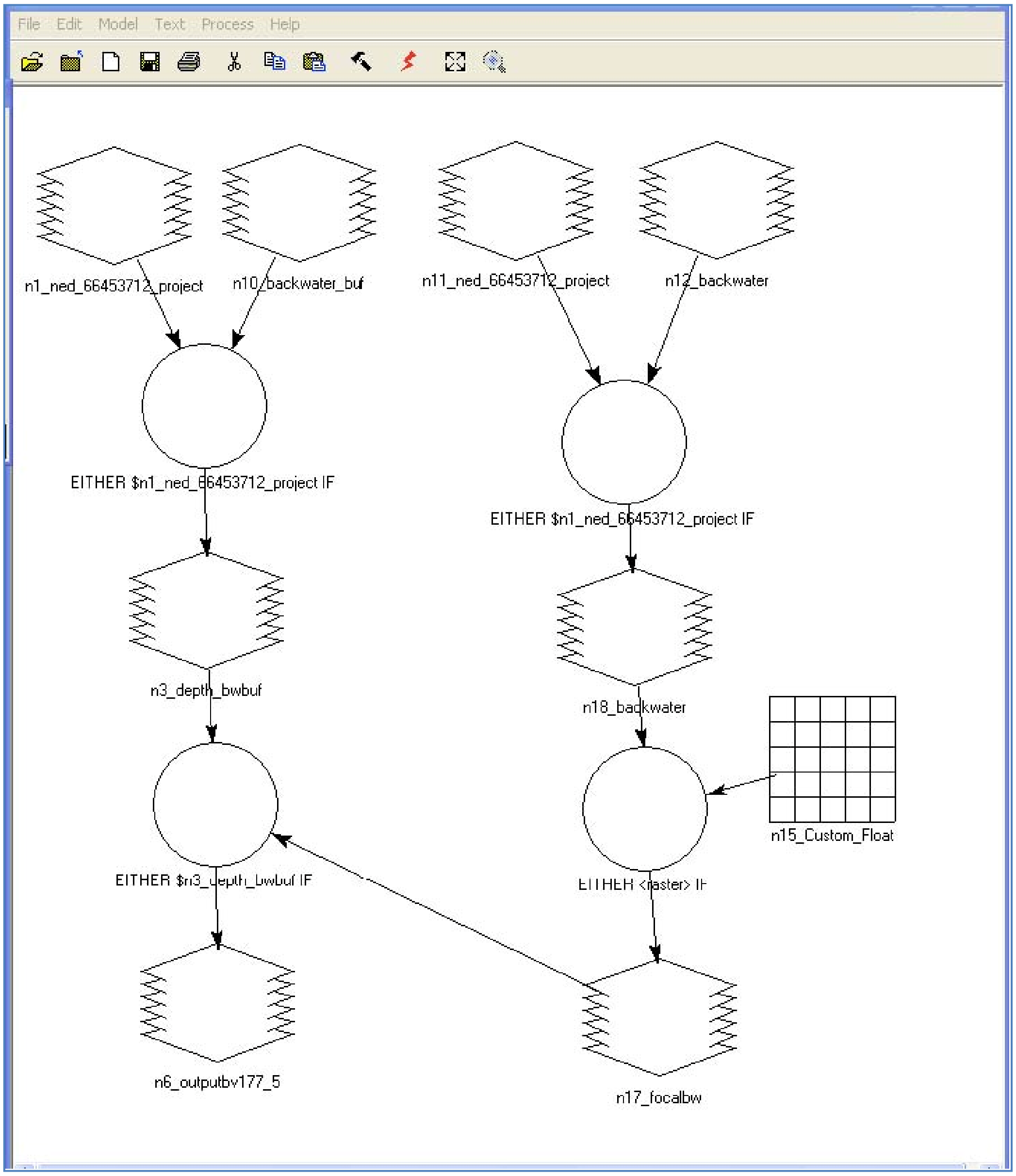

Figure 3b. Model structure used to calculate backwater habitat area for the 177.0 m and 177.5 m water elevation intervals.

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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