# Development of an Integrated Ecological Response Model (IERM) for the Lake Ontario – St. Lawrence River Study

DRAFT

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**Limno-Tech, Inc.**
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Ann Arbor, MI

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# EXECUTIVE SUMMARY

In response to the concern that the existing regulation plan has negatively impacted certain components of the Lake Ontario - St. Lawrence River (LOSL) system, a Study Board has been formed and funded by the International Joint Commission (IJC) to undertake a comprehensive five-year study. The objective of the study is to assess and evaluate the current criteria used for regulating water levels on Lake Ontario and in the St. Lawrence River, and to develop recommendations to the IJC for new criteria and an updated plan for water level and flow regulation. Among the interests being evaluated with respect to their response to alternative regulation plans is the Lake Ontario-St. Lawrence River ecosystem. The ecosystem changes that have occurred since the opening of the Seaway in 1958 have generated concerns that existing water-level regulation criteria are contributing to undesirable ecological impacts, including effects on wetland habitat quality and quantity, fish species utilizing ecological support provided by nearshore and wetland habitats, and terrestrial fauna (birds, mammals, amphibians and reptiles) that inhabit shoreline habitats in the system. Therefore, one of the ***Guiding Principles*** of the Study Board in making its recommendations requires that *"Criteria and Regulation Plans will contribute to the ecological integrity of the Lake Ontario-St. Lawrence River ecosystem."*

In order to deal with the ecological assessment of regulation plans for this system, an Environmental Technology Work Group (ETWG) was formed and charged with development of a suite of environmental **Performance Indicators** (PIs) that could be evaluated with respect to alternative regulation plans and compared on an appropriate basis with other interests being served by the plans (*i.e.*, hydropower, commercial navigation, recreational boating, flood control, and water supply). The ETWG chose to formulate and integrate its quantitative understanding of how the water level and flow-sensitive LOSL ecosystem components (PIs) would respond to alternative plans in an integrated modeling framework, which we call the **Integrated Ecological Response Model (IERM)**. The development and application of the IERM, including a user manual and a presentation and interpretation of its results relative to alternative plans being considered at the time of this writing, is presented in this document.

The development and application of the IERM was led by Limno-Tech, Inc. in close cooperation with our fellow modeler for the lower St. Lawrence River, Jean Morin, and the entire ETWG. Of course, regular interaction with other TWG's, PFEG, and the Study Board throughout the study also contributed to the final product. One of the key assumptions in formulating the IERM, driven in part by a lack of time and resources and in part by the guidance imposed on the overall study, **was that the model was <u>not</u> to consider the response of various performance indicators to forcing functions other than water levels and flows and temperature.** Other recognized important stressors on the LOSL ecosystem, such as nutrient and sediment supplies from the watershed, toxic chemical exposure, land use changes, nuisance exotic species invasions, and, in the case of some species, stocking and harvesting practices, were assumed to be constant among the various plan-scenario conditions tested.

The first part of the process of developing the IERM was the selection of PIs and the metrics used to measure them. This was accomplished through an iterative process that alternated between the application of ecological theory and the assessment of available historical data and newly collected data for the LOSL system. Through its work, the ETWG selected over 600 PIs for the system. Through an extensive process that involved using the IERM to evaluate the response of all of these PIs to alternative plan/supply scenarios, a subset of 32 key PIs was identified on the basis of the following criteria:

- **Significance** – the PI must show some key importance to the ecosystem and region;
- **Certainty** – there must be confidence in the PI results;
- **Sensitivity** – the PI must be significantly affected by changes in levels and flows generated by alternative regulation plans and/or supply scenarios being tested.

The 32 key PIs selected for primary use in comparing and evaluating alternative regulation plans are presented in Tables 3-1 and 3-2 of this document.

A flow chart illustrating the generalized linkages between faunal responses, wetland habitat, and hydrologic/hydraulic forcing functions is presented in Figure 2-1 of this document. This feed-forward framework in which alternative plan/supply scenarios drive water levels and flow, which in turn affect wetland habitat, and finally to species in the indicated faunal groups, which are affected by both levels/flows and changes in wetland habitat characteristics. Through extensive collaborative exchanges with the ETWG researchers, many of which built their own sub-models for their ecological PIs, detailed diagrams were developed to describe the quantitative linkages between metrics for the PIs and hydrologic/hydraulic forcings (i.e., flows and water levels) and habitat quantity and quality. The IERM is essentially an integration of those relationships, which are described in this document.

Ultimately, the IERM was applied to evaluate and rank alternative regulation plans relative to the baseline plan (1958D with deviations – “1958DD”) based on the response of the 32 key ecological PIs. The performance of each plan was evaluated using a “ratio” approach, which provided a summary score for each key PI indicating the percent gain or loss relative to the baseline condition. Uncertainty bounds were developed for each key PI to aid in determining which PI ratio scores should be considered as representing a significant gain or loss. Several approaches were used to summarize the key PI responses for each plan and develop the rationale for ranking candidate alternative plans, including:

- Counting the total percentage of significant gains/losses based on the pre-defined uncertainty bounds (i.e., emphasize direction and magnitude of response);

- Counting the total percentage of significant gains/losses without considering the uncertainty bounds (i.e., emphasize direction of response);

- Evaluating trade-offs within the key PIs by comparing minimum and maximum scores for the 3 LOSL regions (LO, USL, and LSL); and

- Applying a weighting scheme to develop an overall "index of ecological integrity" to compare relative plan performance.

A complete set of plan PI ratio scores and indices of ecological integrity were generated for five supply scenarios, including a historical sequence and four stochastic sequences. The four "options" plans (A, B, D, E) considered by the LOSL Study Board at its April 2005 decision workshop were evaluated against the baseline reference plan (1958DD) and the PreProject plan, which serves as the natural reference condition.

A combination of the approaches described above was used to rank the options plans relative to the two reference plans. Net gain and loss scores and the indices of ecological integrity for all six plans are reported in Tables 3-5 and 3-6 of this document. The results of the plan evaluation suggest the following ranking for the option plans:

1. Plan "E" – this plan has the highest gain/loss net score and the highest index of ecological integrity for all supply scenarios;

2. Plan "B" – this plan has the second highest gain/loss net score for 4/5 supply scenarios, and the second highest index of ecological integrity for all supply scenarios; and

3. Plans "A" / "D" – these two plans score very similarly for both the gain/loss net score and the index of ecological integrity, and the scores are only marginally better than 1958DD.

This plan ranking and the supporting rationale was provided to the Study Board for consideration in developing a final list of options plans for recommendation to the IJC.

# 1. BACKGROUND & INTRODUCTION

## 1.1 STUDY OVERVIEW – LOSL

Regulation of water levels and flows in the Lake Ontario – St. Lawrence River system has been practiced since the construction of the St. Lawrence Seaway was completed in 1958. In response to the concern that the existing regulation plan has negatively impacted certain components of the Lake Ontario - St. Lawrence River (LOSL) system, a Study Board has been formed and funded by the International Joint Commission (IJC) to undertake a comprehensive five-year study. The objective of the study is to assess and evaluate the current criteria used for regulating water levels on Lake Ontario and in the St. Lawrence River, and to develop recommendations to the IJC for new criteria and an updated plan for water level and flow regulation. The Study Team engaged by the IJC is a bi-national group of diverse experts from government, academia, native communities, and interest groups representing the geographical, scientific and community concerns of the Lake Ontario - St. Lawrence system.

The LOSL Study Team is charged with considering the interests of a number of user groups (henceforth called *Interest Groups*) that have been identified as being directly affected by fluctuations of water levels and flows in the Lake Ontario – St. Lawrence River system. In order to quantitatively analyze the effects of different outflow regulation criteria and plans on these interests, scientific and technical data must be collected. Therefore, Technical Work Groups (TWGs) were formed to conduct these investigations on behalf of each Interest Group. The Interest-focused TWGs included in this study are: commercial navigation, hydropower, municipal and industrial water uses, riparian landowners (concerned with coastal flooding and erosion), recreational boating/tourism, and the environment. The latter two Interests were not considered in the development of the original regulation plan for the system. Each of these TWGs were charged with assessing existing data and conducting additional field investigations in order to develop a quantitative, predictive model that could be used to evaluate the response of key components of their interest to alternative regulation plans. The efforts were directed at designing regulation plans that benefit, or at least do not significantly harm, their interest.

Additional Technical Work Groups were formed to assist the Study Board and the Interest-focused TWGs to accomplish the goal of the study. They included:

- **Information Management –** to compile, collect, manage, and share spatial data (bathymetric, topographic, aerial photography, shoreline DEM, etc.) of value to the overall study;
- **Hydrologic and Hydraulic Modeling –** to simulate water levels and flows in Lake Ontario and in the St. Lawrence River to Trois-Rivières, Quebec under various regulation plans and water supply scenarios, thus permitting other TWGs to develop and evaluate regulation plans.

- **Plan Formulation and Evaluation Work Group –** to integrate the work of all other work groups into a "shared vision" computer model (SVM) that provides a tool with which the Study Board and all stakeholders can assess the effects of new regulation plans on the things that are important to stakeholders.

A very important part of the overall study is the **Public Interest Advisory Group**. This group represents the affected public by providing an ongoing forum for public education about the study and for receiving and transferring public input and feedback to the Study Board and TWGs. The Study Board recognized early on that ongoing public consultation is critical to successfully achieving a revised regulation plan that would be generally accepted by all stakeholders.

As mentioned above, the LOSL Plan Formulation and Evaluation Work Group (PFEG) has developed a "Shared Vision Model" (SVM) approach that attempts to combine all the study information into a single computer model in such a way that decision makers and stakeholders can ask "what if" questions and obtain answers about how functions of the system that are important to them are affected by alternative regulation plans. The Shared Vision approach facilitates the identification and resolution of conflicts over water use. For the LOSL Study, the PFEG is using the SVM to support the new regulation plan decision process. The concept of the SVM as used in the LOSL Study is to develop a quantitative connection between three important aspects of the system – regulation plans, criteria, and performance indicators – in terms that allow a fair evaluation of all user group interests. **Regulation Plans** are written rules for making releases to regulate Lake Ontario and the St. Lawrence River. Plans are currently based on rules that govern quarter-monthly releases through the Moses Saunders Dam on the St. Lawrence River. **Criteria** are hydrologic and hydraulic conditions or standards for judging how well regulation plans meet a variety of objectives. **Performance Indicators** (PIs) are measures that describe the impacts (economic, environmental, social, cultural, etc.) that result from a particular level/flow or series of levels/flows. They are based on something that can be measured and predicted to respond to alternative water levels and flows. An example of a performance indicator is the area of wetland meadow marsh habitat surrounding Lake Ontario, expressed in units of hectares.

The Shared Vision Model has been constructed by integrating relationships between water levels/flows and performance indicators obtained from each Interest-focused Technical Work Group into a modeling framework that allows evaluation of a series of alternative regulation plans. Based on hydrologic and hydraulic criteria developed from these relationships, a series of regulation plans have been developed. The SVM generates 101-year dam releases and associated water levels and flows in the system by applying each plan to a series of 101-year basin supply scenarios, representing historic, stochastic wet and dry, and climate change basin supplies. The model then runs each of those plan-supply scenario conditions and computes the 101-year response of system Performance Indicators for each Interest group for comparison among each other and to the existing regulation plan as a reference. The existing baseline regulation plan is known as the 1958D with deviations plan (1958DD).

This report provides documentation of the Integrated Ecological Response Model (IERM), which has been designed to compute and display the response of each of the Environmental Technical Working Group (ETWG) performance indicators to alternative water level and flow regulation plans being considered for the Lake Ontario-St. Lawrence River system. Limno-Tech, Inc. (LTI) and Environment Canada, in collaboration with ETWG researchers and modelers, is responsible for building the IERM and incorporating it as the environmental component of the Shared Vision Model (SVM). That transfer is being made by linking the executable version of the IERM, which is written in Visual Basic 6, to the SVM, which is encoded in STELLA and Microsoft Excel. The model domain, like all the interest-group components of the SVM, includes the entire Lake Ontario system and the St. Lawrence River from the Lake Ontario outlet to Trois-Riviere, Quebec. In the IERM this domain is divided into three geographic regions with specific performance indicators for each region; the regions are Lake Ontario (LO), the upper St. Lawrence River (USL), and the lower St. Lawrence River (LSL).

## 1.2 ETWG AND THE ROLE OF THE IERM

Since 1958, the St. Lawrence Seaway has modified the natural dynamics of discharge from and water level fluctuations in Lake Ontario, the St. Lawrence River (including Lake St. Lawrence and three impoundments in the lower river - Lac St. Francois, Lac St. Louis, and Lac St. Pierre), and associated lacustrine and riverine wetlands. The pattern of annual water-level variation has changed in Lake Ontario while the maximum volume and variability of flow has decreased in the St. Lawrence River and its impoundments. These changes have generated concerns that existing water-level regulation criteria are contributing to undesirable ecological impacts, including effects on wetland habitat quality and quantity, fish species utilizing ecological support provided by nearshore and wetland habitats, and terrestrial fauna (birds, mammals, amphibians and reptiles) that inhabit shoreline habitats in the system. Therefore, one of the ***Guiding Principles*** of the Study Board requires that *"Criteria and Regulation Plans will contribute to the ecological integrity of the Lake Ontario-St. Lawrence River ecosystem."*

The recommendations from the LOSL study will be due at the end of 2005 and will be used to support decisions regarding alteration of the current regulation criteria and resulting plan. The role of the Environmental Technical Work Group (ETWG) and its Integrated Ecological Response Model (IERM) in the overall LOSL Study is graphically depicted in Figure 1.

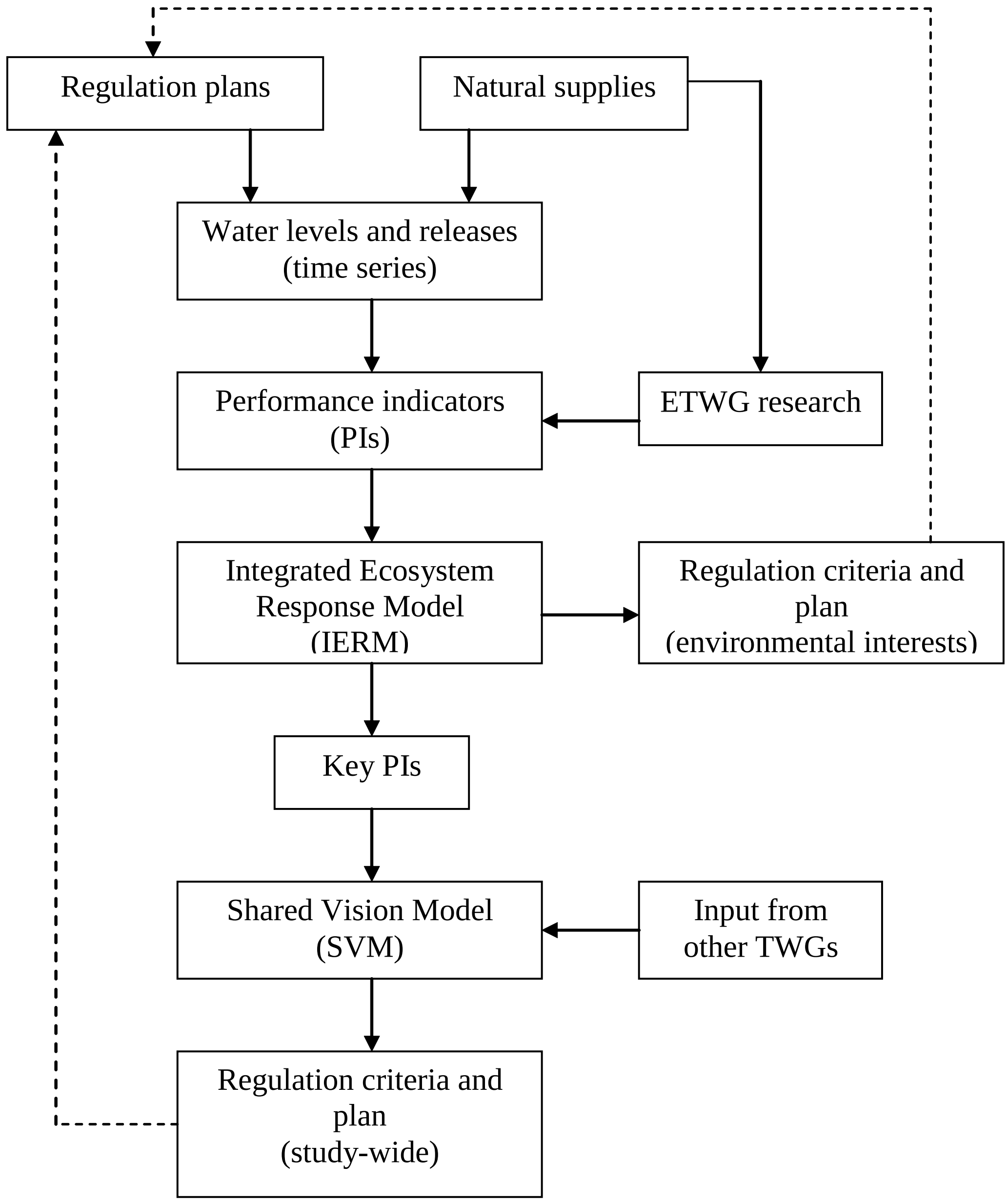


**Figure 1-1. Relationship between IERM, ETWG research, and overall study; the dashed arrows represent feedback loops for iteration to define desirable regulation plans.**

In the review of regulation plans for this system, the ETWG was charged with development of a suite of environmental **Performance Indicators** (PIs) that can be evaluated with respect to alternative regulation plans and compared on an appropriate basis with other interests being served by the plans (*i.e.*, hydropower, commercial navigation, recreational boating, flood control, and water supply). The ETWG has considered a wide variety of indicators of ecological change that may be sensitive to patterns of water level and flow changes that result from the imposition of alternative regulation plans on a range of potential natural hydrometeorological basin supply conditions. Of primary concern is the impact of these hydrologic and hydraulic conditions on the integrity of sensitive ecosystem components.

The first task of the ETWG in identifying and defining Performance Indicators that would best represent the system's ecological response to water levels and flows was to recognize that PIs might be categorized into one of six broad ecosystem groups: wetland vegetation, fish, birds, mammals, herptiles, and species-at-risk. Species-at-risk are those species that are especially threatened or endangered, whether identified in laws from one of the participating countries or not. Species-at-risk can belong to any of the other five groups. Once the biota comprising the environmental PIs were identified, members of the ETWG developed and undertook field research programs that would permit the development of predictive relationships for how those species or guilds of species would respond to patterns of water levels and flows in a part of the LOSL system under investigation.

The results of the various field research and data analysis programs are presented in a series of reports from each of the ETWG research teams. However, the Study Board and ETWG recognized the need for an integrating framework to permit all environmental PIs to be driven by the same set of forcing functions (water levels and flows, and their impact on habitat within the study domain) and to permit simultaneous evaluation of all environmental PIs so that conflicts might be identified and understood. This framework also had to have predictive capability to simulate the system response to alternative regulation plans applied to varied supply scenarios; and it had to have a useful result synthesis and visualization capability in order to compare and evaluate those alternate plans/scenarios being considered by the Study. The approach taken to obtain this integrative and quantitative assessment tool to evaluate the ecological impacts of alternative flow and water level regulation plans for the Lake Ontario-St. Lawrence River system was to develop and implement the Integrated Ecological Response Model (IERM). The current version of the IERM contains over 600 environmental Performance Indicators. Therefore, in order to facilitate interpretation of model results and comparison of alternative plans in a reasonable way, 32 PIs were identified as being "key PIs". The process for identifying these key PIs is presented below, as well as how they are used in the plan selection and prioritization process.

Given the role of ETWG and its integrated model in the overall study, the objectives for building the IERM framework can be summarized as follows:

1. Develop, in cooperation with ETWG researchers, predictive algorithms for all of the quantified relationships between time series of water levels and flows and selected ecological PIs. Integrate these algorithms into a single modeling framework such that they are all driven by the same forcing functions, and fauna respond to the same set of wetland habitat change simulations for each geographic region in the model.
2. Synthesize and extrapolate the research findings of the ETWG into this integrated framework so that it can be used to evaluate synergy and trade-offs

among the various ecosystem components of concern and thereby develop regulation criteria that provide the most benefit possible to the integrity of these sensitive ecosystem components. This includes developing appropriate aggregation and visualization tools for carrying out alternative plan evaluations.

3. Apply the IERM to assist ETWG in developing alternative regulation plan proposals that provide the most benefit to the ecosystem.
4. Transfer the IERM into the *Shared Vision Model* in a way that it serves as the environmental assessment sub-model of the SVM, and in a way that permits the environmental response to be compared and evaluated with other interests for use of the system.

Limno-Tech, Inc. was given the charge of conceptualizing and constructing the overall IERM; however, Jean Morin, Environment Canada, and his colleagues were responsible for developing the lower St. Lawrence River portion of the IERM. The lower river model was then integrated into the overall IERM (including all three geographic regions) by Limno-Tech, Inc.

## 1.3 SCOPE OF THIS DOCUMENT

This document presents a description of the development and site-specific application of the IERM. It also contains a discussion of the visualization and decision-support capabilities of the IERM. Section 2 presents the IERM theory and development, including the problem specification, conceptual model, model theory and construction, performance indicator development, and available information for model evaluation and confirmation. Section 3 presents an overview of plan formulation and evaluation, a description of the selection of key PIs, guidelines for using the IERM in plan results interpretation and comparative evaluation, and an example of the application of those guidelines to prioritization of existing candidate regulation plans with regard to environmental benefits and impacts. In addition, the appendices contain the short fact sheets developed for all key PIs in the IERM, an IERM User Manual, and some sample IERM output used in the example evaluation of existing candidate regulation plans.

# 2. IERM DEVELOPMENT

## 2.1 PROBLEM SPECIFICATION

Problem specification is the first, and in many ways the most important, step in the process of developing and applying a problem-specific model. The IERM is no exception. Problem specification guides the development of the conceptual model and essentially governs the model complexity (i.e., model complexity is determined by spatial, temporal, and process resolution). It must, therefore, include a clear and complete statement of policy, management, and/or scientific objectives, a specification of model spatial and temporal domain and resolution characteristics, and equally important, a statement of program constraints (e.g., legal, institutional, data, time and economics). The model that results from the problem specification must be consistent with the expectations of all stakeholders and must be consistent with the data that will be available to support the model. It can be just as inappropriate and misleading to build a model too complex for the available data as it is to build a model so simple that it falls short of answering the management questions being asked.

The IERM problem specification includes a statement for each of the three aspects of problem specification mentioned above:

- **Regulatory or research objectives** are statements of what questions a model is expected to answer. The statement of modeling objectives should include the state variables of concern, the stressors (model inputs) driving those state variables and their control options, appropriate time and space scales, model user acceptance, and, very importantly, the degree of accuracy and precision of the model.
- Specifying the **model domain characteristics** includes: identification of the environmental domain being modeled, specification of transport and transformation processes within that domain that are relevant to the policy/management/research objectives, specification of important time and space scales inherent in transport and transformation processes within that domain in comparison with the time and space scales of the problem objectives, and any peculiar conditions of the domain that will affect model selection or new model construction.
- Problem specification should include a discussion of the potential **programmatic constraints**. It must cover time and budget, available data or resources to acquire more data, legal, and institutional considerations; computer resource constraints; and experience and expertise of the modeling staff.

### 2.1.1 Model Assumptions

Specification of objectives, model domain characteristics, and programmatic constraints leads to several key model assumptions that affect the construction and complexity of the IERM. As presented in Section 1, the objective of the ETWG modeling effort was to develop a model that quantitatively relates the response of key environmental performance indicators (representing six groups of flora and fauna in the LOSL ecosystem) to a pattern of water levels and flows determined by applying alternative regulation plans (a set of rules for dam releases) to a series of representative net basin supply scenarios. The output of the model for a given plan-scenario would be compared to the simulation of the reference (existing) plan (1958DD) applied to the same supply scenario. In this way, the direction and magnitude of change of environmental PIs for the alternative plan relative to the baseline reference plan is the output of concern, rather than the absolute value of a PI for a given plan. Used in this way, the model can accept more uncertainty than it could if it were required to determine if a given target value was achieved for a given PI. Several alternative plans can then be compared by determining which one responds most favorably relative to the baseline reference plan.

No specific guidance was given on the selection of performance indicators other than that they should be responsive to alterations in water levels and flow in the system. The process of selection of PIs and the metrics used to measure them was therefore left to the ETWG. This was accomplished through an iterative process that alternated between the application of ecological theory and the assessment of available historical data and newly collected data for the LOSL system. The selection of PIs for the system and the reduction of the list of over 600 PIs down to a subset of 32 key PIs will be discussed in more detail below.

**An important technical constraint that was placed on the model (driven in part by a lack of time and resources, and in part by the guidance imposed on the overall study) was that the model was <u>not</u> to consider the response of various performance indicators to forcing functions other than water levels and flows and temperature.** Other recognized important stressors on the Lake Ontario-St. Lawrence River ecosystem, such as nutrient and sediment supplies from the watershed, toxic chemical exposure, land use changes, nuisance exotic species invasions, and, in the case of some species, stocking and harvesting practices, were assumed to be constant among the various plan-scenario conditions tested. This assumption limits somewhat our ability to conclude anything about the full ecosystem integrity or sustainability; however, it does not limit the comparison of important ecosystem responses to water levels and flows. Therefore, this assumption can be included without concern because the model was not to be designed to simulate absolute values of the various PIs but rather to simulate the relative responses to <u>only</u> hydrologic and hydraulic (H&H) conditions.

Another specification of importance for the model development was the stipulation that the modeling should be conducted using the existing flow control and water supply infrastructure on the system. No changes or re-design of the infrastructure of the Seaway was to be included in the analysis.

With regard to the model spatial domain and resolution, it was desired to have a model that covered Lake Ontario and the St. Lawrence River down to Trois-Rivières. Within that domain, three different geographic areas were identified as potentially having different ecosystem structure and functions and responding differently to regulation: Lake Ontario, the upper St. Lawrence River above the Moses Saunders Dam, and the lower St. Lawrence River below the dam. In defining and computing environmental PIs for the system, a different set of PIs is potentially included for each geographic region with potentially different H&H response relationships for PIs in each region. A related assumption is that these three model regions only interact in terms of having a consistent set of levels and flows. In other words, if water is held back to allow water level to increase in the lake and upper river, then there will be less water delivered to the lower river, causing levels in the lower river to tend to decrease. With regard to the ecological relationships, it was assumed that an ecological response in one of the three regions had no impact on an ecological response in the other two. Details of the model that resulted from this domain specification are provided below.

Another programmatic constraint is that the model must compute the PI responses to H&H conditions over the course of a 101-year hydrograph that has been determined by applying a given regulation plan option to a given 101-year supply scenario. In doing so we must recognize that there are both long and short time scales to be considered: *long*, inter-annual scales of responses to changes in habitat that result from the hydrograph input (e.g., changes in the available area of meadow marsh wetland habitat in response to annual flooding and drying cycles during the growing season), and *short*, intra-annual responses to changes in water levels during a critical season in the life cycle of a given species (e.g., rapid increases in water levels during wetland bird nesting can reduce nesting success). Most PIs are responsive to both the quarter-monthly changes in water levels and the longer-term changes in suitable habitat that also result from water levels fluctuations. Again, these detailed relationships for each environmental PI are presented in more detail below.

The primary programmatic constraints leading to the assumptions described above are related to the time and resources available to design and implement the IERM. Although this was a five-year study, the LTI project and the decision to build the IERM for synthesis and integration of the ETWG studies were not initiated until the second year of the study. By that time, the general groups of PIs and the field studies associated with those PIs had already been determined. Therefore, the IERM was constrained in terms of available data and PI relationships that could be included in the model, and in terms of the time available for IERM development. An environmental response model had to be constructed within a three-year time frame so that it could be incorporated into the SVM and could thus be used in final form for the decision process taking place during the final year of the five-year study.

### 2.1.2 Model Implementation Criteria

Including and in addition to the various model design criteria and constraints discussed above, the following model implementation attributes were specified with regard to the IERM construction and application:

- IERM will contain an appropriate blend of process and empirical cause-effect relationships, depending on the availability of process data and ecological theory understanding for a given PI.
- IERM will be a time-variable model and will compute dependent variables (model output) as a function of time.
- IERM will operate at appropriate time scales. It should be able to function at a range of temporal scales that respect the inherent response scales of the system and its components, as well as those of the management questions. The model will then also have the capability to aggregate (average or accumulate) model output to larger time scales (*e.g.,* 101-year average) if needed.
- IERM will operate at space scales appropriate to the questions being asked and the available data. It will compute each dependent variable at a space scale that is relevant to that performance indicator. The model will then also have the capability to aggregate (average or accumulate) model output to larger space scales (*e.g.,* whole lake, whole system) if needed.
- IERM will be constructed in a modular framework to permit easy upgrade or revision based on revisions made in sub-models by any of the ETWG researchers or in response to new information or data that may result from adaptive management of this system or improved understanding of ecological relationships.
- Measures of performance indicators (model output variables) in IERM will meet the criteria set forth by ETWG relative to the system response and sensitivity to water level and flow fluctuations and also be consistent with the needs and desires of other study participants, including PFEG members, Study Board, and PIAG members.
- The IERM assumes all exogenous forcing conditions (*e.g.,* nutrient loads, land use patterns, aquatic nuisance species, etc.) will remain constant at historical forcing conditions and performance responses will only be evaluated relative to the H&H conditions determined by alternative regulation plans in comparison to those for the baseline reference condition. The reference condition is the current regulation plan (1958D with deviations) applied to a given net basin supply scenario.
- IERM should utilize input data/sub-models developed by ETWG and other Study Board TWGs.
- IERM will have a user-friendly interface for data input and an easy-to-understand output visualization component to facilitate interpretation and decision support.

- IERM will be constructed in such a way to permit sensitivity, diagnostic and threshold analyses as desired. The model will also allow scenario and hypothesis testing that might be conceived by other participants in this study, including the Study Board and PIAG.IERM will serve as the framework for development of algorithms and PI impact evaluation functions that will be used by PFEG in its SVM. IERM PI results in the SVM must be relevant to all stakeholders and must be comparable on an appropriate basis with other user interests.

## 2.2 CONCEPTUAL MODEL

The ETWG conducted more than 20 research studies for the purpose of quantifying the linkage between various ecosystem components and water levels / flows in the Lake Ontario – St. Lawrence River system. Given the large volume of information and data generated by these studies, it was critically important that a conceptual model be developed to reflect and illustrate interrelationships between the key ecosystem components. The conceptual model was developed in an iterative fashion, with ETWG members providing feedback based on conceptual model diagrams presented at meetings and provided via e-mail. Ultimately, the conceptual model was used to identify and understand the linkage between the ecological *performance indicators* that were developed based on the ETWG studies. This section provides a discussion of the conceptual model development process, and how this process was used to facilitate the development of sub-models and performance indicators that were eventually coded into the IERM modeling framework.

### 2.2.1 Flow of Information/Diagrams

The conceptual model development effort was used to identify major ecological components to be included in the IERM framework, and to establish the important linkages between those components. Conceptual model diagrams were developed in an iterative fashion over a period of more than a year. Prototype conceptual models were initially developed by LTI and presented to ETWG members in Year 2 of the Study (fall 2003). As specific information about the various ETWG studies began to emerge in Year 3, the conceptual model development effort began in earnest. Detailed diagrams were developed to describe the major ecosystem components and the hypothesized linkages of those components to hydrologic/hydraulic forcings (i.e., flows and water levels) and habitat quantity and quality. Through exchanges with the ETWG researchers, the feed-forward relationship between wetland habitat abundance/diversity and faunal response was identified as a fundamental linkage. A flow chart illustrating the generalized linkages between faunal responses, wetland habitat, and hydrologic/hydraulic forcings is provided in Figure 2-1.

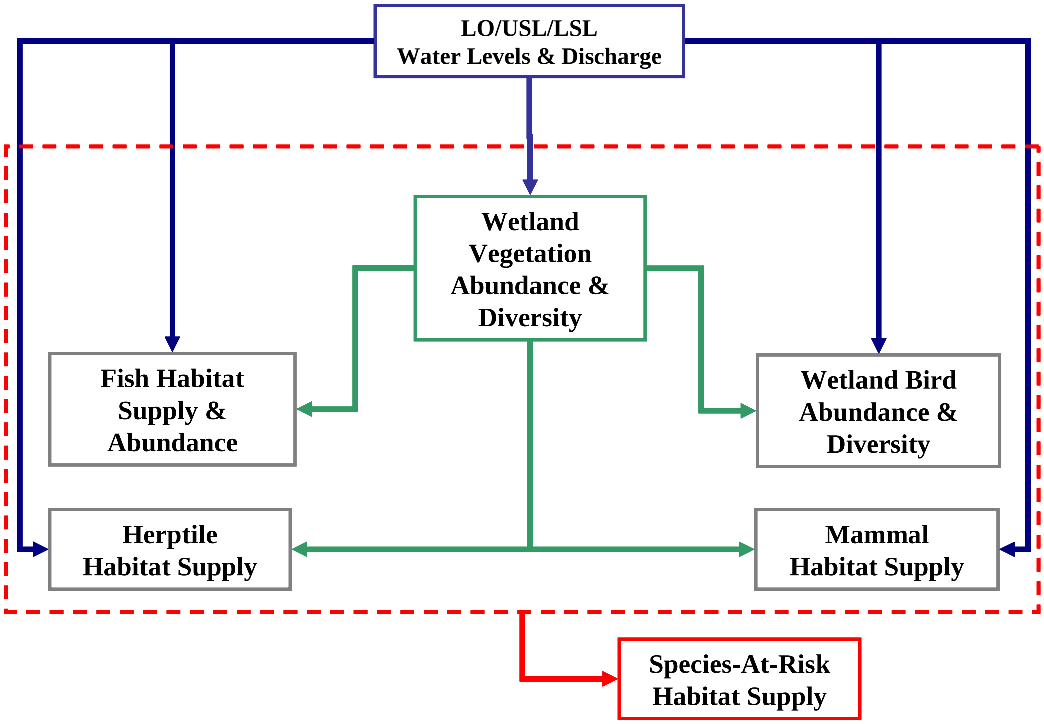


**Figure 2-1. LOSL Ecosystem Conceptual Model**

The diagram in Figure 2-1 illustrates that the wetland vegetation abundance/diversity component was considered to be important to each of the five faunal component groups, including fish habitat supply and abundance, wetland bird abundance and diversity, herptile habitat supply, mammal habitat supply, and species-at-risk habitat supply. It should be noted that the species-at-risk component consists of a subset of the other 5 components, which is why all of these groups contribute to the species-at-risk box in the diagram.

The conceptual model was continually enhanced and refined as ETWG field studies were concluded in Year 3 and data analyses and interpretation were conducted in Year 4. During this refinement process, it became evident that the conceptual and numerical models developed for the lower St. Lawrence River would be unique from the Lake Ontario and the upper St. Lawrence River models. In general, ETWG researchers studying elements of the lower river ecosystem were able to take advantage of fine-scale physical data that was not available for a majority of the LOSL system above the Moses Saunders dam. The availability of fine-scale physical data (e.g., digital elevation models) also provided the potential for a fine-scale, two-dimensional model approach. In addition to differences in spatial scale between the LO/USL and LSL systems, some ecosystem components and processes that were emphasized in one portion of the system were not given equal emphasis in the other portion of the system. Despite the differences between the LO/USL and LSL regions, the linkages between wetland habitat and faunal responses are a key feature in both systems.

In addition to identifying ecosystem linkages that could be supported based on ETWG studies and associated data analyses, the conceptual model proved useful in terms of identifying the limitations of the modeling framework. It was recognized early in the conceptual model development process that it would not be feasible to represent the influence of all important system stressors on the ecosystem components of interest. Examples of system stressors that were not directly considered in the ecological studies include water quality (e.g., nutrients, toxics), sediment quality, land development, and invasive species. Given the relatively short amount of time available to conduct the environmental studies, it was necessary for ETWG researchers to focus their studies on isolated ecosystem responses to system hydrologic/hydraulic attributes. While the ETWG studies did provide a great deal of information to support linkages to hydraulic attributes and associated habitat responses, the scope and time scale of these studies was not sufficient for quantifying the impact of stressors that impact the ecosystem over the course of longer time periods (e.g., decadal). A more detailed discussion of the sub-model algorithms and associated assumptions is provided in Section 2.3.

### 2.2.2 Performance Indicators & Metrics

The conceptual model described in the previous section was used to guide the development of ecological *performance indicators*. As described in Section 1.2, performance indicators were defined within the Study as measures that describe the impacts resulting from a particular level/flow or series of levels/flows in the LOSL system. The concept of performance indicators was applied across the LOSL Study to describe environmental, economic, social, and cultural impacts. Examples of economic indicators developed for the study include flooding damage costs, shore protection maintenance costs, shipping costs, and hydropower revenue. The following section provides an overview of the ecological performance indicators, and the “ratio” approach implemented within the IERM/SVM to evaluate the response of these indicators to regulation plans.

*Performance Indicator Metrics*

A complete set of ecological performance indicators was developed to represent habitat supply and/or population response in each of the 3 regions (LO, USL, LSL) for 6 indicator groups: wetland vegetation, fish species/guilds, wetland birds, herptiles (amphibians and reptiles), mammals, and species-at-risk. A specific metric (and associated units) was identified for each PI. The PI metric provides a means for measuring/computing the annual PI response. For example, fish habitat supply PIs were calculated as weighted suitable habitat area in hectares. The algorithms/metrics developed for each performance indicator were applied within the IERM to generate a time series of predicted annual scores for each regulation plan based on hydraulic outputs provided by the SVM.

A complete listing of performance indicators and associated metrics for Lake Ontario and the upper St. Lawrence River is provided in Table 2-1, and an equivalent listing for the lower St. Lawrence River is provided in Table 2-2. A detailed discussion of the methodologies associated with the development of the PIs and the supporting sub-models is provided in Section 2.3.1.

*Performance Indicator Ratio Approach*

Given the large number of potential ecological performance indicators, it was important to adopt an approach that could be used to effectively compare the responses of many indicators to alternative regulation plans. A performance indicator "ratio" approach was developed collaboratively by LTI and ETWG to provide a means for rapidly evaluating plan responses. In this approach, a performance indicator ratio (*PIRatio*) is typically computed by:

$$PIRatio = \frac{PIAggScore_{Alt}}{PIAggScore_{Base}} \tag{2-1}$$

where $AggScore_{Alt}$ and $AggScore_{Base}$ are aggregate scores calculated for the alternative regulation plan and the baseline regulation plan, respectively. Plan 1958DD, the existing regulation plan, would typically be treated as the baseline plan in the ratio approach; however, this approach provides flexibility in comparing PI responses for any two regulation plans of interest. For example, the "pre-project" regulation plan could be used as the baseline to evaluate the impact of alternative regulation plans relative to the natural flow regime.

The approach used to compute the aggregate scores shown in Equation 2-1 was determined by the ETWG researchers based on an indicator-specific evaluation. In general, the aggregate score (*PIAggScore*) for a particular PI was defined as some function of the time series output array (*[PISeries]*) generated by the PI algorithm for a given regulation plan:

$$PIAggScore = f([PISeries]) \tag{2-2}$$

A variety of different aggregation functions were built into the IERM framework, including average of annual PI scores, and percentage of annual PI scores exceeding the first quartile PI score for plan 1958DD. In the initial version of the IERM (v1.0) released to ETWG in June 2004, the average of the PI output time series was used as the default aggregation approach for all PIs. The aggregation approach used for each PI was adjusted based on feedback received from the individual ETWG researchers following evaluation of IERM results.

An alternative method for computing the PI ratio was suggested by the LO/USL fish subgroup led by Ken Minns and Sue Doka. Instead of computing a ratio based on a PI aggregate score, this method computes an array of annual ratios (*PIAnnRatios*) as:

$$PIAnnRatios(i) = \frac{PISeries_{Alt}(i)}{PISeries_{Base}(i)} \tag{2-3}$$

where $PISeries_{Alt}(i)$ and $PISeries_{Base}(i)$ are the time series output for the baseline and alternative regulation plans for year *i*. Based on this approach, the final PI ratio (*PIRatio*) is computed by taking the average of the annual ratios:

$$PIRatio = \frac{\sum_{i=1}^{N} PIAnnRatios(i)}{N} \qquad (2\text{-}4)$$

where *PIAnnRatios(i)* is the annual ratio computed for year *i*, and *N* is the total number of years in the time series. The potential value in applying the average of annual ratios approach is that, in some cases, it might preserve major differences in the PI response between plans for individual years more effectively than the ratio of the annual average PI scores.

After a series of ETWG plan evaluation exercises spanning 6 months (June 2004 – January 2005), only three different ratio/aggregation approaches were ultimately selected for use with the performance indicators:

- Ratio (alternative/baseline) of annual (101-year) average PI scores;
- Average of annual ratios (alternative/baseline) based on PI scores; and
- Percentage of PI scores for an alternative plan that exceed the first quartile (Q1) score derived from the PI scores for plan 1958DD.

A summary of the ratio/aggregation approach selected for each set of PIs is provided in Tables 2-1 and 2-2.

## Table 2-1. Ecological Performance Indicators for the Lake Ontario / Upper St. Lawrence

| PI Category | Location | PI Description(s)[1] | PI Metric | PI Ratio Approach | ETWG Researcher(s) |
|---|---|---|---|---|---|
| **Wetland Plant Abundance & Diversity** | Lake Ontario, Upper SL River (R1) | Meadow marsh and "non-cattail" surface area in Lake Ontario and the Thousand Islands area for: 1) full 101-year period, and 2) low-supply periods only. | Surface area (hectares) | Ratio of average annual PI score | Doug Wilcox<br>Joel Ingram |
| **Fish Habitat Supply & Abundance** | Lake Ontario, Upper SLR (R1, R2, R3) | Habitat weighted suitable area (hectares) for 8 fish guilds covering a range of thermal (10, 14, 18, 24°C) and vegetation (low/high) preference. | Habitat supply (hectares) | Average of annual ratios | Ken Minns<br>Sue Doka |
| | | Habitat weighted suitable area (hectares) for 6 species: northern pike, smallmouth bass, largemouth bass, yellow perch, *pugnose shiner*, and *bridle shiner*. | Habitat supply (hectares) | Average of annual ratios | |
| | | Species population density indices for multiple life stages (spawn, fry, young-of-year, juvenile, adult) for 4 species: northern pike, smallmouth bass, largemouth bass, and yellow perch. | Population density (index) | Average of annual ratios | |
| | Upper SL River (R1) | Northern pike egg production and young-of-year production in Thousand Islands area | Productivity (# eggs) (grams – wet weight) | Ratio of annual avg. PI score | John Farrell<br>Jerry Mead |
| **Wetland Bird Abundance & Diversity** | Lake Ontario | Obligate marsh species richness | Richness (# species) | Percent scores exceeding first quartile score for plan 1958DD | Joel Ingram<br>Bruno Drolet<br>J.-L. Des Granges |
| | Lake Ontario, Upper SL River (R3) | Wetland bird reproductive index for 7 species in Lake Ontario (song sparrow, veery, American bittern, marsh wren, common moorhen, *least bittern*, *black tern*, and Virginia rail) and 1 species in Lake St. Lawrence (Virginia rail) | Reproductive Index | | |
| **Herptile Habitat Supply** | Lake Ontario, Upper SL River (R1) | Habitat suitability indices (0-1 scale) for 6 species: Midland painted turtle, snapping turtle, *Blanding's turtle*, green frog, leopard frog, and American toad. | Probability of occurrence (index) | Ratio of average annual PI score | James Gibbs<br>Heather Jensen |
| **Muskrat Abundance** | Upper SL River (R1) | Muskrat house density | Density (#/ha) | Ratio of average annual PI score | John Farrell<br>Jason Toner |
| **Species-at-Risk (Vegetation)** | Lake Ontario | Suitable habitat area for *Carex atherodes* (awned sedge) | Surface area (hectares) | Ratio of average annual PI score | Jana Lantry<br>Al Schiavone |

| PI Category | Location | PI Description(s)[1] | PI Metric | PI Ratio Approach | ETWG Researcher(s) |
|---|---|---|---|---|---|
| **Species-at-Risk (Fish)** | Lake Ontario Upper SL River (R1, R2, R3) | Habitat weighted suitable area for 2 species: *pugnose shiner*, *bridle shiner* (spawning, young-of-year, and adult life stages). [Note crossover with fish subgroup.] | Habitat supply (hectares) | Average of annual ratios | Jana Lantry<br>Al Schiavone<br>Sue Doka |
| **Species-at-Risk (Wetland Birds)** | | Habitat weighted suitable area for 5 species: *least bittern*, *black tern*, *king rail*, *yellow rail*, and *pied-billed grebe*. [Note crossover with bird subgroup.] | Habitat supply (hectares) | Average of annual ratios | Jana Lantry<br>Al Schiavone |
| **Species-at-Risk (Herptiles)** | Lake Ontario | Habitat weighted suitable area for 1 species: *Blanding's turtle*. [Note crossover with herptile subgroup.] | Habitat supply (hectares) | Average of annual ratios | Jana Lantry<br>Al Schiavone |
| | | Nesting success for *spiny softshell turtle* based on water level fluctuations in June-July. | Nesting success (%) | Average of annual ratios | Jana Lantry<br>Al Schiavone |

[1]Note: species-at-risk are highlighted in italics.

## Table 2-2. Ecological Performance Indicators for the Lower St. Lawrence River

| PI Category | Location | PI Description(s)[1] | PI Metric | PI Ratio Approach | ETWG Researcher(s) |
|---|---|---|---|---|---|
| **Wetland Habitat Quantity & Quality[3]** | Lake St. Pierre | Surface area (or percent cover) of wetland vegetation classes, including total wetland, emergent marsh, high marsh, and open marsh | Surface area ($km^2$, % cover) | Percent scores exceeding first quartile score for plan 1958DD. | Christiane Hudon |
| | | Submerged aquatic vegetation (SAV) biomass | Biomass (metric tons) | | |
| | | Progression rate for *Phragmites australis* (invasive species) | Progression Rate (m/yr) | | |
| **Wetland Habitat Quantity[2]** | Lake St. Louis - Trois-Rivières | Surface area of wetland emergent plant classes, including: treed swamp, shrubby swamp, prairie meadow, shallow marsh, deep marsh, open water, and invasive prairie meadow, and total wetland area. | Surface area (hectares) | Percent scores exceeding first quartile score for plan 1958DD. | Jean Morin<br>Katrine Turgeon |
| | | Surface area of submerged aquatic vegetation species, including: Vallisneria, Water Star Grass, Eurasian watermilfoil, Richardson's pondweed, and narrowleaf water-plantain. | Surface area (hectares) | | |
| | | Submerged aquatic vegetation (SAV) density index | Index | | |
| **Fish Habitat Supply[2]** | Lake St. Louis - Trois-Rivières | Fish feeding habitat supply for several species, including: pumpkinseed, northern pike, lake sturgeon, golden shiner, brown bullhead, largemouth bass, sauger, yellow perch, walleye, and shiner. | Habitat supply (hectares) | Percent scores exceeding first quartile score for plan 1958DD. | Marc Mingelbier<br>Jean Morin |
| | | Fish reproduction habitat supply for northern pike and yellow perch. | Habitat supply (hectares) | | |
| **Fish Abundance & Migration[3]** | Lower St. Lawrence River | Fish abundance indices for several species, including: rock bass, channel catfish, mooneye, yellow perch, sauger, shallow water species, and wetland species. | Index | Percent scores exceeding first quartile score for plan 1958DD. | Yves de Lafontaine |
| | | Median date for American eel migration to Atlantic Ocean. | Migration date (Julian day) | | |
| | Boucherville Islands | Northern pike year-class strength index (YCSI) | Index | | Alain Armellin |
| | | | | | |

| PI Category | Location | PI Description(s)[1] | PI Metric | PI Ratio Approach | ETWG Researcher(s) |
|---|---|---|---|---|---|
| **Wetland Bird Abundance & Diversity**[2] | Lake St. Louis - Trois-Rivières | Obligate marsh species richness | Richness (# species) | Percent scores exceeding first quartile score for plan 1958DD. | J.-L. Des Granges<br>Bruno Drolet<br>Joel Ingram<br>Jean Morin |
| | | Wetland bird reproductive index for 7 species in Lake Ontario: song sparrow, veery, American bittern, marsh wren, common moorhen, *least bittern*, black tern, and Virginia rail. | Reproductive index | | |
| **Wildfowl Habitat Supply & Abundance**[2] | Lake St. Louis - Trois-Rivières | Migratory wildfowl floodplain habitat availability. | Habitat supply (hectares) | Percent scores exceeding first quartile score for plan 1958DD. | Denis Lehoux<br>Jean Morin |
| | | Migratory wildfowl productivity. | Productivity (# juveniles) | | |
| | | Migratory wildfowl nesting success. | Nest success (# nests) | | |
| **Herptile Habitat Supply**[2] | Lake St. Louis - Trois-Rivières | Reproductive habitat availability for frog, toad, and turtle species. | Habitat supply (hectares) | Percent scores exceeding first quartile score for plan 1958DD. | Alain Armellin<br>Jean Morin |
| **Muskrat Abundance**[2] | Lake St. Louis - Trois-Rivières | Total number of surviving muskrat houses at the end of the winter season. | Abundance (# houses) | Percent scores exceeding first quartile score for plan 1958DD. | Jean Morin<br>Valerie Ouellet |
| **Species-at-Risk (Fish)** [2] | Lake St. Louis - Trois-Rivières | Reproduction habitat availability for 3 species-at-risk: *channel darter*, *Easter sand darter*, and *bridle shiner*. | Habitat supply (hectares) | Percent scores exceeding first quartile score for plan 1958DD. | Sylvain Giguere<br>Jean Morin |
| **Species-at-Risk (Wetland Birds)** [2] | | Reproduction habitat availability for *yellow rail*. | Habitat supply (hectares) | | |
| | | Reproductive index for *least bittern* (see "Wetland Bird Abundance & Diversity" description). | Reproductive index | | |
| **Species-at-Risk (Herptiles)** [2] | | Reproduction habitat availability for *spiny softshell turtle* and *Northern map turtle* (combined indicator). | Habitat supply (hectares) | | |

[1] Note: species-at-risk are highlighted in italics.
[2] Performance indicators are based on two-dimensional modeling approach.
[3] Performance indicators are based on one-dimensional, statistical approach.

## 2.3 MODEL DESCRIPTION

The IERM was developed as a joint effort between LTI and ETWG members. The IERM framework, including the design and integration of the source code and supporting databases, was developed by LTI staff. Performance indicator algorithms and supporting documentation were provided by ETWG researchers to LTI for inclusion in the IERM. The following sections provide summaries of the various ecological sub-models developed by ETWG for the LOSL system as well as a discussion of the IERM framework design and implementation.

### 2.3.1 Sub-Models – Theory/Algorithms/Data

The IERM was constructed based on a collection of ecological sub-model algorithms developed by ETWG members based on their respective studies. The following sub-sections provide an overview of each sub-model, including:

- Background on data and theory used to develop the sub-models;
- An overview of the key sub-model algorithms;
- A brief description of how the sub-models were integrated into the IERM framework; and
- A summary of the performance indicators that were developed based on the applied sub-models.

Complete treatments of ETWG sub-models and associated theory can be found in technical reports developed by the individual researchers, which are referenced in appropriate locations throughout this section. Additional detail on specific performance indicators can be found in the PI fact sheets provided in Appendix A.

#### *2.3.1.a Lake Ontario / Upper St. Lawrence River*

A series of ecological sub-models were developed for the portion of the LOSL system above the Moses Saunders Dam, including Lake Ontario and the upper St. Lawrence River. For a variety of reasons, nearly all of the ETWG studies and associated data collection above the Moses Saunders Dam focused on Lake Ontario and the Thousands Islands region (IJC Shoreline Unit R1). However, performance indicator algorithms were developed to represent fish and wetland bird response in the upper St. Lawrence River below the Thousand Islands area (IJC Shoreline Units R2-R3) based on limited existing data. This section provides a summary of each sub-model developed for Lake Ontario and the upper St. Lawrence River.

*Wetland Sub-Model*

Wetland plant species composition and bathymetry/topography data were collected by Doug Wilcox, Joel Ingram, and their respective teams at 32 wetland sites along the shoreline of Lake Ontario and the upper St. Lawrence River (Thousand Islands area).

Selected study sites were evenly distributed among the four geomorphic wetland types found in this region:

- Barrier beach,
- Drowned river mouth,
- Open embayment, and
- Protected embayment.

The wetland plant and bathymetry/topography data collected were used to support the development of a wetland sub-model that predicts annual plant community distributions for each of the four geomorphic types based on water level history. The following paragraphs explain how the data were used to build the wetland plant model, and how the model results were used to: 1) develop performance indicators for wetland vegetation, and 2) produce predictive habitat information that could be applied within the faunal sub-models developed for Lake Ontario and the upper St. Lawrence River.

Information regarding the total surface area of each geomorphic wetland type was compiled for all wetlands in Lake Ontario and the Thousand Islands area. Detailed bathymetry/topography data is not available for a large majority of these wetland sites; however, the selected wetland study sites represent 12-26% of the total wetland inventory area for each geomorphic type. Bathymetry/topography data collected for the 32 study sites were used to develop “typical” wetland geometry for each of the four geomorphic types. Because the configuration for a given wetland geomorphic type is generally consistent from site to site, the use of a typical/average geometry was considered adequate for representing wetlands occurring across the Lake Ontario and Thousand Islands shoreline area. The typical profiles developed for the four geomorphic types are shown in Figure 2-2. It should be noted that only the 73.00-75.75 meter range was included in the analysis because bathymetry/topography data were not available below 73.00 meters, and wetland area existing above 75.75 is considered to be permanent upland area (i.e., flooding never occurs above this elevation).

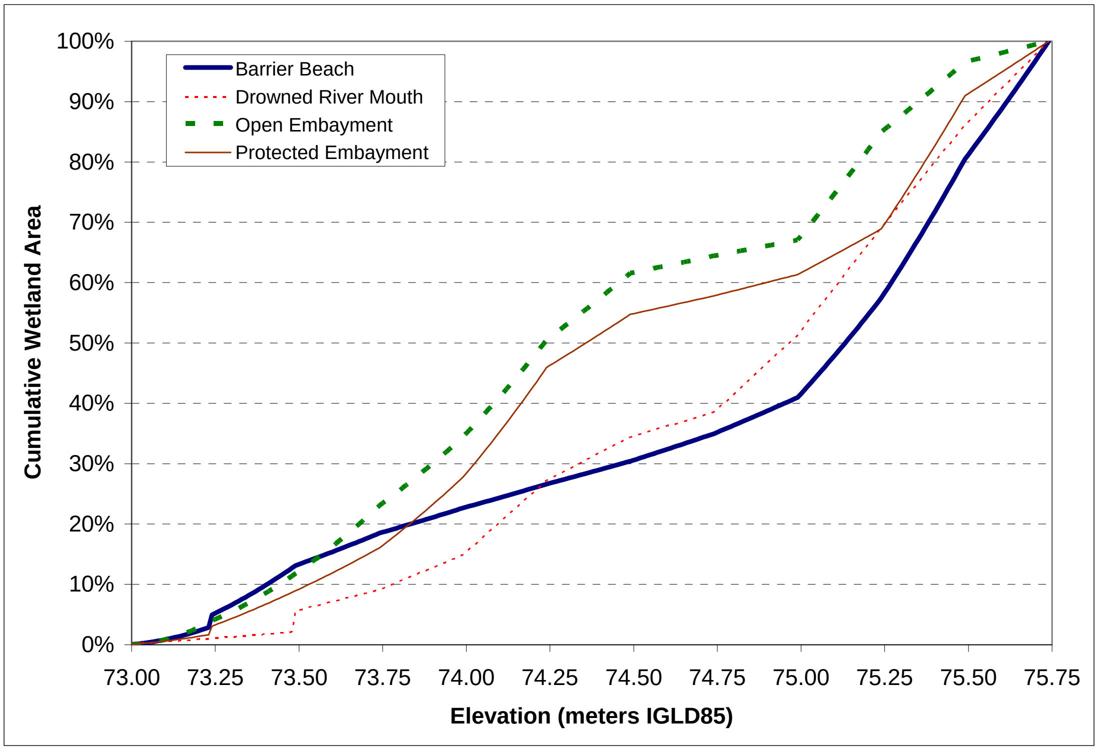


**Figure 2-2. Typical Wetland Geometry Profiles**

Plant quadrat sampling was conducted along 7 transects for each of the 32 wetland study sites. Each of the selected transects represent a unique hydroperiod condition, including elevations that have not been flooded in decades, elevations that have been flooded and/or dewatered in recent years, and elevations that have not been dewatered in decades. Plant species composition data collected at the 7 transects were analyzed across the 8 study sites for each wetland geomorphic type using an ordination technique, which provided a means for evaluating similarities in species richness and diversity among the various samples. Based on this evaluation, five unique plant communities were identified for the four geomorphic wetland types:

- Upland transition community ("U") – last flooded > 30 years ago;
- Meadow marsh community ("ABC") – last flooded 5-30 years ago;
- Emergent marsh community #1 ("D") – last flooded < 5 years and/or last dewatered < 4 years ago;
- Emergent marsh community #2 ("EF") – last dewatered 4-39 years ago; and
- Submerged/floating leaf community ("G") – last dewatered > 39 years ago

In addition, the plant species composing these five plant communities were assigned to 15 wetland plant structural categories. These structural categories and their relative percent cover (averaged across geomorphic type) within each of the plant communities described above are shown in Table 2-3. It should be noted that a column for the upland community ("U") is not included in the table because this community is associated with the plant community occurring above the first sampled transect ("A").

**Table 2-3. Structural Type Distribution by Wetland Plant Community**

| Wetland Plant Structural Category | ABC[1] | D[1] | EF[1] | G[1] |
|---|---|---|---|---|
| Tree Overstory | **30%** | 0% | 0% | 0% |
| Shrubs/Saplings/Seedlings | **20%** | 4% | 0% | 0% |
| Ferns | 5% | 1% | 0% | 0% |
| Forbs | **24%** | 6% | 1% | 0% |
| Grasses | **14%** | **11%** | 7% | 1% |
| Sedges | 7% | 3% | 1% | 0% |
| Thin-Stem Emergent | 1% | 3% | 3% | 1% |
| Broad-Leaf Emergent | 0% | 2% | 2% | 2% |
| Thin-Stem Persistent Emergent | 1% | **41%** | **42%** | 2% |
| Submerged Broad-Leaf | 0% | 0% | 0% | 1% |
| Submerged Narrow-Leaf | 0% | 0% | 3% | **37%** |
| Floating Leaf | 0% | 7% | **21%** | **14%** |
| Algae | 0% | 0% | 2% | **13%** |
| Vines | 4% | 1% | 1% | 0% |
| Moss | 0% | 0% | 0% | 0% |

[1]Percent cover values >10% are shown in bold font.

The percent cover values in Table 2-3 indicate that the meadow marsh ("ABC") community is characterized by a high degree of plant diversity, is dominated by short emergent vegetation (grasses, forbs, sedges, etc.), and includes some shrub and tree overstory. In contrast, the emergent marsh communities ("D", "EF") are dominated by thin-stem persistent emergent vegetation (mainly cattail) and do not support the same level of diversity supported by the meadow marsh community. Finally, the "G" community is dominated by submerged vegetation, floating leaf vegetation, and algae. The use of structural plant categories in addition to the more generalized plant communities provided multiple options for linking the wetland plant sub-model predictions to the habitat-based faunal sub-models. Each faunal sub-model section provided below includes a detailed description of how this habitat linkage was accomplished.

The wetland vegetation sub-model calculates the annual percent coverage of each wetland plant community (ABC, D, EF, and G) within each of the four geomorphic wetland types (barrier beach, drowned river mouth, open embayment, and protected embayment) based on the following steps:

1. Calculate and track the flooding and dewatering elevations for each simulation year;
2. Assign an elevation range to each of the 5 wetland plant communities based on the flooding/dewatering history calculated in step #1; and
3. Calculate the percent cover for each plant community (U, ABC, D, EF, G) based on 1) the elevation ranges determined in step #2, and 2) the

"typical" wetland geometries representing the four geomorphic wetland types.

In step #1, the flooding elevation is calculated as the minimum water level occurring within the 4 quarter-month period surrounding the peak annual Lake Ontario water level. The dewatering elevation is calculated as the maximum water level occurring during the growing season (April-October) for a given year. The "typical" wetland geometry and the wetland sub-model algorithm were originally developed within the ArcGIS/ArcView framework by associates of Doug Wilcox at Eastern Michigan University. LTI integrated the wetland sub-model into the IERM by 1) constructing a wetland database to house key input/output data, including wetland geometry and plant community information; and 2) re-coding the wetland sub-model into Visual Basic modules within the IERM framework. In order to match the GIS representation of the wetland geometry as closely as possible, each "typical" wetland was discretized into 275 elevation segments representing 1-cm increments between 73.00 and 75.75 meters.

The wetland vegetation performance indicators of interest were identified as the area-weighted average percent coverage of the meadow marsh (ABC) and "non-cattail" (U, ABC, and G) communities across the wetland geomorphic types. These PIs were implemented in two different ways across the 101-year simulation period:

1) Meadow marsh and non-cattail coverage calculated for each year in the 101-year period, and

2) Meadow marsh and non-cattail coverage calculated for low-supply periods within the full 101-year period.

For the supply-based approach, the start of a "low supply" period was defined as the year following a year where the January-June average net total supply to Lake Ontario is less than 6,792 $m^3/s$. A "low supply" period ends when the same average net total supply exceeds 7,917 $m^3/s$. For both approaches, the PI ratios were calculated as the ratio (alternative/baseline) of the annual (101-year) average meadow marsh or non-cattail percent cover for years where results were available.

Complete documentation for the Lake Ontario wetland plant sub-model and supporting data collection and analyses can be found in Wilcox, *et al*. (2005).

*Fish Guild & Species Sub-Models*

The ETWG fish subgroup, led by Ken Minns and Sue Doka, developed a series of habitat supply and population models to evaluate fish response to water level regulation in Lake Ontario and the upper St. Lawrence River. Habitat supply models were developed for 8 fish guilds representing a range of thermal (10, 14, 18, 24°C) and vegetation (high/low) preferences. An equivalent set of habitat supply models was developed for 4 species (northern pike, smallmouth bass, largemouth bass, and yellow perch) and 2 species-at-risk (pugnose shiner, bridle shiner). In addition, population models were developed to predict relative population response for northern pike, smallmouth bass, largemouth bass, and yellow perch.

Each of the habitat supply models predicts daily weighted suitable habitat area for 5 life stages: spawning, fry, young-of-year, juvenile, and adult. The weighted suitable area calculations are based on complex algorithms that determine local habitat suitability based on water levels and a range of factors, including:

- Daily water temperature (adjusted for nearshore locations);
- Site-specific hypsographic profiles for nearshore and wetland areas;
- Substrate type;
- Depth-based predictions of submerged aquatic vegetation (SAV) cover; and
- Predictions of emergent vegetation cover generated by the wetland plant sub-model.

Daily estimates of habitat supply were summed across each calendar year to obtain total annual habitat supplies in units of hectare-days. The 4 species population models predict annual young-of-year, juvenile, and adult population densities based on calculations of daily growth and survival for each of the 5 life stages. The population models require several inputs, including:

- Daily weighted suitable area estimates (as generated by the habitat supply models);
- Daily water temperature (adjusted for nearshore locations);
- Species-specific bioenergetic and mortality rates; and
- Probability of stranding based on water level fluctuations.

The guild and species habitat supply models were applied for representative sub-regions in Lake Ontario and the upper St. Lawrence, including IJC Shoreline Units R1, R2, and R3. For Lake Ontario, 6 sub-regions were represented in the model: Bay of Quinte, Presquile, North Central Shore, West Shore, South Central Shore, and the Outlet Basin. For the upper St. Lawrence, 3 sub-regions were represented: Lake Ontario to below Ogdensburg, below Ogdensburg to Iroquois, and Iroquois to Cornwall (Lake St. Lawrence). The species population models were applied to simulate local population trends within each of the LO/USL sub-regions listed above. The pugnose shiner and bridle shiner habitat supply models were applied only for local areas where these species have been observed, including Sodus Bay and portions of the eastern Lake Ontario shoreline and outlet basin.

The fish habitat supply and population sub-models were provided to LTI in the form of Visual Basic code and supporting databases. These models were integrated into the overall IERM framework by LTI staff. The collection of guild and species models produced a large number of potential performance indicators, including annual weighted suitable habitat area for the 5 life stages, and annual density/biomass for the young-of-year, juvenile, and adult life stages for each sub-region. Ultimately, the raw performance indicators were distilled into a subset of indicators by aggregating results across the various lake and river sub-regions and focusing on the most sensitive life stages. The PI ratios for all of the fish habitat supply and population indicators were calculated as the average of annual ratios (alternative/baseline). Complete documentation for the fish habitat supply and population models can be found in Minns, *et al*. (2005).

*Northern Pike Sub-Model*

In addition to the species habitat and population models developed by Minns and Doka, a northern pike population model was developed by John Farrell and Jerry Mead based on data collected for 16 drowned river mouth, protected embayment, and open embayment wetland sites in the upper St. Lawrence River (Thousand Islands area). The population model predicts the annual growth and abundance of young-of-year pike for each of these wetland sites based on site-specific digital elevation models and predictions of submergent/emergent vegetative cover generated by the wetland plant sub-model.

The northern pike population sub-model was coded in FORTRAN 90 and provided to LTI as an executable program. The sub-model was integrated into the IERM framework by adding code to the IERM to "call" the external executable. Output generated by the executable is stored in ASCII files, which are processed and stored in the IERM database. The total annual young-of-year production (grams/hectare), which is calculated as the sum of production for all modeled sites, serves as the performance indicator. The PI ratio for this northern pike performance indicator is calculated as the ratio (alternative/baseline) of annual (101-year) average young-of-year production.

*Wetland Bird Sub-Model*

The wetland bird sub-model was developed based on non-linear regressions of breeding pair density and nest losses due to flooding and stranding events. These regressions were based on extensive field density data collected in the lower St. Lawrence River and Ontario and Quebec nesting chronology records. The wetland bird performance indicators developed for Lake Ontario represent indices of reproductive success for 8 species: veery, song sparrow, American bittern, marsh wren, common moorhen, least bittern, black tern, and Virginia rail. Of these 8 species, all except veery (treed swamp) and song sparrow (shrub swamp) utilize emergent marsh vegetation as principle nesting habitat. The reproductive success performance indicator for Virginia rail was extended to Lake St. Lawrence (IJC Shoreline Unit R3) so that reproductive habitat impacts could be evaluated for this location as well.

The reproductive success indicators are the product of two factors: wetland bird breeding pair density and nesting success related to potential flooding/stranding events. The breeding pair density is computed annually for the breeding season (roughly late May – July) based on a species-specific function of water depth in the preferred breeding habitat (emergent marsh, treed swamp, or shrub swamp). The density functions are shown in Figure 2-3. A second calculation is performed to estimate the nesting success of each species during the breeding season for each year. The nest success estimate is based on the probability of flooding and/or stranding of the nest due to water level fluctuations occurring during the initial nesting period and subsequent re-nesting attempts.

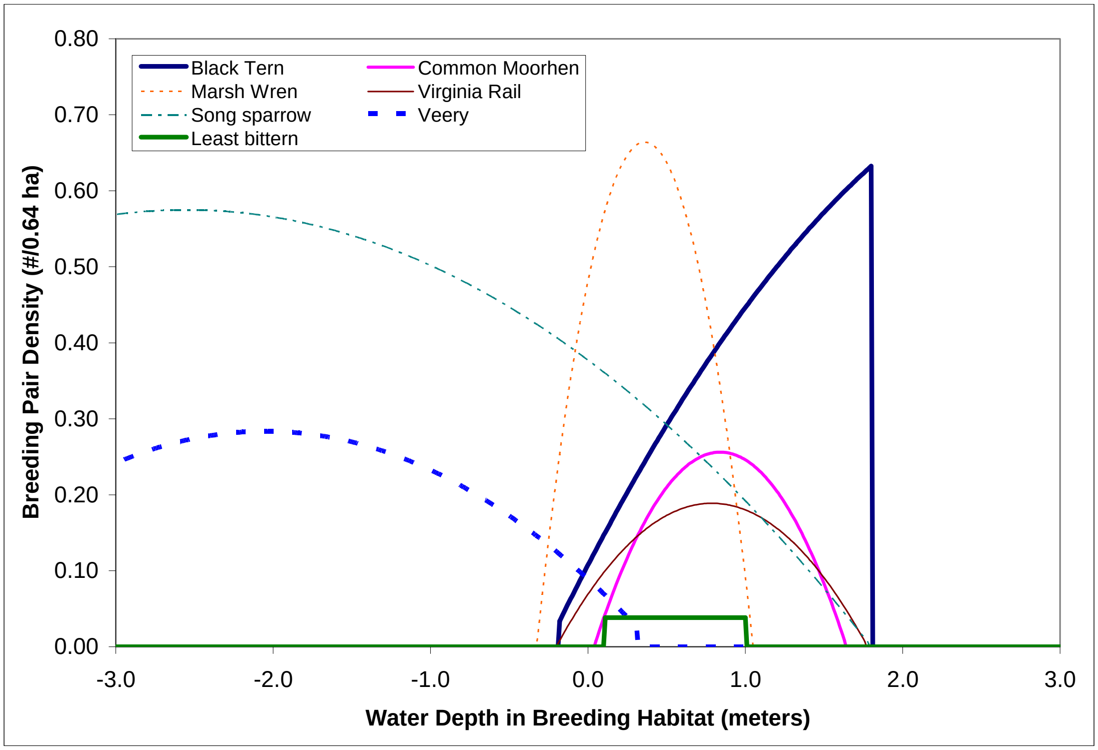


**Figure 2-3. Wetland Bird Density Functions**

After the breeding pair density and nesting success has been computed for a given simulation year, these two values are multiplied together to obtain an overall reproductive index. For Lake Ontario, fluctuations in water level during the wetland bird breeding season are typically minor; therefore, the annual PI response is largely determined by the breeding pair density, which is driven by the seasonal (late May-July) availability of water in the preferred breeding habitat.

The wetland bird sub-model algorithms were provided to LTI in spreadsheet format by Joel Ingram, Jean-Luc DesGranges, and Bruno Drolet. LTI staff integrated the wetland bird sub-model into the IERM framework by coding the algorithms into a Visual Basic module and a supporting database, and constructing the necessary linkages to the wetland plant sub-model. The wetland bird habitat types were defined relative to the wetland plant sub-model communities as follows:

- Treed swamp (“A” for all geomorphic types);
- Shrub swamp (“B” for barrier beach / drowned river mouth wetlands);

- Meadow marsh ("BC" for open/protected embayments, "C" for barrier beach / drowned river mouth wetlands); and
- Emergent marsh ("DEF" for all geomorphic types).

The reproductive index for a species within a single wetland geomorphic type is calculated based on Equation 2-5:

$$RIndex_j = \sum_{i}^{N} (SDens_{i,j} * NSuccess_{i,j} * Area_{i,j}) \qquad (2\text{-}5)$$

where: $SDens_{i,j}$ = species breeding pair density (# / 0.64ha) based on mean local water depth for the late May – July period for segment $i$ in geomorphic type $j$;

$NSuccess_{i,j}$ = species nesting success for segment $i$ in geomorphic type $j$;

$Area_{i,j}$ = total wetland area associated with elevation segment $i$ in geomorphic type $j$; and

$RIndex_j$ = total lakewide reproductive index for geomorphic type $j$.

The reproductive indices ($RIndex_j$) calculated for the 4 geomorphic wetland types are summed to obtain a total reproductive index for the Lake Ontario and Thousand Islands region for each wetland bird species. The PI ratios for all wetland bird performance indicators are computed based on the percentage of alternative plan scores exceeding the first quartile score for plan 1958DD. Complete documentation for the wetland bird sub-model can be found in DesGranges, *et al*. (2005).

*Herptile Sub-Model*

This herptile (reptile/amphibian) sub-model is based on logistical regression analyses of field capture data collected for 300 trap locations within eastern Lake Ontario and upper St. Lawrence River (Thousand Islands area) protected embayment wetlands. The regression models predict the probability of occurrence for each species as a function of water depth and percent cover of several plant communities, including upland, shrub/scrub, fine-leaved emergent vegetation, broad-leaved emergent vegetation, and submerged/floating vegetation. The herptile performance indicators represent the probability of occurrence, or relative habitat suitability, on a 0-1 scale for six species: Midland painted turtle, snapping turtle, Blanding's turtle, green frog, leopard frog, and American toad.

The herptile sub-model algorithms were provided to LTI in spreadsheet format by James Gibbs and Heather Jensen in winter 2004. LTI staff integrated the herptile model into the IERM framework by coding the algorithms into a Visual Basic module and constructing the necessary linkages to the wetland plant sub-model. The first step in integrating the herptile sub-model into the IERM was "mapping" the various structural categories defined for the wetland plant sub-model onto the habitat types defined for the herptile study. Following several iterations with the herptile researchers, the cross-mapping shown in Table 2-4 was adopted.

**Table 2-4. Habitat Mapping for Herptile Sub-Model**

| Herptile Habitat Category | Corresponding Structural Type(s) |
|---|---|
| Upland | Tree overstory |
| Shrub/scrub | Shrubs/seedlings/saplings |
| Fine-leaved emergent | Ferns, Forbs, Grasses, Sedges |
| Broad-leaved emergent | Broad-leaf emergent, Thin-stem persistent emergent |
| Submerged/floating | Submerged broad-leaf, Submerged narrow-leaf, Floating leaf, Algae |

The second step in linking the herptile sub-model to the wetland plant sub-model was to resolve the different spatial scales used within the two sub-models. This was accomplished by applying the herptile algorithms to each 1-cm wetland elevation segment within the IERM. It should be noted that the herptile model was only applied to the protected embayment wetland type in the IERM in order to be consistent with the herptile study locations. The average probability of occurrence for a species within protected embayment wetlands is calculated based on Equation 2-6:

$$TotalPOccur = \sum_{i=1}^{275} (POccur_i * AreaFrac_i) \qquad (2\text{-}6)$$

where: $POccur_i$ = local probability of species occurrence for elevation segment *i*;

$AreaFrac_i$ = area fraction of elevation segment *i* for the “typical” protected embayment wetland; and

$TotalPOccur$ = average probability of species occurrence in protected embayment wetlands.

The PI ratios for all herptile performance indicators are calculated as the ratio (alternative/baseline) of the annual (101-year) average probability of occurrence.

*Muskrat Sub-Model*

The muskrat sub-model was developed based on two primary data sources: 1) winter house censuses conducted for the 2001-2004 period, and 2) digital elevation maps constructed for 6 upper St. Lawrence wetland (drowned river mouth) study sites in the Thousand Islands area. Logistic regression analysis of the field data indicated that fall and winter water depth within the wetland cattail communities and winter air temperature are important variables controlling the density and sustainability of muskrat populations in the Thousand Islands area. Complete documentation for the herptile predictive models and supporting data is available in Jensen (2004).

The muskrat sub-model combines calculations of presence/absence (probability of occupancy) and the annual density of active muskrat houses into a single muskrat house density performance indicator. The muskrat sub-model computes the probability of muskrat occupancy based on the mean winter (December-February) water depth within the wetland emergent marsh (cattail) plant community. If the probability of occupancy is less than the threshold value of 0.35 for a given year, the wetland cannot support a muskrat population for that year. If the probability of occupancy is greater than 0.35, the actual muskrat house density is calculated based on the mean fall (September-November) water depth within the emergent marsh plant community and the mean winter air temperature. See Appendix A for a more detailed presentation of the muskrat sub-model algorithms.

The muskrat sub-model and performance indicator information were provided to LTI by John Farrell and Jason Toner in fall 2004. LTI staff integrated the muskrat sub-model into the IERM framework by coding the algorithms into a Visual Basic module and building the necessary linkages to the wetland plant sub-model. Because the muskrat model is strongly dependent on water depth in the emergent marsh (cattail) community, it was important to use the annual elevation range predicted by the wetland sub-model for this plant community. This was accomplished within the IERM by calculating winter and fall water depths for the muskrat sub-model based on the minimum/lower elevation of the emergent community (“EF”). Per discussions with John Farrell, the water level for all of the muskrat sites (in the Thousands Islands area) was assumed to be 14-cm lower than the corresponding average quarter-month Lake Ontario water level. To maintain consistency with the muskrat study, geometry from the 6 muskrat study sites was used for all of the muskrat regression calculations within the IERM. The muskrat PI ratio is calculated within the IERM as the ratio (alternative/baseline) of the annual (101-year) average muskrat house density.

*Species-at-Risk Sub-Models*

A distinct set of sub-models and performance indicators was developed by Jana Lantry and Al Schiavone to represent the response of species that are considered to be vulnerable, threatened, or endangered by either the United States or Canada. Based on an initial literature review, a list of species-at-risk (SAR) whose habitat may be impacted by water level regulation was developed. These species are listed by performance indicator group in Table 2-5.

**Table 2-5. Species-at-Risk Summary**

| Indicator Group | Species-at-Risk |
|---|---|
| Vegetation | *Carex atherodes*, various dune plant species |
| Fish | Pugnose shiner, bridle shiner |
| Wetland Birds | Least bittern, black tern, king rail, yellow rail |
| Herptiles | Blanding's turtle, spiny softshell turtle |
| Mammals | (none) |

Habitat supply sub-models and corresponding performance indicators were developed for each the species-at-risk listed in Table 2-5 with the exception of the dune plant species and *Carex atherodes*. Because the dune plant species of concern depend on periodic high and low Lake Ontario water levels to drive dune processes (e.g., replenishment), it was decided that hydrologic criteria could be used to adequately represent this SAR. Habitat for the emergent plant species *Carex atherodes* (awned sedge) is provided exclusively by the meadow marsh plant (ABC) community represented in the wetland plant sub-model. Because *Carex atherodes* could be directly represented by the meadow marsh performance indicators, this SAR was not explicitly modeled within the IERM framework.

Habitat supply models for pugnose shiner and bridle shiner were developed by the fish subgroup (Ken Minns, Sue Doka) using similar methodology to that used for the non-SAR fish habitat supply models representing 8 guilds and 4 species. As for the non-SAR models, daily habitat weighed suitable areas (WSAs) for pugnose shiner and bridle shiner were computed based on complex suitability rules accounting for water depth, substrate, local water temperature, and the presence/absence of submerged and emergent vegetation. Daily WSA estimates were summed over calendar years to generate annual estimates of habitat supply in units of hectare-days. The habitat suitability models were applied to specific locations in Lake Ontario (Sodus Bay for both species; southeast lake and outlet basin for bridle shiner) and the upper St. Lawrence River where these species have been previously observed. The PI ratios for pugnose shiner and bridle shiner were calculated within the IERM as the average of annual ratios (alternative/baseline).

Habitat supply models and associated performance indicators were developed for four wetland bird species (least bittern, black tern, yellow rail, and king rail) and one herptile species (Blanding's turtle). Each of these literature-based models relied on wetland sub-model predictions for the various structural categories (Table 2-3) to estimate total suitable habitat area for a given year. The structural categories that were considered suitable for nesting habitat for each species are indicated in Table 2-6 below.

**Table 2-6. Habitat Mapping for Wetland Bird and Herptile SARs**

| Wetland Plant Structural Category | Least Bittern | Black Tern | Yellow Rail | King Rail | Blanding's Turtle |
|---|---|---|---|---|---|
| Shrubs/Saplings/Seedlings | X | X | | | |
| Ferns | | | | | X |
| Forbs | | | | | X |
| Grasses | X | X | X | X | X |
| Sedges | X | X | X | X | X |
| Thin-Stem Emergent | X | X | X | X | X |
| Broad-Leaf Emergent | X | X | X | X | X |
| Thin-Stem Persistent Emergent | X | X | | X | X |

It is important to note that the habitat supply PIs for least bittern, black tern, and Blanding's turtle overlapped with performance indicators developed by the wetland bird and herptile subgroups. Ultimately, the PIs developed by the subgroups were used in favor of the habitat supply PIs for evaluating regulation plans because the former were developed based on field data.

All SAR algorithms and habitat assignments described above were provided to LTI by Jana Lantry. These algorithms and the habitat mappings were coded into Visual Basic modules and IERM databases and linked to the wetland sub-model by LTI staff. The PI ratios for all SARs, with the exception of pugnose shiner and bridle shiner, were calculated within the IERM as the ratio (alternative/baseline) of the annual (101-year) average habitat supply.

### *2.3.1.b Lower St. Lawrence Model*

Model development for the lower St. Lawrence River was coordinated by Jean Morin and his team at Environment Canada in Quebec City. A majority of the performance indicators for the LSL were developed based on a fine-scale, 2-dimensional (2-D) model of the physical system. The 2-D model grid represents the LSL channel and the entire floodplain for Lake St. Louis and the reach from Montreal Harbor to Lake St. Pierre. The 2-D modeling framework is linked to a flexible database system, which allows calculation of relevant physical and biological (i.e., vegetative cover) parameters for each grid node. Node results computed by the 2-D model and stored in the database system can be aggregated to provide summaries of model output for key locations in the LSL system.

Jean Morin and his team collaborated with a majority of the ETWG faunal researchers working on the LSL system to link their PI algorithms to predictions of physical parameters (e.g., depth, velocity) and wetland plant distribution (i.e., percent cover by habitat type) generated by his 2-D modeling system. The fine-scale performance indicator algorithms were developed by combining biological field data and modeled physical/wetland variables to predict habitat surface area for 4 sub-regions in the lower St. Lawrence River:

- Lake St. Louis,
- Montreal Harbor to Sorel,
- Sorel Island, and
- Lake St. Pierre to Trois-Rivières.

Performance indicators representing the total habitat surface area between Lake St. Louis and Trois-Rivières were computed by summing the predicted habitat area for these 4 sub-regions. The 2-D physical and wetland models were applied to produce a suite of performance indicator responses for 8 scenarios representing a range of discharge conditions at Sorel. The results from these 8 simulations were then extrapolated to produce continuous, one-dimensional response functions based on discharge for each performance indicator metric. The footnotes provided in Table 2-2 indicate which performance indicators are based on the 2-D modeling approach.

Environment Canada staff working out of the Centre Saint Laurent (Montreal) produced a second suite of wetland vegetation and fish performance indicators for the lower St. Lawrence River. These indicators were derived from one-dimensional statistical analyses of datasets collected at specific locales within the LSL system, including Lake St. Pierre and the Boucherville Islands. The footnotes provided in Table 2-2 indicate which performance indicators are based on the one-dimensional, statistical approach.

All performance indicator algorithms developed for the LSL system were coded into Visual Basic 6 modules and a supporting Microsoft Access database by Jean Morin's team. The code and database were integrated into the overall IERM framework by LTI staff in similar fashion to the code and databases for developed by the LO-USL fish subgroup.

### 2.3.2 Coding & Implementation

The IERM framework was developed as a collection of modules, class module, forms, and other objects in Microsoft Visual Basic 6.0 (VB6). The IERM code is essentially divided into two components, a simulation component and a visualization component. All model simulation and visualization capabilities can be accessed directly or indirectly through the IERM Main Menu (Figure 2-4).

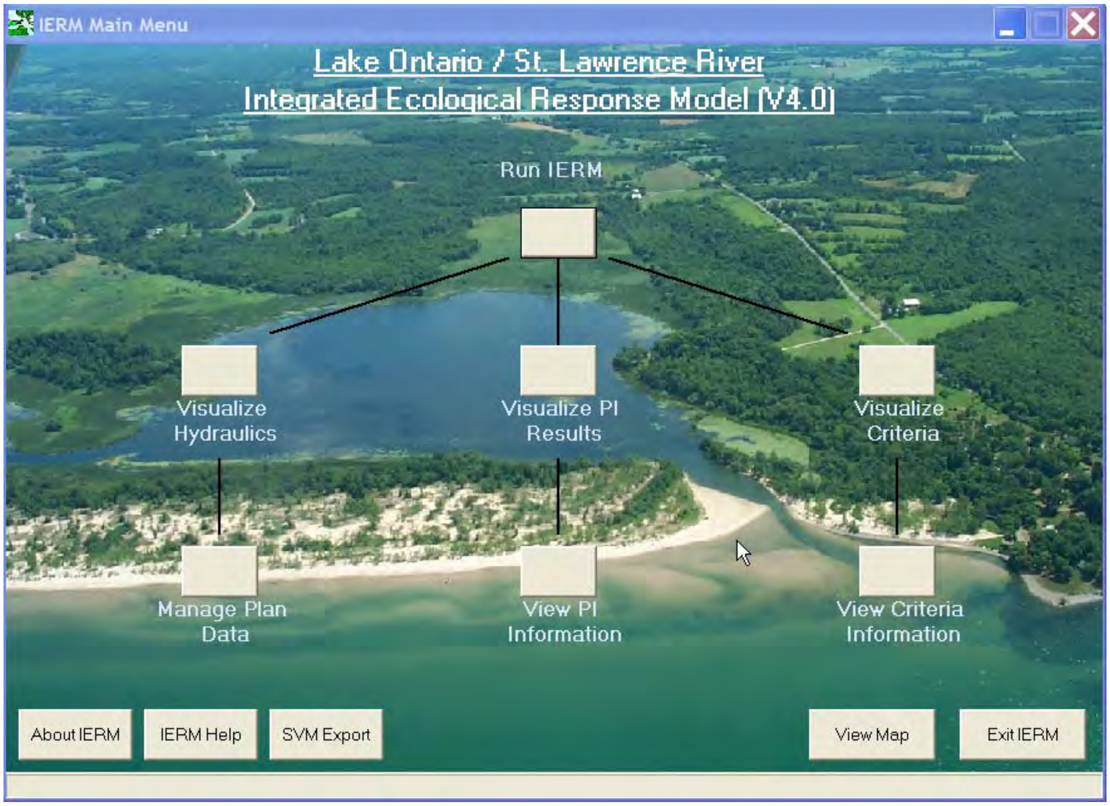


**Figure 2-4. IERM Main Menu**

The IERM simulation component contains all code relevant to the hydraulic simulation, ecological sub-models and associated performance indicators, and the hydrological criteria evaluation. Ecological sub-models were coded into standalone modules or class modules that could be accessed from the main IERM calling sequence. This modularized approach provided a great deal of flexibility in adding and modifying sub-models as the IERM development progressed in Year 3. The exact implementation of the various sub-models varied; see Section 2.3.1 for descriptions of how each sub-model was integrated into the IERM framework. The simulation code interacts with a series of Microsoft Access databases that provide efficient storage and transfer of model input/output data using Microsoft's Data Access Objects (DAO) library (Figure 2-5). An IERM simulation can be launched by clicking the "Run IERM" button on the Main Menu (Figure 2-4) and selecting the desired regulation plan(s).

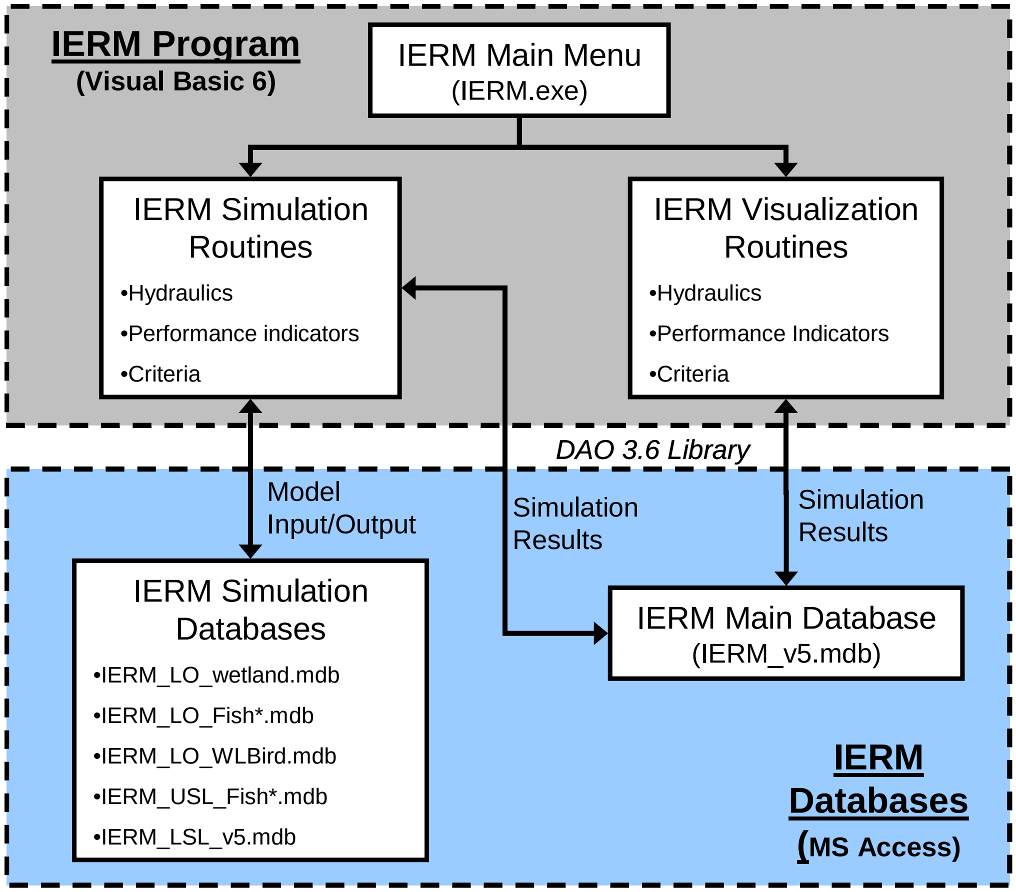


**Figure 2-5. IERM Framework Flow Chart**

The IERM visualization component contains all code relevant to graphical user interface (GUI) displays of the hydraulic, performance indicator, and criteria output generated by the simulation component. The IERM interface was designed using VB6 forms and controls and Gigasoft's ProEssentials v5 graphics library. The IERM visualization component was designed to provide the user with a variety of tools for reviewing the simulation results. These visualization tools can be accessed by clicking on the appropriate "Visualize…" buttons on the IERM Main Menu (Figure 2-4). The IERM also provides a direct link to documentation developed by ETWG members for the key ecological PIs. The documentation for the key PIs can be accessed (in Microsoft Word or Adobe PDF format) by clicking the "View PI Information" on the IERM Main Menu and selecting the key PI of interest.

The simulation and visualization components are decoupled within the IERM framework so that results from one or many simulations can be stored in the main IERM database for access by the visualization tools without re-running the IERM. The linkage between the two components through the main IERM database (IERM_v5.mdb) is illustrated in Figure 2-5.

Four different IERM versions were released to ETWG and PFEG during Year 4 of the Study. With the exception of the Version 1.0 release in June 2004, IERM releases coincided with Study Board workshops. Table 2-7 provides a summary of each IERM release, including the purpose of the release.

**Table 2-7. IERM Major Release Versions**

| IERM Version | Release Date | Description | Purpose |
|---|---|---|---|
| 1 | June 2004 | Initial version containing incomplete sub-models and "beta" interface. | Intended primarily for ETWG review and comment. |
| 2 | October 2004 | Second version incorporating substantial updates and improvements to sub-models and PIs. A full simulation version was released to PFEG complete with a built-in feature for exporting "key" PI results to the SVM Post Processor. | Version 2 was used to evaluate plans for the October (2004) Study Board Practice Decision Workshop. |
| 3 | January 2005 | Near-final version with 95% final sub-models, PIs, and key PI selections. | Version 3 was used to evaluate plans for the January (2005) Study Board Practice Decision Workshop. |
| 4 | March 2005 | Final version including final sub-models, PIs, and key PI selections for inclusion in the SVM. A full simulation version was provided to PFEG in early March. | Version 4 was used to evaluate plans for the March/April (2005) Study Board Decision Workshops |

The following sections provide a detailed discussion of the IERM pre- and post-processing capabilities and requirements, including a description of how the IERM was linked to the Shared Vision Model.

### *2.3.2.a Pre-Processing/Data Input*

The IERM framework was designed to minimize the number of inputs required to run model simulations. This was accomplished by coding the SVM hydraulic algorithms directly into the IERM framework. The SVM hydraulic simulation computes water levels and flow at locations of interest using a series of linear and non-linear regressions developed by David Fay of Environment Canada. Several different types of quarter-monthly input forcings are required to apply the regressions, including:

- Lake Ontario net total basin supply (NTS) rates;
- Tributary inflow rates for the Ottawa River and other major tributaries to the LSL;
- Ice factors at several locations in the USL and the LSL; and
- Releases at the Moses Saunders Dam associated with a given regulation plan.

With the exception of releases at the Moses Saunders Dam, all of the hydrologic/hydraulic forcings listed above are held constant for all plan evaluations conducted for a given supply scenario. Therefore, it was possible to maintain a static "copy" of the time series for the tributary flows and ice factors in the IERM database. After the necessary time series data was incorporated into the IERM database and the hydraulic algorithms were re-coded, the IERM hydraulic output was compared against the SVM hydraulic output to verify that the two models produced the same water level and flow results.

Because the SVM hydraulic algorithms are integrated directly into the IERM framework, the only input dataset required to run an IERM simulation is the quarter-monthly releases associated with the regulation plan of interest. A plan import utility was developed to allow the user to import plan releases directly from a Microsoft Excel spreadsheet. This utility can be accessed by clicking the "Manage Plan Data" button on the IERM Main Menu (Figure 2-4). After a set of plan releases has been imported via the plan utility, the user may begin a full IERM simulation by clicking the "Run IERM" button on the Main Menu and selecting the new/revised plan.

A linkage between the IERM and the SVM Post Processor was also developed to eliminate the need to manually load plan releases into the IERM database for each individual simulation. Section 2.3.2.c provides a more detailed description of the IERM-SVM linkage.

### *2.3.2.b Post-Processing/Visualization*

A single IERM simulation generates a large quantity of output for the hydraulic, performance indicator, and criteria evaluations. During the course of an IERM sub-model simulation, these results are stored internally in arrayed variables. After a sub-model simulation has been completed, the simulation results are transferred to the appropriate tables in the main IERM database (IERM_v5.mdb), as illustrated in Figure 2-5. Output datasets transferred from the simulation code to the main IERM database include:

- <u>Hydraulics</u>: Quarter-monthly water levels and/or flows for Lake Ontario, Thousand Islands area, Ogdensburg, Cardinal, Montreal Harbor, and Sorel are stored in the "Reg_Hydraulics" table.
- <u>Performance Indicators</u>: Annual scores for each performance indicator metric are stored in the "PI_Results" table.
- <u>Hydrologic Criteria</u>: Number of years each criterion is successfully met and total deviations for years where the criterion is not met are stored in the "Criteria_Results" table.

At the end of simulation, the IERM computes the aggregate scores for all performance indicators. These scores are later used to compute PI ratios for display in the PI visualization tools based on the equations provided in Section 2.2.2.

The IERM provides a variety of visualization tools that allow the user to compare the simulation results for multiple regulation plans. The hydraulic visualization can be accessed by clicking the "Visualize Hydraulics" button on the IERM Main Menu (Figure 2-4). This visualization allows the user to plot, review, and export quarter-monthly water level / flow output for key locations. The hydrologic criteria visualization can be accessed by clicking the "Visualize Criteria" button on the IERM Main Menu. This visualization allows the user to generate bar charts and X-Y charts to compare the criteria evaluations for an alternative and a baseline plan.

An extensive set of tools is available in the IERM for visualizing performance indicator results. These tools can be accessed by clicking the "Visualize PI Results" button on the IERM Main Menu. The PI visualization tools are designed to allow the user to review PI simulation results at multiple levels. The target plot, which serves as a "parent" to the other PI visualization tools, displays ratio output for all PIs for selected baseline and alternative regulation plans (Figure 2-6).

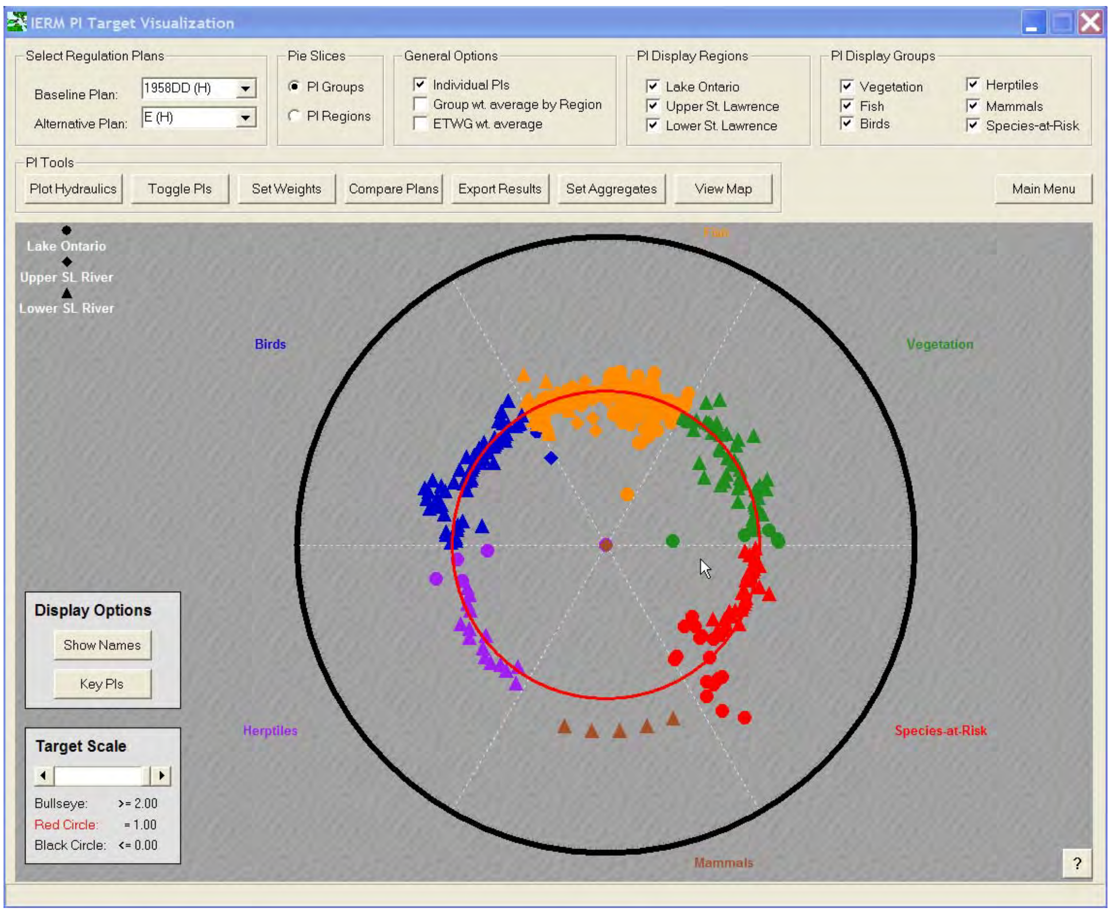


**Figure 2-6. IERM Target Comparison**

The ratios are displayed as points, with shapes and colors indicating the region and group that each PI belongs to. The various regions and PI groups can be toggled on or off using the check box controls at the top of the form. A summary form displaying the comparative scores for a specific PI can be accessed by double-clicking on the associated target point. The user can "drill down" to the PI time series visualization from this summary form. The PI time series visualization, which is shown in Figure 2-7, allows the user to view annual results as well as the ratio and aggregate scores for the selected PI. Results for different plans can be quickly compared by changing the baseline and/or alternative plan selections at the top of the form.

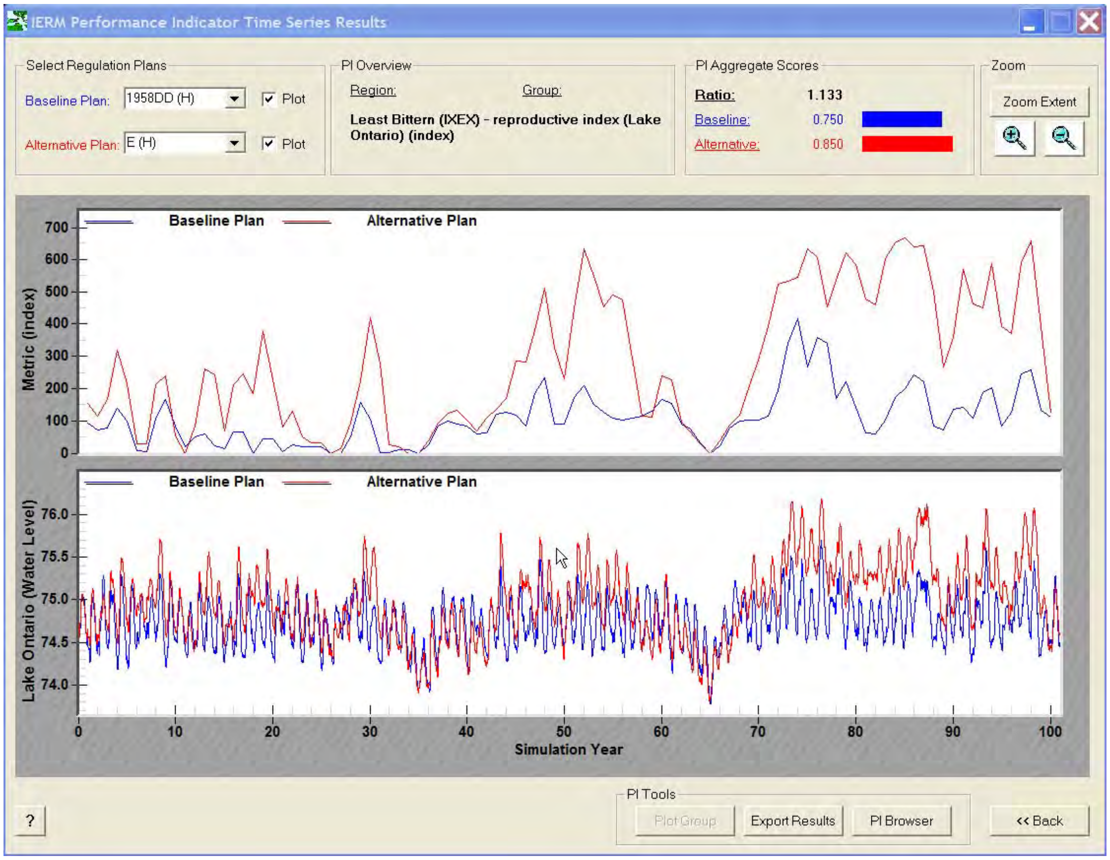


**Figure 2-7. IERM Performance Indicator Time Series Output**

A number of other PI visualization tools can be accessed from the options on the PI target form. These tools and the hydraulic/criteria visualization tools are discussed in detail in the IERM User's Manual (Appendix B).

### *2.3.2.c Linkage to Shared Vision Model*

A linkage between the IERM and the SVM Post Processor was developed to provide a means for efficiently transferring data between the two modeling frameworks. As described above, the IERM framework includes all of the necessary code for simulating hydraulics (i.e., water levels and flows) in the LOSL system. The only input data required to run an IERM simulation for a given regulation plan is a time series of quarter-monthly release rates at the Moses Saunders dam. To eliminate the need to manually load plan releases into the IERM database for each simulation, a pre-processing option was added to the IERM interface that allows the user to select the plan of interest on a worksheet in the SVM Post Processor, and then import the selected releases and begin a full IERM simulation with the click of a button.

Because the SVM was used as the vehicle for displaying performance indicator and criteria evaluation results for all economic and environmental interests, it was important to develop a linkage that would transfer IERM results to the SVM Post Processor. An "SVM Export" option was added to the IERM Main Menu that allows the user to select plans that have been simulated in the IERM and export the associated key PI results to the corresponding plan worksheets in the SVM Post Processor. The export process transfers the complete 101-year time series of results and aggregate scores for all 32 key PIs as well as a summary of the hydrologic criteria evaluation. In this manner, the IERM results are entirely preserved in the SVM Post Processor and the SVM Board Room files that were used by the Study Board to evaluate and rank regulation plans.

A complete description of the steps required to link the IERM to the SVM Post Processor is provided in the IERM User's Manual (Appendix B).

## 2.4 MODEL VERIFICATION/VALIDATION

Verification of the IERM simulation component was conducted in a variety of ways. The hydraulic algorithms in the IERM were constructed to duplicate the hydraulic results generated by the SVM. Therefore, it was possible to verify the IERM hydraulic computations by directly comparing the results to the quarter-monthly water level and flow predictions generated by the SVM framework. Criteria evaluation results were verified by performing manual calculations. When possible, verification of performance indicator results was conducted by developing detailed spreadsheet calculations that were intended to reproduce the IERM output for a given performance indicator. For some of the more complex sub-models, it was necessary to develop simplified spreadsheet calculations that could adequately reproduce the relative PI response when comparing two regulation plans. Verification of the IERM sub-models was also achieved through an iterative process where the individual ETWG researchers reviewed model results and provided feedback after each version of the IERM was released. Ultimately, a "stamp of approval" was obtained from each researcher pertaining to the implementation of their specific research in the IERM.

Validation of the various ecological sub-models that are included in the IERM framework is being conducted by the ETWG researchers. The extent of validation conducted for the key performance indicators will vary considerably. In many cases, no independent datasets are available for model validation, and a "qualitative" validation of the sub-models will be necessary based on expert opinion and review. Specific information regarding validation of the key PIs can be found in the PI documentation provided in Appendix A and the final reports cited in Section 2.3.1.

# 3. IERM APPLICATION

## 3.1 OVERVIEW OF PLAN FORMULATION & EVALUATION

The primary purpose of the IERM was to permit ETWG an effective means of evaluating alternative regulation plans in terms of their relative impacts on the LOSL ecosystem as represented by the over 600 PIs defined during the Study. For the most part, the plans being evaluated were developed by another workgroup of the Study, the Plan Formulation and Evaluation Work Group (PFEG). PFEG developed plans by applying flow control rule curves to a given basin supply scenario in order to develop quarter-monthly releases from the Moses Saunders Dam. These releases constituted the input to the IERM for its computations. However, an additional use of the IERM was to develop and provide to PFEG input on criteria that would benefit ecological PIs. In this way, ETWG could influence PFEG's formulation of plans aimed at maximizing environmental benefits in the system. The iterative nature of this process is illustrated in Figure 3-1, including the relationships between defining and evaluating PI responses, criteria, and regulation plans. It also points out how the IERM is used in this process.

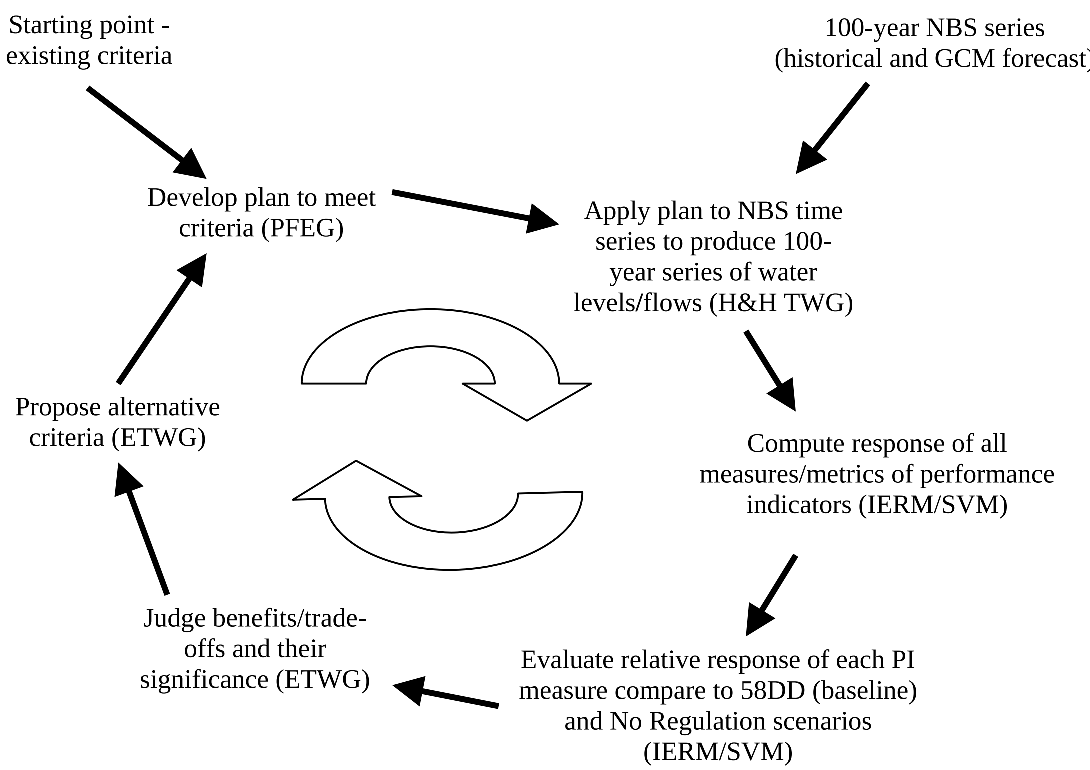


**Figure 3-1. Iterative procedure to evaluate alternative regulation plans and to incorporate the computation of PIs in the development of criteria.**

The IERM provides a means of computing and visualizing the response of each PI relative to the baseline plan (1958DD) as described in Section 2.3.2.b. These results are then judged by the ETWG in terms of the overall environmental benefits; and then these benefits are interpreted in terms of hydrologic and hydraulic conditions that drove them in order to propose criteria to PFEG for new plan development.

## 3.2 KEY PI SELECTION

As we have already discussed, the IERM has been incorporated into the Shared Vision Model (SVM), which permits all stakeholders, including the Study Board, to compare and evaluate alternative plans in terms of all of the interests in the LOSL system. In order to facilitate Study Board and other stakeholders to more efficiently evaluate the PI responses to alternative plans, the IERM supported a process undertaken by the ETWG to reduce the number of PIs to 32 "key" PIs. It is these key PIs that are transferred to the SVM.

The process of distilling the original list of PIs to define key PIs was based first on evaluations of certainty, sensitivity (to water regulation), and significance, and then on the extent to which PIs could be grouped together based on similar responses to water levels and flows (representativeness). In other words, each key PI may represent a number of other PIs that behave similarly in response to water level fluctuations and/or habitat availability. Descriptions of each of the key PIs, including comments on certainty, sensitivity and significance, are included in the fact sheets presented in Appendix A.

### 3.2.1 Sensitivity/Uncertainty/Significance

The tables on the following three pages (Table 3-1, Table 3-2) summarize the "key" performance indicators (PIs), as well as their significance, uncertainty and sensitivity. This list has been distilled from an original list of over 600 PIs. The process of reducing the larger list to the key PI list involved eliminating certain PIs that were determined to be either too uncertain, or to be insensitive to water level variations, or were judged by the ETWG scientists to be relatively insignificant in terms of overall ecosystem integrity. The first column in Tables 3-1 and 3-2 indicates the label used for each key PI within the SVM framework (e.g., "E5").

**Table 3-1. Key Ecological PIs for Lake Ontario and Upper St. Lawrence River**

| SVM ID | Region | PI Group | PI Description | PI Units | Researchers | Significance | Certainty | Sensitivity |
|---|---|---|---|---|---|---|---|---|
| **E1** | Lake Ontario | Vegetation | Wetland Meadow Marsh Community - total surface area, supply-based (Lake Ontario) | ha | Wilcox, Ingram | 5 | 5 | 5 |
| **E2** | Lake Ontario | Fish | Low Veg 18C - spawning habitat supply (Lake Ontario) | ha-days | Minns, Doka, Chu, Bakelaar, Leisti | 2 | 3 | 4 |
| **E3** | Lake Ontario | Fish | High Veg 24C - spawning habitat supply (Lake Ontario) | ha-days | Minns, Doka, Chu, Bakelaar, Leisti | 3 | 3 | 4 |
| **E4** | Lake Ontario | Fish | Low Veg 24C - spawning habitat supply (Lake Ontario) | ha-days | Minns, Doka, Chu, Bakelaar, Leisti | 2 | 3 | 4 |
| **E5** | Lake Ontario | Fish | Northern Pike - YOY recruitment index (Lake Ontario) | index | Minns, Doka | 3 | 4 | 5 |
| **E6** | Lake Ontario | Fish | Largemouth Bass - YOY recruitment index (Lake Ontario) | index | Minns, Doka | 3 | 4 | 4 |
| **E7** | Lake Ontario | Birds | Virginia Rail (RALI) - median reproductive index (Lake Ontario) | index | DesGranges, Ingram, Drolet | 4 | 4 | 5 |
| **E8** | Lake Ontario | Species-at-Risk | Least Bittern (IXEX) - median reproductive index (Lake Ontario) | index | DesGranges, Ingram, Drolet | 5 | 2 | 5 |

| SVM ID | Region | PI Group | PI Description | PI Units | Researchers | Significance | Certainty | Sensitivity |
|---|---|---|---|---|---|---|---|---|
| **E9** | Lake Ontario | Species-at-Risk | Black Tern (CHNI) - median reproductive index (Lake Ontario) | index | DesGranges, Ingram, Drolet | 5 | 3 | 5 |
| **E10** | Lake Ontario | Species-at-Risk | Yellow Rail (CONO) - preferred breeding habitat coverage (Lake Ontario) | ha | Lantry, Schiavone | 2 | 2 | 5 |
| **E11** | Lake Ontario | Species-at-Risk | King Rail (RAEL) - preferred breeding habitat coverage (Lake Ontario) | ha | Lantry, Schiavone | 2 | 2 | 5 |
| **E12** | Upper SL River | Fish | Low Veg 18C - spawning habitat supply (Upper St. Lawrence) | ha-days | Minns, Doka, Chu, Bakelaar, Leisti | 2 | 3 | 4 |
| **E13** | Upper SL River | Fish | High Veg 24C - spawning habitat supply (Upper St. Lawrence) | ha-days | Minns, Doka, Chu, Bakelaar, Leisti | 3 | 3 | 4 |
| **E14** | Upper SL River | Fish | Low Veg 24C - spawning habitat supply (Upper St. Lawrence) | ha-days | Minns, Doka, Chu, Bakelaar, Leisti | 2 | 3 | 4 |
| **E15** | Upper SL River | Fish | Northern Pike - YOY recruitment index (USL) | index | Minns, Doka | 3 | 4 | 5 |
| **E16** | Upper SL River | Fish | Largemouth Bass - YOY recruitment index (USL) | index | Minns, Doka | 3 | 4 | 4 |
| **E17** | Upper SL River | Fish | Northern Pike - YOY net productivity (USL - Thousand Islands) | grams/ha | Farrell | 2 | 4 | 5 |

| SVM ID | Region | PI Group | PI Description | PI Units | Researchers | Significance | Certainty | Sensitivity |
|---|---|---|---|---|---|---|---|---|
| **E18** | Upper SL River | Birds | Virginia Rail (RALI) - median reproductive index (Lake St. Lawrence) | index | DesGranges, Ingram, Drolet | 3 | 3 | 5 |
| **E19** | Upper SL River | Mammals | Muskrat (ONZI) - house density in drowned river mouth wetlands (Thousand Islands area) | #/ha | Farrell, Toner | 4 | 4 | 5 |

**Table 3-2. Key Ecological PIs for Lower St. Lawrence River**

| SVM ID | Region | PI Group | PI Description | PI Units | Researchers | Significance | Certainty | Sensitivity |
|---|---|---|---|---|---|---|---|---|
| **E20** | Lower SL River | Fish | Golden Shiner (NOCR) - suitable feeding habitat surface area (Lake St. Louis to Trois-Rivières) | ha | Mingelbier, Morin | 4 | 4 | 5 |
| **E21** | Lower SL River | Fish | Wetlands fish - abundance index (Lower St. Lawrence) | index | de Lafontaine, Marchand | 2 | 4 | 5 |
| **E22** | Lower SL River | Fish | Northern Pike (ESLU) - suitable reproductive habitat surface area (Lake St. Louis to Trois-Rivières) | ha | Mingelbier, Morin | 3 | 4 | 5 |
| **E23** | Lower SL River | Birds | Migratory wildfowl - floodplain habitat surface area (Lake St. Louis to to Trois-Rivières) | ha | Lehoux, Dauphin, Champoux, Morin | 3 | 4 | 5 |
| **E24** | Lower SL River | Birds | Virginia Rail (RALI) - reproductive index (Lake St. Louis to Trois-Rivières) | index | DesGranges, Ingram, Drolet | 4 | 4 | 5 |
| **E25** | Lower SL River | Birds | Migratory wildfowl - productivity (Lake St. Louis to to Trois-Rivières) | # juveniles | Lehoux | 3 | 4 | 5 |
| **E26** | Lower SL River | Birds | Black Tern (CHNI) - reproductive index (Lake St. Louis to Trois-Rivières) | index | DesGranges, Ingram, Drolet | 5 | 4 | 5 |
| **E27** | Lower SL River | Herptiles | Frog sp. - reproductive habitat surface area (Lake St. Louis to Trois-Rivières) | ha | Armellin, Champoux, Morin, Rioux | 3 | 2 | 5 |

| SVM ID | Region | PI Group | PI Description | PI Units | Researchers | Significance | Certainty | Sensitivity |
|---|---|---|---|---|---|---|---|---|
| **E28** | Lower SL River | Mammals | Muskrat (ONZI) - surviving houses (Lake St. Louis to Trois-Rivières) | # of houses | Ouellet, Morin | 4 | 2 | 5 |
| **E29** | Lower SL River | Species-at-Risk | Least Bittern (IXEX) - reproductive index (Lake St. Louis to Trois-Rivières) | index | DesGranges, Ingram, Drolet | 5 | 2 | 5 |
| **E30** | Lower SL River | Species-at-Risk | Eastern Sand Darter (AMPE) - reproductive habitat surface area (Lake St. Louis to Trois-Rivières) | ha | Giguère, Laporte, Morin | 4 | 1 | 5 |
| **E31** | Lower SL River | Species-at-Risk | Spiny Softshell Turtle (APSP) - reproductive habitat surface area (Lake St. Louis to Trois-Rivières) | ha | Giguère, Laporte, Morin | 4 | 2 | 5 |
| **E32** | Lower SL River | Species-at-Risk | Bridle Shiner (NOBI) - reproductive habitat surface area (Lake St. Louis to Trois-Rivières) | ha | Giguère, Laporte, Morin | 4 | 2 | 5 |

### 3.2.2 Representativeness

The key PIs were also selected on the basis of their representativeness of other PIs that behaved similarly in response to water level magnitude and/or fluctuation. Thus, one key PI may in fact represent the response of many other PIs from the original list. The importance of a particular key PI in the final evaluation will depend in part on the number of other PIs it is representing.

Review of all the PI responses to alternative regulation plan/scenario hydrographs was conducted in order to group the PIs and identify what other PIs were represented by the initial list of key PIs based on sensitivity, certainty, and significance. Examples of key PI representativeness are:

- Key PI: Supply-Based Meadow Marsh in Lake Ontario
    - Carex atherodes (SAR) – a sedge species found [exclusively] in meadow marsh plant communities
    - Meadow marsh (non-supply based)
    - Non-cattail (non-supply based)
    - Non-cattail (supply-based)
    - Veery – reproduction index
    - Swamp sparrow – reproduction index
    - Song sparrow – reproduction index
    - Green frog – probability of occurrence
- Key PIs: Virginia Rail and wetland bird species-at-risk
    - Black tern (SAR) – reproduction index
    - American bittern – reproduction index
    - Common moorhen – reproduction index
    - Marsh wren – reproduction index
    - Common snapping turtle – probability of occurrence (moderate sensitivity)
    - Northern leopard frog – probability of occurrence (low sensitivity)
    - Midland painted turtle – probability of occurrence (low sensitivity)
    - American toad – probability of occurrence

## 3.3 HYDROLOGIC CRITERIA

A series of environmental criteria were developed to describe the hydrologic attributes associated with the key PIs discussed in Section 3.2. Separate lists of criteria were developed for the LO/USL system and the LSL system. The hydrologic criteria for the LO/USL system are typically described relative to the elevation range of a one or more plant communities defined by the wetland sub-model (Table 3-3). The criteria for the LSL system are typically described relative to absolute water levels, although several criteria are based on the elevation of the shallow marsh plant community (Table 3-4).

## Table 3-3. Hydrologic Criteria for Lake Ontario and Upper St. Lawrence River

| PI Group | Criteria Description[1] | January | | | | February | | | | March | | | | April | | | | May | | | | June | | | | July | | | | August | | | | September | | | | October | | | | November | | | | December | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
| | Periodic low water levels to maintain meadow marsh community (ABC) | | | | | | | | | | | | | | | | | Approximately every 20 years, when supplies do not exceed an average January-June quarter month net total supply of 6,800 m³/s, hold lake levels to 74.5m or lower for 2 successive years followed by 2 to 4 years at or below 74.85m. Preferred frequency - every 20-30 years. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Vegetation* | Periodic high water levels to maintain overall wetland diversity | | | | | | | | | | | | | | | | | Approximately every 40 years, when supplies exceed an average January-June quarter month net total supply of 8,400m³/s, allow the lake levels to peak at 75.6m or higher and remain above 75.4m for a 2 month or longer duration around the QM peak level for 1 year. Preferred frequency range - every 30-50 years. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Long-term maintenance of dune habitats | | | | | | | | | | | | | | | | | Vegetation in dune habitats respond best to periodic erosion events (high water levels) followed by deposition events (low water levels). During periods of high water supplies hold summer levels at or greater than 75.6m once approximately every 30 years. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Northern pike (spawning) | | | | | | | | | | | H >= 15 cm over meadow marsh (ABC) during high supply | | | | | D < 10 cm/QM | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Largemouth bass (spawning) | | | | | | | | | | | | | | | | | | | | | 0.2 < H < 1.0 m over DEFG | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Fish* | Bridle Shiner (SAR) - adult habitat | | | | | | | | | | | | | 0.1 < H < 2.0 over DEFG | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Bridle Shiner (SAR) - spawning habitat | | | | | | | | | | | | | | | | | | | 0.1 < H < 1.0 m over FG | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Northern Pike (USL - juveniles year-class strength, postseaway conditions) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Mean H < 74.9 during periods of low supply | | | | | | | | | | | | | | | | | | | |
| | Wetland birds & Least Bittern (SAR) | | | | | | | | | | | | | | | | | | 0.8>H>0.2 m (DEF,Emergent marshes) D & R ≤ 0.2 m / qm | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Wetlands birds nesting success (1st nesting attempt) | | | | | | | | | | | | | | | | | | | | | D or R < 0.30m | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Birds* | Wetlands birds nesting success (2nd nesting attempt) | | | | | | | | | | | | | | | | | | | | | | | D or R < 0.30m | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Black Tern (SAR) | | | | | | | | | | | | | | | | | | 1.8>H>0.4 m over emergent marsh (DEF) D & R ≤ 0.2 m / QM | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Yellow Rail (SAR) | | | | | | | | | | | | | | | | | | | H<0.2m; R ≤ 0.10 m/QM | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | King Rail (SAR) | | | | | | | | | | | | | | | | | | | H~0.6m; D & R <0.10 m/QM | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Mammal* | Muskrat (winter survival) | H >= 10 cm over emergent marsh (DEF) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | H >= 10 cm over emergent marsh (DEF) | | | | | | | | | | | | | | | |

[1] Key to abbreviations: "WL" – Lake Ontario water level, "H" – water depth, "D" – drop in water level, "R" – rise in water level. Vegetation abbreviations (e.g., "DEF") refer to plant communities included in wetland plant sub-model.

# Table 3-4. Hydrologic Criteria for Lower St. Lawrence River

| PI Group | Criteria Description[1] | January | | | | February | | | | March | | | | April | | | | May | | | | June | | | | July | | | | August | | | | September | | | | October | | | | November | | | | December | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
| *Fish* | Fish reproduction (natural marshes) | | | | | | | | | | | | | H ≥ 0.35m over Shallow Marsh[2] | | | | | | D ≤ 0.3 m/QM | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Fish reproduction (managed marshes)[3] | | | | | | | Mean H >5.6m; starting QM should be determined based on water temperature | | | | | | | | | | | | | | | | | H ≤ 5.0m | | | | | | | | | | | | | | | | | | | | | | | | |
| | Fish living & feeding habitat | | | | | | | | | | | | | | | | | | | | | | | | | | | | | H<4.60m (Q<9500 m³/s) | | | | | | | | | | | | | | | | | | | |
| | Bridle Shiner (SAR) | | | | | | | | | | | | | | | | | | | | | D ≤ 0.2 m/QM | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Birds* | Wetland bird reproduction habitat | | | | | | | | | | | | | | | | | | 0.5 m over Shallow Marsh[2]; D & R ≤ 0.2 m | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Least Bittern (SAR) | | | | | | | | | | | | | | | | | | | | R ≤ 0.30m / QM | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Wildfowl migration | | | | | | | | | | | | | | H ≥ 5.4m/QM | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Wildfowl reproduction #1 | | | | | | | | | | | | | 6.45 m >H> 5.60 m | 6.30 m >H> 5.55 m | 6.50 m >H> 5.80 m | 6.65 m >H> 6.00 m | 6.60 m >H> 5.80 m | 6.50 m >H> 5.60 m | 6.30 m >H> 5.25 m | 6.05 m >H> 5.10 m | 5.75 m >H> 5.00 m | 5.45 m >H> 4.90 m | 5.30 m >H> 4.85 m | 5.25 m >H> 4.85 m | 5.25 m >H> 4.75 m | 5.20 m >H> 4.70 m | 5.20 m >H> 4.65 m | 5.20 m >H> 4.60 m | 5.15 m >H> 4.2m | 5.10 m >H> 4.2m | 5.10 m >H> 4.2m | 5.00 m >H> 4.2m | 4.90 m >H> 4.2m | 4.90 m >H> 4.2m | 4.90 m >H> 4.2m | 5.00 m >H> 4.2m | 5.05 m >H> 4.2m | 5.10 m >H> 4.5m | 5.10 m >H> 4.6m | 5.10 m >H> 4.6m | | | | | | | | |
| | Wildfowl reproduction #2[4] | | | | | | | | | | | | | | | | R ≤ 0.4m/QM if H≥4.9m | | R ≤ 0.2m/QM if H≥4.9m | | | | | | | R ≤ 0.3m if H≥4.9m | | | | | | | | | | | | | | | | | | | | | | | |
| *Herptile* | Spiny Softshell Turtle & Northern Map Turtle habitat | | | | | | | | | | | | | | | | | | | | | | R ≤ [H(QM22) + 0.5m] | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Mammal* | Muskrat (winter survival) | [Mean H (QM41-44) + 0.3m] ≥ H ≥ [Mean H (QM41-44) - 0.2m] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | [Mean H (QM41-44) +0.3m] ≥H≥ [Mean H (QM41-44) - 0.2m] | | | |

[1] Key to abbreviations: "WL" – water level at Sorel gage, "H" – water depth, "D" – drop in water level, "R" – rise in water level.
[2] Shallow marsh is calculated as the Y = 1.8993*X^2 - 16.46*X + 39.899, where Y is the mean elevation (m) of the shallow marsh (relative to Sorel gage) and X is the mean water level (m) at Sorel during the growing season (QM 13-42) for the previous 3 years.
[3] Fallback criterion for fish reproduction in natural marshes.
[4] Fallback criterion for "wildfowl reproduction #1" criterion.

The hydrologic criteria presented in Tables 3-3 and 3-4 are in effect simplified expressions of the performance indicator algorithms to which they are related. Therefore, the criteria evaluation will generate results that are very similar to the corresponding PI results. The hydrologic criteria are beneficial in that they provide a means for: 1) verifying that the PI algorithms are generating reasonable results, and 2) understanding how the more complex PI algorithms respond to hydrologic/hydraulic conditions during various seasons.

## 3.4 PLAN EVALUATION/INTERPRETATION GUIDELINES

The process of evaluating and ranking regulation plans focused primarily on the use of IERM output for the 32 key performance indicators presented in Section 3.2. The selection of a smaller set of key PIs was crucially important to meaningful interpretation of the IERM results in the context of the SVM and the decision-making process. The key PIs provide a concise, yet representative summary of the complete set of IERM results. As discussed throughout the preceding sections, the “ratio” approach was adopted for evaluating the key PI responses to alternative regulation plans relative to plan 1958DD. The ratio approach provides a straightforward summary of the relative response across regulation plans and across the key PIs. Because the ratio scores represent a summary of the complete results for a key PI, it is important to use the annual PI results to assist in understanding the direction and magnitude of response indicated by these scores.

It is important to realize that the key PI ratios provide a very good indication of the direction of response for each alternative plan relative to plan 1958DD; however, evaluation of the magnitude of the response requires some assessment of the uncertainty inherent in the underlying PI results. The uncertainty bounds for a majority of the key PIs were identified as being roughly +/-10%. The exceptions to this rule were the fish habitat and population PIs for LO and USL, which were associated with an uncertainty range of +/- 5% based on discussions with the ETWG fish subgroup. The uncertainty bounds can be used to determine which key PI ratios represent a significant difference between a given alternative plan and the baseline (plan 1958DD). For example, using an uncertainty range of +/- 10%, a ratio of 1.15 for plan “X” would represent a significant improvement in the PI response for that plan relative to 1958DD. Continuing with this example, a ratio of 1.05 for plan “Y” would not necessarily represent a significant improvement, although the ratio does indicate movement in the right direction (i.e., improvement over the baseline).

The use of the key PIs and associated bounds of uncertainty provide a framework for evaluating PI responses to a variety of plans, and developing a ranking for candidate plans. The key PI ratios reported for a given alternative regulation plan can be summarized in a number of ways, including:

- Counting the total percentage of significant gains/losses based on the pre-defined uncertainty bounds (i.e., emphasize direction and magnitude of response);

- Counting the total percentage of significant gains/losses without considering the uncertainty bounds (i.e., emphasize direction of response);
- Evaluating trade-offs within the key PIs by comparing minimum and maximum scores for the 3 LOSL regions (LO, USL, and LSL); and
- Applying a weighting scheme to develop an overall “index of ecological integrity” to compare relative plan performance.

The plan evaluation techniques described above are straightforward to apply with the exception of the overall index of ecological integrity. The index of ecological integrity was developed by LTI as an additional tool for summarizing and comparing plan results. The index was developed based on a weighting scheme that assigns weighting factors to individual PIs, PI groups within the 3 LOSL regions, and the 3 LOSL regions (Table 3-5). Based on these weighting factors, the PI ratios are collapsed into group weighted average ratios, region weighted average ratios, and finally a single index of ecological integrity. The complete weighting scheme and an example application for one of the regulation plans are provided in Appendix C, Table C-6.

It is important to note that the overall index of ecological integrity provides an overview of the key PI results, but the index by itself should not be considered sufficient to evaluate and rank plans. The index is most valuable as a screening tool to determine which plans perform poorly relative to 1958DD or much better than 1958DD. Important differences between regulation plans, such as the number and magnitude of ecological losses relative to 1958DD, will be obscured by the index. Therefore, it is important to always evaluate the individual key PI ratios in addition to the index of ecological integrity.

Ultimately, a combination of the plan evaluation approaches outlined above should be used to inform plan ranking and the decision-making process. It is important that these techniques be used to evaluate plan responses across multiple supply scenarios, including the historical and stochastic series. Unlike a majority of the economic and social PIs included in the SVM, the environmental PIs are strongly dependent on serial effects of hydrology/hydraulics and habitat response. As a result, alternate 101-year supply sequences can produce very different responses for a key PI, even if the overall supply distribution is similar. In addition, evaluating the results of the historical scenario alone may be misleading because artifacts of the supply sequence may have an important impact on the relative response of one or more key PIs. On the other hand, the use of the stochastic supply scenarios in addition to the historical supply scenario allows for a more complete evaluation of the anticipated long-term improvement or detriment to each key PI. The use of stochastic results is particularly important for the lower St. Lawrence River key PIs because the first 60 years of the historical supply period (i.e., 1900-1959) is based on an historical representation of seasonal flow contributions from the Ottawa River that does not reflect recent flow management practices. As a result, LSL key PI results generated for the 1900-1959 period are not considered in the evaluation of plans within the IERM or SVM.

The use of the climate change scenarios to evaluate the performance of the key ecological PIs for different plans is not advised. The climate change scenarios represent different climate conditions applied to the historical period 1960-1988. Because this period only includes 29 years, it is necessary to repeat the supply sequence 3+ times to obtain a complete 101-year time series. The 29-year series begins with several years of extreme low water level conditions followed by an extended (25-year) period of high supplies. Therefore, the artificial 101-year supply sequence developed based on the 29-year time series does not reflect a typical (or even realistic) trend of supplies over a century. Because a majority of the ecological PIs represented in the IERM are serially dependent on hydrology and/or habitat, the artifacts present in the 101-year climate change time series will result in the calculation of unreliable and misleading PI responses. It is important to note that the stochastic supply scenarios produce a range of supply conditions that are similar to the range of supplies observed in the climate change scenarios. Therefore, it is best practice to simply use the historical and stochastic scenarios to evaluate the response of key ecological PIs to a variety of supply conditions.

## 3.5 EXAMPLE APPLICATION

At the Study Board Decision Workshop in April 2005, PFEG presented three categories of regulation plans to the Study Board for its consideration:

- Reference Plans – regulation plans that alternative plans can be compared against (1958DD, Preproject, 1958D, 1998);
- Option Plans – regulation plans to be considered as viable options for recommendation to the IJC (Cornell 5 – "A", Natural Y – "B", Benefits – "D", Preproject-ice – "E"); and
- Fencepost Plans – regulations plan that are not viable options, but serve as optimal or "fencepost" plans for a particular interest (OntRip3, RecBoat).

For simplicity and clarity, only the two key reference plans (1958DD, Preproject) and the four options plans (A, B, D, E) are included in the following plan evaluation exercise. The IERM was used to simulate the response of key ecological PIs to regulation plans A, B, D, and E for 5 supply scenarios:

- Historical (H) – century based on 1900-2000 historical supplies;
- Stochastic #1 (S1) – century with the driest segment;
- Stochastic #2 (S2) – century with the wettest segment;

- Stochastic #3 (S3) – century with supply distribution similar to historical; and

- Stochastic #4 (S4) – century with the longest drought.

Ratios relative to reference plan 1958DD were computed for each of the 4 option plans (A, B, D, E) as well as the pure Preproject plan (PP). The uncertainty bounds (+/-5% and +/-10%) described in Section 3.4 were used to determine which PIs were significantly positively or adversely affected under a given regulation plan and supply scenario. The results of this analysis are tabulated in Table 3-5. In this table, the total number of key PI gains/losses is shown in parentheses, and the net score (gains minus losses) is shown at the top of the cell. The "Net Gain/Loss" column shows the total gains/losses and net score across all 5 supply scenarios. The complete set of key PI ratios for the regulations plans and supply scenarios shown in Table 3-5 are provided in Appendix C, Tables C-1 thru C-5.

**Table 3-5. Plan Evaluation: Gain/Loss Summary for Key Ecological PIs**

| Regulation Plan | Historical Supply | S1 Supply | S2 Supply | S3 Supply | S4 Supply | Net Gain/Loss |
|---|---|---|---|---|---|---|
| 1958DD | 0<br>(0/0) | 0<br>(0/0) | 0<br>(0/0) | 0<br>(0/0) | 0<br>(0/0) | **0**<br>**(0/0)** |
| Cornell 5<br>("A") | +2<br>(5/3) | -1<br>(6/7) | +6<br>(7/1) | +10<br>(11/1) | -6<br>(7/13) | **+11**<br>**(36/25)** |
| Benefits<br>("D") | -1<br>(2/3) | +2<br>(8/6) | +6<br>(8/2) | +7<br>(9/2) | -2<br>(4/6) | **+12**<br>**(31/19)** |
| Natural Y<br>("B") | +4<br>(7/3) | +5<br>(6/1) | +14<br>(14/0) | +8<br>(9/1) | +2<br>(5/3) | **+33**<br>**(41/8)** |
| PreProject-ice<br>("E") | +8<br>(11/3) | +8<br>(9/1) | +14<br>(14/0) | +14<br>(15/1) | +2<br>(9/7) | **+46**<br>**(58/12)** |
| PreProject<br>(PP) | +9<br>(12/3) | +8<br>(9/1) | +14<br>(14/0) | +14<br>(15/1) | +2<br>(9/7) | **+47**<br>**(59/12)** |

The results shown in Table 3-5 provide can be used to rank the option plans based on their performance in terms of gains/losses relative to 1958DD and PreProject, which effectively serves as the environmental "fencepost" plan. Looking across the 5 supply scenarios, the net scores (gains minus losses) for PreProject (+47) are greatest of all of the plans. PreProject-ice ("E") scores essentially the same as PreProject (+46), which is to be expected due to the similarities between these two plans (PreProject-ice applies constraints to winter releases based on ice formation). Of the three other option plans, plan "B" scores the next best with a net score of +33. It is interesting to note the results for plan "B" indicate that this plan has fewer gains and losses relative to PreProject-ice ("E"). Plans "A" (+11) and "D" score similarly (+12), and both of these plans have substantially less gains and/or more losses than plan "B."

The index of ecological integrity, which was discussed in detail in Section 3.4, is a second "tool" that can be used to evaluate the relative performance of the option plans. Indices of ecological integrity are tabulated in Table 3-6 for the 4 option plans (A, B, D, E), plan 1958DD, and PreProject for the 5 supply scenarios. In this table, the relative ranking (1-4) of each option plan for a given scenario is indicated below the index value in each cell. The "Average Index" column at the far right provides the average index across the 5 supply scenarios and the corresponding ranking. The complete weighting scheme used to compute the indices of ecological integrity and an example application to plan "B" are provided in Appendix C, Table C-6.

**Table 3-6. Plan Evaluation: Ecological Integrity Indices**

| Regulation Plan | Historical Supply | S1 Supply | S2 Supply | S3 Supply | S4 Supply | Average Index |
|---|---|---|---|---|---|---|
| 1958DD | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | **1.00** |
| Cornell 5 ("A") | 1.15 (3) | 1.11 (3) | 1.07 (4) | 1.15 (3) | 0.96 (3) | **1.09 (3)** |
| Benefits ("D") | 1.03 (4) | 0.98 (4) | 1.08 (3) | 1.12 (4) | 0.93 (4) | **1.03 (4)** |
| Natural Y ("B") | 1.41 (2) | 1.40 (2) | 1.35 (2) | 1.37 (2) | 2.35 (2) | **1.58 (2)** |
| PreProject-ice ("E") | 3.97 (1) | 2.34 (1) | 1.93 (1) | 4.62 (1) | 2.76 (1) | **3.12 (1)** |
| PreProject (PP) | 3.88 | 2.27 | 1.93 | 4.60 | 2.58 | **3.05** |

Overall, the net/raw gain and loss scores reported in Table 3-5 and the ecological integrity indices reported in Table 3-6 suggest the following ranking for the option plans:

4. <u>Plan "E"</u> – this plan has the highest gain/loss net score and the highest index of ecological integrity for all supply scenarios;

5. <u>Plan "B"</u> – this plan has the second highest gain/loss net score for 4/5 supply scenarios, and the second highest index of ecological integrity for all supply scenarios; and

6. <u>Plans "A" / "D"</u> – these two plans score very similarly for both the gain/loss net score and the index of ecological integrity.

For both performance metrics, plan "A" and plan "D" perform only marginally better than plan 1958DD. Plan "B" clearly ranks well above plan "A" and plan "D" because it maximizes ecological gains and minimizes ecological losses across all five supply scenarios.

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# APPENDICES

# APPENDIX A - KEY PI FACT SHEETS

**PI Name/Short Description:** Wetland Meadow Marsh Community – surface area, supply-based (Lake Ontario & Thousand Islands) **[E1]**

**Technical Workgroup:** Environmental TWG

**Researched By:** Wilcox, Ingram
**Modeled By:** Eastern Michigan University, LTI (Redder, DePinto)

**Performance Indicator Metric:** Basin level area estimate of meadow marsh vegetation (hectares/year) in years following a low water supply period.

**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 to 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 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 great diversity of plant species, but it occurs in a relatively narrow hydrologic range in comparison to the other wetland vegetation communities.

Awned sedge (*Carex atherodes*) was also documented to occur in Lake Ontario coastal wetlands and within the meadow marsh community specifically. Awned sedge is designated as endangered in New York State.

**Temporal Validity:** An area estimate is computed for each 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 frequency of flooding and dewatering at specific elevations.

**Spatial Validity:** Percent cover of meadow marsh habitat is computed using generalized wetland plant community and elevation models for four wetland types. The generalized plant community and elevation models are assumed to be representative of all coastal wetlands of each geomorphic type located within all the Lake Ontario shore units and the Upper St. Lawrence RIV 1 shore unit (see Calibration Data). As such, the model outputs are extrapolated to a complete coastal wetland database for Lake Ontario and the Upper St. Lawrence River to obtain a basin-level annual estimate of meadow marsh area.

**Hydrology Link:** Wetland plant community evolution is strongly dependent on the hydroperiod (i.e., flooding and dewatering history) at a particular elevation. The wetland plant model uses flooding and dewatering intervals at specific elevations based on a 0.05-meter interval between 73.00 and 75.75 meters (IGLD85) to assign a plant community, such as meadow marsh or emergent marsh to those elevations on an annual basis.

**Algorithm:** The performance indicator model is based upon field sampling completed for the IJC study. Specific elevations with ecological significance based on past water-level history were located and sampled within 32 wetland study sites. Since the existing wetland vegetation in the lake has developed in response to the history of high and low lake levels, the selected elevations reflect unique growing season water-level histories. The elevations (IGLD85) are as follows: A) 75.60 m, last flooded 30 years ago; B) 75.45 m, last flooded 10 years ago; C) 75.35 m, last flooded 5 years ago; D) 75.0 m, last flooded 1 year ago and last dewatered during growing season 2 years ago (variable flooding and dewatering over past 3 years); E) 74.85 m, last dewatered during growing season 4 years ago; F) 74.7 m last dewatered during growing season 38 years ago; G) 74.25 m, last dewatered during growing season 68 years ago.

Vegetation assignments to various elevations ranges are based upon the following vegetation rules-based models.

**Open Embayment Wetlands**

Not flooded >30 years: assign to U (transition to Upland) and go up to elevation of 75.75m
Not flooded 5-30 years: assign to (A+B+C) and go up to elevation of 75.75m
Not flooded <5 years or not dewatered <4 years: assign to (D)
Not dewatered 4-39 years: assign to (E+F)
Not dewatered 40 years or more: assign to (G) and go down to elevation of 73.0m

**Protected Embayment Wetlands**

Not flooded >30 years: assign to U (transition to Upland) and go up to elevation of 75.75m
Not flooded 5-30 years: assign to (A+B+C) and go up to elevation of 75.75m
Not flooded <5 years or not dewatered <4 years: assign to (D)
Not dewatered 4-20 years: assign to (E)
Not dewatered 21-39 years: assign to (F)
Not dewatered 40 years or more: assign to (G) and go down to elevation of 73.0m

**Barrier Beach Wetlands**

Not flooded >30 years: assign to U (transition to Upland) and go up to elevation of 75.75m
Not flooded 5-30 years: assign to (A+B+C) and go up to elevation of 75.75m
Not flooded <5 years or not dewatered <4 years: assign to (D)
Not dewatered 4-39 years: assign to (E+F)
Not dewatered 40 years or more: assign to (G) and go down to lowest elevation in model

**Drowned River Mouth Wetlands**

Not flooded >30 years: assign to U (transition to Upland) and go up to elevation of 75.75m
Not flooded 5-30 years: assign to (A+B+C) and go up to elevation of 75.75m
Not flooded <5 years or not dewatered <4 years: assign to (D)
Not dewatered 4-39 years: assign to (E+F)

Not dewatered 40 years or more:  assign to (G) and go down to lowest elevation in model

The A+B+C transect plant species assemblage represents a meadow marsh vegetation community within the above wetland models.

**Calibration Data:** Within each of the 32 wetland study sites (8 wetlands of each geomorphic type), quadrat sampling was completed along specific elevation transects (see above) within two randomly placed study areas. In each quadrat, the plant species present were identified, and percent cover estimations were made by visual inspection. Correlations between specific elevations and accompanying vegetation data were analyzed by species prominence using non-metric multidimensional scaling (NMDS). Transects A, B, and C showed the highest species diversity and were similar across wetland types. Transect D vegetation was identified as a second community and was similar across all wetland types. Transects E and F comprised a third community and were similar in all wetland types, except protected embayments in which E and F were separate communities. Vegetation at transect G was identified as the fourth unique community and was also found to be similar across all wetland types.

Plant species were then assigned vegetation structural categories and summarized by mean cover for each unique transect in order to provide generalized habitat information for performance indicator development and faunal models. Based on this analysis, transects A+B+C were assigned to a meadow marsh vegetation community within the wetland models.

**Validation Data:** Wetland vegetation mapping from historically aerial photography of the study sites were used to validate model predictions.

**Documentation & References:**

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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Working Committee 2. 1993. Levels Reference Study, Great Lakes-St. Lawrence River Basin: Annex 2 – Land Use and Management. Levels Reference Study Board.

**Confidence, Significance and Sensitivity:**

**1) Confidence:** Plant quadrat sampling along specific elevations representing unique flooding and dewatering histories clearly demonstrated the ordination of wetland plant species along a hydrologic gradient. The wetland study results only represent a 'snap-shot' in time, but the flooding/dewatering histories of the transects add the time dimension to the study. The timing of response of various plant communities to low and high water-level cycles was inferred from the current plant community distribution, published literature, and expert opinion. Shifts in the distribution and abundance of wetland plant communities in response to changing inter-annual water levels is a certainty, the specific timing of response and persistence of communities may vary from that within the vegetation rules-based model.

The area estimates should be considered as representative for plan comparison and not absolute. Sampling only occurred within a subset of the wetlands, and basin-level estimates were created by extrapolating from generalized models. There will be error in the area estimates for any specific wetland due to in accuracies in the site-level elevation models and extrapolations. Overall, we are very confident in the models and the PI.

**2) Significance:** The wetland habitat models are very significant, as many of the other wetland PIs are dependant 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, but 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 arrest 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 Lake Ontario 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 very great 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 within their life cycle.

Awned sedge (*Carex atherodes*) was also documented to occur in Lake Ontario coastal wetlands and within the meadow marsh community specifically. Awned sedge is designated as endangered in New York State.

**3) Sensitivity:** Regulation of the Lake Ontario and Upper St. Lawrence River system impacts over 1,000 kilometres of shoreline and thousands of hectares of wetlands. Due to the area of influence, small alterations in the hydrograph can lead to large changes in area of wetland habitats and numbers of dependant fauna. Wetland plant communities represent a critical component of habitat requirements for hundreds of fish and wildlife species and must be incorporated into the environmental assessment of alternate water-level regulation plans.

**PI Name/Short Description:** Low Vegetation, 18C fish guild – spawning habitat supply (Lake Ontario) **[E2]**

**Technical Workgroup**: Environmental TWG

**Researchers:** Minns, Doka, (Chu, Bakelaar, Leisti)
**Modeled by:** Moore, LTI (DePinto, Redder)

**Performance Indicator Metric:** This performance indicator represents the annual habitat supply (weighted suitable area) for the LV18 guild spawning in the Lake Ontario reach group located in the Lake Ontario. Emergent vegetation, submergent vegetation, substrate composition, water levels, and reach elevations (used to calculate water depths) are used to compute habitat suitability and supply for the LV18 guild in the Lake Ontario study area. Temperature is used to calculate the appropriate time window for the annual calculations.

**Ecological Importance/Niche:** The members of the LV18 guild occupy shallow water (<20 m) during their life histories and prefer spawning in low vegetation and 18-22 degrees C. The species that comprise the guild have been recorded in the Lake Ontario & St. Lawrence systems and their species-specific habitat requirements have been used to calculate weighed suitable areas in the appropriate part of the system. Specific habitat requirements used for calculations are available (see report section).

**Temporal Validity:** LV18 spawning habitat supply is computed on a daily basis and then summed over an appropriate thermal window to generate annual habitat supply results (in units of hectare-days). Currently, a ratio of annual habitat supplies between baseline (1958DD) and proposed regulation plans is calculated annually and then the ratios are averaged and a coefficient of variation is calculated over the 101-year simulation period.

**Spatial Validity:** This LV18 habitat supply performance indicator is valid for a contiguous group of 2455 reaches and 541 wetlands that comprise the Lake Ontario reach group. The weighted suitable area for different fish guilds, based on thermal and vegetation preference during spawning, are calculated for all reaches within Lake Ontario.

**Hydrology Link:** Habitat suitability for the LV18 guild spawning, which is used to compute weighted suitable area in hectare-days, depends on the interaction between emergent vegetation, submergent vegetation, substrate composition, and water depth in the Lake Ontario study area. Water depth inputs for the habitat suitability model are calculated daily, based on interpolated quarter-monthly water levels. WSAs can be combined across life stages, where appropriate, based on weightings determined by their responsiveness to hydrology.

**Calibration Data:** No specific calibration data are available, 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 of the LV18 guild spawning. Individual habitat components, such as shoreline substrate type and temperatures, have been calibrated with different sources of information.

**Validation Data:** No specific validation datasets are available for weighted suitable areas. Temperatures used in the habitat supply calculations have been validated using simulated data from different thermal models for Lake Ontario or empirical datasets specific to the Lake Ontario study area, when available.

**Algorithm:** Specific equations and algorithms used in the calculation of weighted suitable areas have been documented in IJC Lake Ontario – St. Lawrence Study reports (available at ftp://wtoftpa.on.ec.gc.ca) and are too extensive to list here. The equations are part of a habitat supply submodel and database of the IERM for the LV18 guild in Lake Ontario.

**Documentation & References:** The documentation and details of the algorithms used to calculate this PI are summarized in:

Minns, C.K.; S. Doka; C. Bakelaar; C. Chu; K. Leisti, and J.E. Moore. 2005. Year 4 Final Report for Burlington Fish Habitat & Modelling Group.

**Risk and Uncertainty Assessment:** 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, weighted suitable area 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.

**PI Name/Short Description:** High Vegetation, 24C fish guild – spawning habitat supply (Lake Ontario) **[E3]**

**Technical Workgroup**: Environmental TWG

**Researched by:** Minns, Doka, (Chu, Bakelaar, Leisti)
**Modeled by:** Moore, LTI (DePinto, Redder)

**Performance Indicator Metric:** This performance indicator represents the annual habitat supply (weighted suitable area) for the HV24 guild spawning in the Lake Ontario reach group located in the Lake Ontario. Emergent vegetation, submergent vegetation, substrate composition, water levels, and reach elevations (used to calculate water depths) are used to compute habitat suitability and supply for the HV24 guild in the Lake Ontario study area. Temperature is used to calculate the appropriate time window for the annual calculations.

**Ecological Importance/Niche:** The members of the HV24 guild occupy shallow water (<20 m) during their life histories and prefer spawning in high vegetation and >=24 degrees C. The species that comprise the guild have been recorded in the Lake Ontario & St. Lawrence systems and their species-specific habitat requirements have been used to calculate weighed suitable areas in the appropriate part of the system. Specific habitat requirements used for calculations are available (see report section).

**Temporal Validity:** HV24 spawning habitat supply is computed on a daily basis and then summed over an appropriate thermal window to generate annual habitat supply results (in units of hectare-days). Currently, a ratio of annual habitat supplies between baseline (1958DD) and proposed regulation plans is calculated annually and then the ratios are averaged and a coefficient of variation is calculated over the 101-year simulation period.

**Spatial Validity:** This HV24 habitat supply performance indicator is valid for a contiguous group of 2455 reaches and 541 wetlands that comprise the Lake Ontario reach group. The weighted suitable area for different fish guilds, based on thermal and vegetation preference during spawning, are calculated for all reaches within Lake Ontario.

**Hydrology Link:** Habitat suitability for the HV24 guild spawning, which is used to compute weighted suitable area in hectare-days, depends on the interaction between emergent vegetation, submergent vegetation, substrate composition, and water depth in the Lake Ontario study area. Water depth inputs for the habitat suitability model are calculated daily, based on interpolated quarter-monthly water levels. WSAs can be combined across life stages, where appropriate, based on weightings determined by their responsiveness to hydrology.

**Calibration Data:** No specific calibration data are available, 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 of the HV24 guild spawning. Individual habitat components, such as shoreline substrate type and temperatures, have been calibrated with different sources of information.

**Validation Data:** No specific validation datasets are available for weighted suitable areas. Temperatures used in the habitat supply calculations have been validated using simulated data from different thermal models for Lake Ontario or empirical datasets specific to the Lake Ontario study area, when available.

**Algorithm:** Specific equations and algorithms used in the calculation of weighted suitable areas have been documented in IJC Lake Ontario – St. Lawrence Study reports (available at ftp://wtoftpa.on.ec.gc.ca) and are too extensive to list here. The equations are part of a habitat supply submodel and database of the IERM for the HV24 guild in Lake Ontario.

**Documentation & References:** The documentation and details of the algorithms used to calculate this PI are summarized in:

Minns, C.K.; S. Doka; C. Bakelaar; C. Chu; K. Leisti, and J.E. Moore. 2005. Year 4 Final Report for Burlington Fish Habitat & Modelling Group.

**Risk and Uncertainty Assessment:** 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, weighted suitable area 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.

**PI Name/Short Description:** Low Vegetation, 24C fish guild – spawning habitat supply (Lake Ontario) **[E4]**

**Technical Workgroup**: Environmental TWG

**Researched by:** Minns, Doka, (Chu, Bakelaar, Leisti)
**Modeled by:** Moore, LTI (DePinto, Redder)

**Performance Indicator Metric:** This performance indicator represents the annual habitat supply (weighted suitable area) for the LV24 guild spawning in the Lake Ontario reach group located in the Lake Ontario. Emergent vegetation, submergent vegetation, substrate composition, water levels, and reach elevations (used to calculate water depths) are used to compute habitat suitability and supply for the LV24 guild in the Lake Ontario study area. Temperature is used to calculate the appropriate time window for the annual calculations.

**Ecological Importance/Niche:** The members of the LV24 guild occupy shallow water (<20 m) during their life histories and prefer spawning in low vegetation and >=24 degrees C. The species that comprise the guild have been recorded in the Lake Ontario & St. Lawrence systems and their species-specific habitat requirements have been used to calculate weighed suitable areas in the appropriate part of the system. Specific habitat requirements used for calculations are available (see report section).

**Temporal Validity:** LV24 spawning habitat supply is computed on a daily basis and then summed over an appropriate thermal window to generate annual habitat supply results (in units of hectare-days). Currently, a ratio of annual habitat supplies between baseline (1958DD) and proposed regulation plans is calculated annually and then the ratios are averaged and a coefficient of variation is calculated over the 101-year simulation period.

**Spatial Validity:** This LV24 habitat supply performance indicator is valid for a contiguous group of 2455 reaches and 541 wetlands that comprise the Lake Ontario reach group. The weighted suitable area for different fish guilds, based on thermal and vegetation preference during spawning, are calculated for all reaches within Lake Ontario.

**Hydrology Link:** Habitat suitability for the LV24 guild spawning, which is used to compute weighted suitable area in hectare-days, depends on the interaction between emergent vegetation, submergent vegetation, substrate composition, and water depth in the Lake Ontario study area. Water depth inputs for the habitat suitability model are calculated daily, based on interpolated quarter-monthly water levels. WSAs can be combined across life stages, where appropriate, based on weightings determined by their responsiveness to hydrology.

**Algorithm:** Specific equations and algorithms used in the calculation of weighted suitable areas have been documented in IJC Lake Ontario – St. Lawrence Study reports (available at ftp://wtoftpa.on.ec.gc.ca) and are too extensive to list here. The equations are part of a habitat supply submodel and database of the IERM for the LV24 guild in Lake Ontario.

**Calibration Data:** No specific calibration data are available, 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 of the LV24 guild spawning. Individual habitat components, such as shoreline substrate type and temperatures, have been calibrated with different sources of information.

**Validation Data:** No specific validation datasets are available for weighted suitable areas. Temperatures used in the habitat supply calculations have been validated using simulated data from different thermal models for Lake Ontario or empirical datasets specific to the Lake Ontario study area, when available.

**Documentation & References:** The documentation and details of the algorithms used to calculate this PI are summarized in:

Minns, C.K.; S. Doka; C. Bakelaar; C. Chu; K. Leisti, and J.E. Moore. 2005. Year 4 Final Report for Burlington Fish Habitat & Modelling Group.

**Risk and Uncertainty Assessment:** 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, weighted suitable area 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.

**PI Name/Short Description:** Northern Pike – young-of-year (YOY) recruitment index (Lake Ontario) **[E5]**

**Technical Workgroup:** Environmental TWG

**Researched by:** Minns, Doka, (Chu, Bakelaar, Leisti), Casselman, Farrell
**Modeled by:** Moore, LTI (DePinto, Redder)

**Performance Indicator Metric:** This performance indicator provides an index of YOY recruitment for Northern pike in Lake Ontario. A daily average of the temperatures within the Lake Ontario area is used to estimate daily growth of Northern pike parameterized for specific life stages. In addition, WSA is used to apply density-dependent effects on growth and survival based on space requirements at different life stages. (See WSA PI documentation for additional information.)

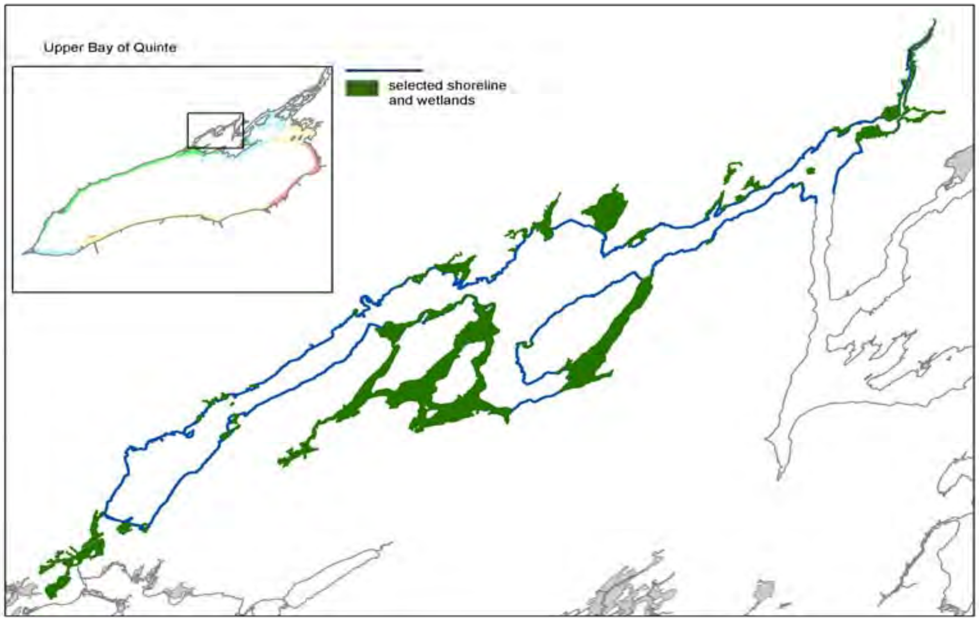
**Ecological Importance/Niche:** Northern pike is an important top predator that is a recreationally important species, spawning in early spring and belonging to the cool water fish guild in nearshore systems.

**Temporal Validity:** Northern pike recruitment is computed on an annual basis and is affected by daily habitat supply results. Each year the total surviving recruits or young-of-the-year are tallied. Currently, a ratio of northern pike recruitment between baseline (1958DD) and proposed regulation plans is calculated annually and then the ratios are averaged and a coefficient of variation is calculated over the 101-year simulation period to generate two metrics for comparison.

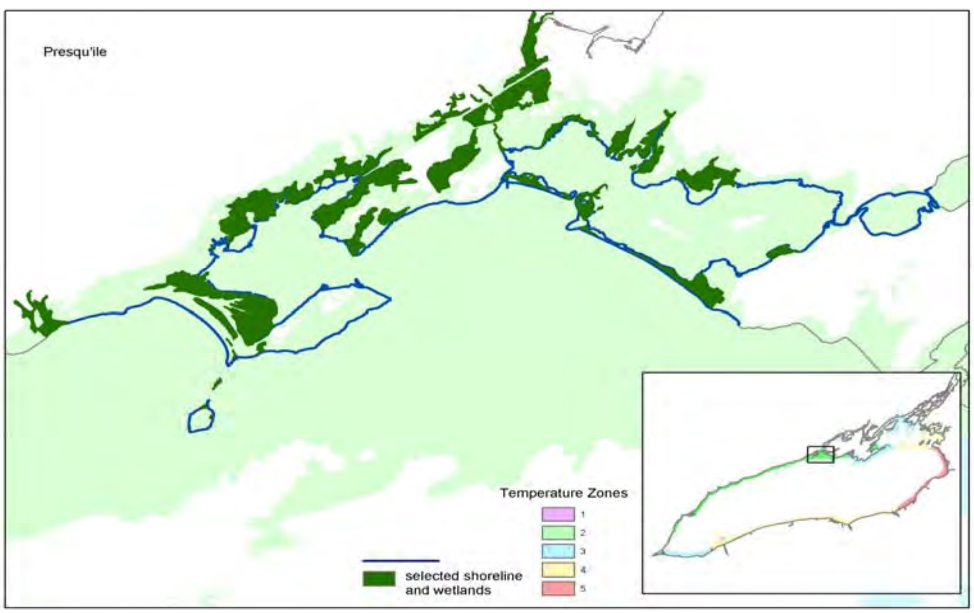
**Spatial Validity:** This northern pike performance indicator is valid for the following six contiguous groups, with the number of reaches and wetlands indicated:

- Bay of Quinte: 279 reaches and 56 wetlands
- Presquile: 139 reaches and 31 wetlands
- North Central Shore: 100 reaches and 19 wetlands
- West Shore: 83 reaches and 9 wetlands
- South Central Shore: 102 reaches and 33 wetlands
- Outlet Basin: 141 reaches and 51 wetlands

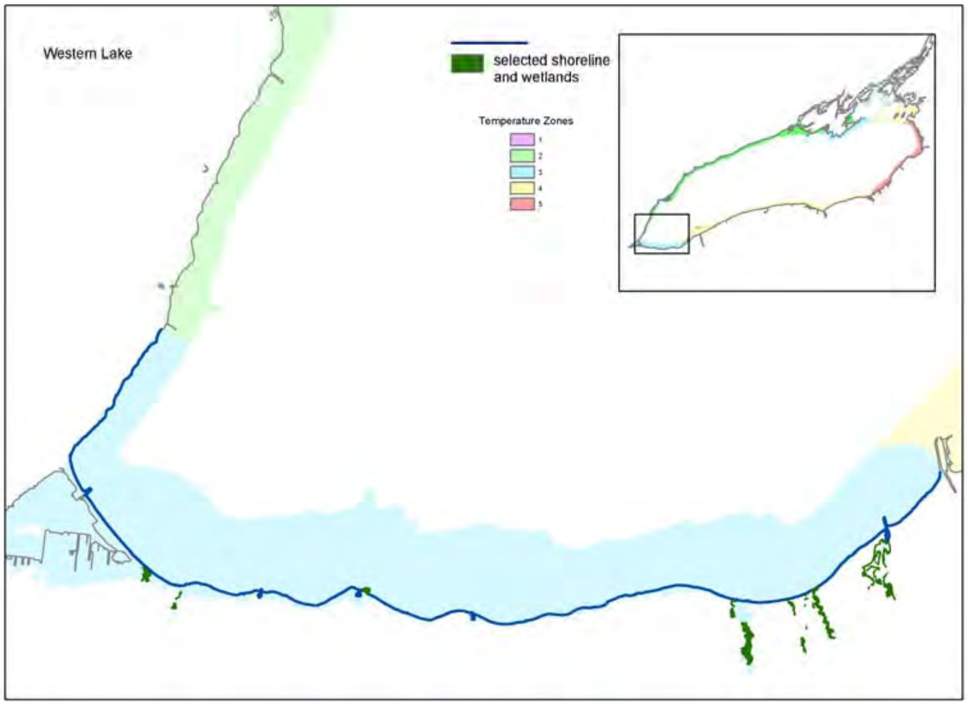
Each reach group was selected to represent temperature zones, sampled wetlands, and different geographic regions across Lake Ontario. The size of the reach group area is adequate for supporting distinct northern pike populations. Population estimates can be combined across reach groups, where appropriate, based on weightings determined by responsiveness to hydrologic changes. The population modeling reach groups were selected based on habitat variables such as temperature zone, presence of sampled wetlands and represent general geographic zones across the lake. The size of the reach group area is adequate for supporting distinct northern pike populations. WSAs can be combined across reach groups with a region, where appropriate, based on weightings determined by responsiveness of the PI to hydrology.



Upper Bay of Quinte
selected shoreline
and wetlands

Presqu'ile
Temperature Zones
1
2
3
4
5
selected shoreline
and wetlands


Western Lake
selected shoreline
and wetlands
Temperature Zones
1
2
3
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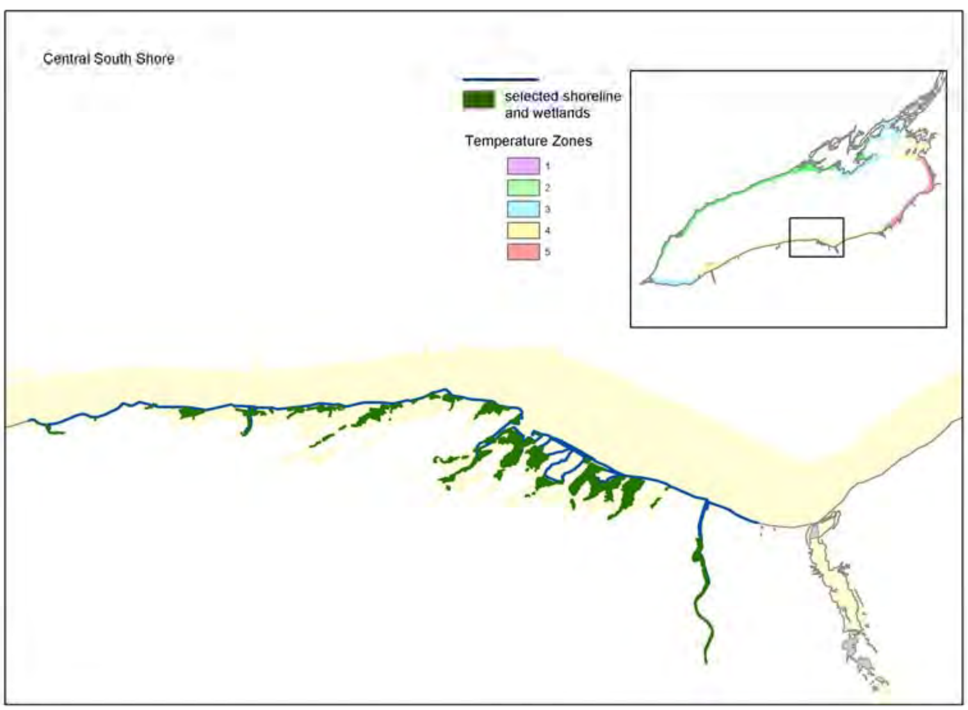
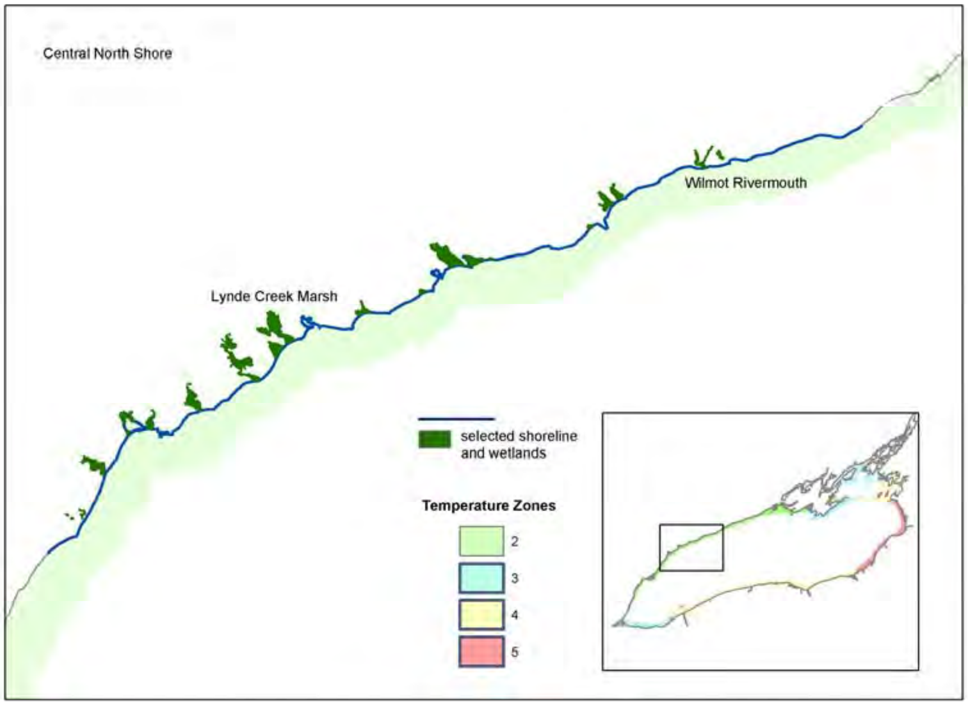
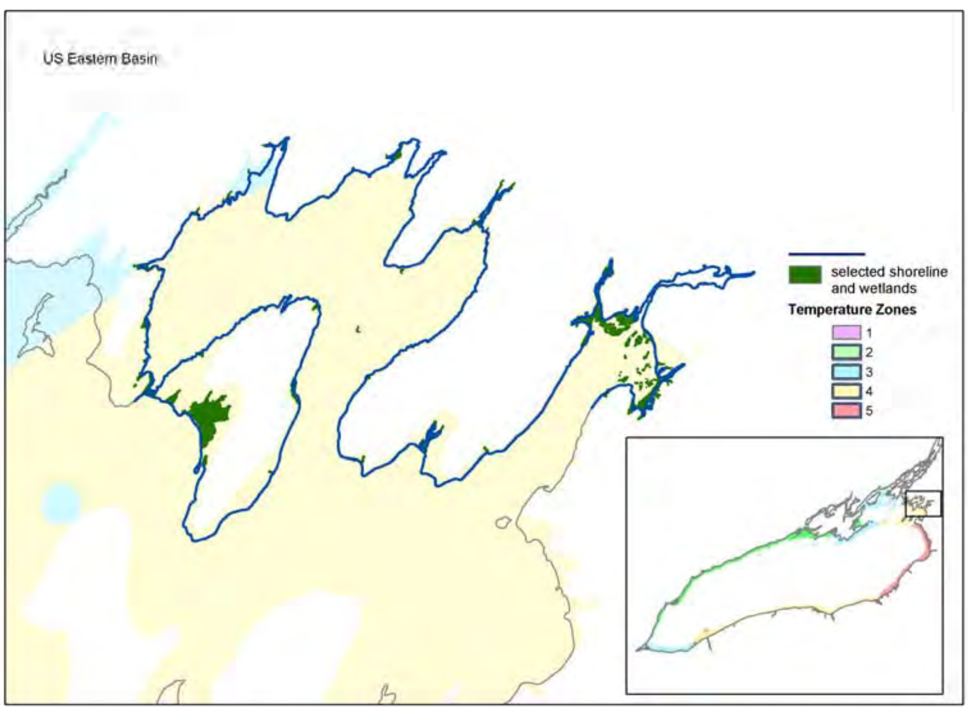
5


Central South Shore
selected shoreline
and wetlands
Temperature Zones
1
2
3
4
5


Central North Shore
Wilmot Rivermouth
Lynde Creek Marsh
selected shoreline
and wetlands
Temperature Zones
2
3
4
5


US Eastern Basin
selected shoreline
and wetlands
Temperature Zones
1
2
3
4
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**Hydrology Link:** Daily weighted suitable area, partly a function of hydrology, is used to calculate the density-dependent effects on growth and mortality of the appropriate life stages of northern pike in the six study areas. In addition, a stranding factor is applied to the northern pike spawning component of the model. This factor simulates the mortality of developing eggs and hatchlings associated with catastrophic stranding events in wetland and nearshore habitats. A decrease in water level results in a proportional decrease in egg and hatchling survival.

**Calibration Data:** No specific calibration data are available for northern pike recruitment, but the bioenergetic and mortality rates used are based on a large body of literature and information available on the species in the Great Lakes. Bioenergetics parameters used in the northern pike model for early life stages were calibrated specifically for the IJC study area (Farrell).

**Validation Data:** No specific validation datasets are available for weighted suitable areas. Temperatures used in the habitat supply calculations have been validated using simulated data from different thermal models for Lake Ontario or empirical datasets specific to the study areas, when available.

**Algorithm:** Specific equations and algorithms used in the calculation of weighted suitable areas have been documented in IJC Lake Ontario – St. Lawrence Study reports (available at ftp://wtoftpa.on.ec.gc.ca) and are too extensive to list here. The equations are part of a habitat supply submodel and database of the IERM for northern pike in Lake Ontario.

**Documentation & References:** The documentation and details of the algorithms used to calculate this PI are summarized in:

Minns, C.K.; S. Doka; C. Bakelaar; C. Chu; K. Leisti, and J.E. Moore. 2005. Year 4 Final Report for Burlington Fish Habitat & Modelling Group.

**Risk and Uncertainty Assessment:** Population models assume prey is abundant and growth is limited by density-dependent effects and temperature. Uncertainties exist in our density-dependent effects on growth, as currently growth decreases as densities increase. Currently cumulative uncertainties have not been estimated but errors and uncertainties exist at four levels of the analysis: spatial habitat information, habitat models, weighted suitable area calculations, and population models. The relative differences between scenarios should be equally affected by these cumulative uncertainties.

**PI Name/Short Description:** Largemouth Bass – young-of-year (YOY) recruitment index (Lake Ontario) **[E6]**

**Technical Workgroup:** Environmental TWG

**Researched by:** Minns, Doka, (Chu, Bakelaar, Leisti), Casselman, Farrell
**Modeled by:** Moore, LTI (Redder, DePinto)

**Performance Indicator Metric:** This performance indicator provides an index of YOY recruitment for Largemouth Bass in Lake Ontario. A daily average of the temperatures within the selected areas is used to estimate daily growth of largemouth bass parameterized for specific life stages. In addition, WSA is used to apply density-dependent effects on growth and survival based on space requirements at different life stages. (See WSA PI documentation for additional information.)

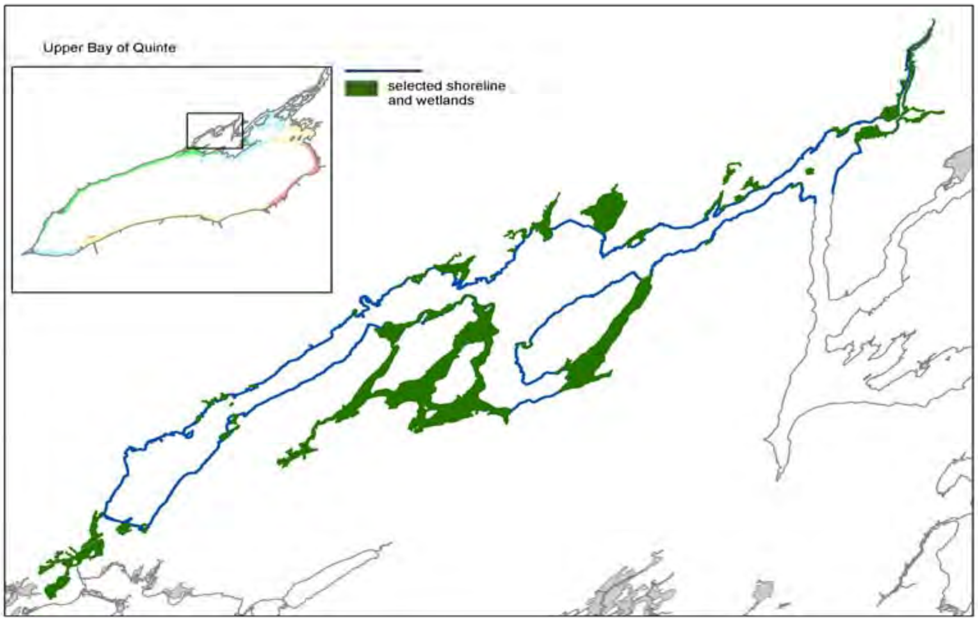
**Ecological Importance/Niche:** Largemouth bass is an important predator that is a recreationally important species, spawning in summer and belonging to the warm water fish guild in nearshore systems.

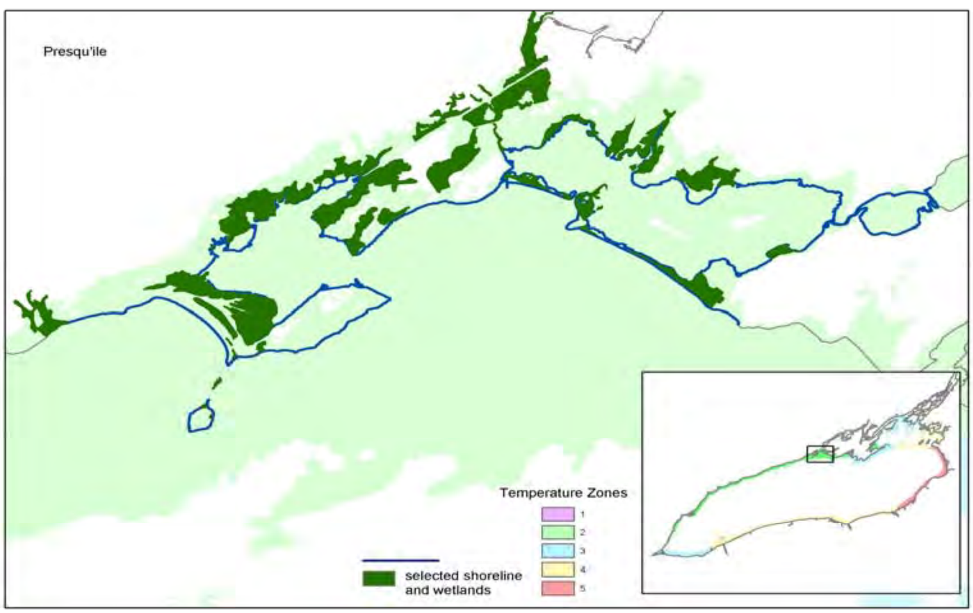
**Temporal Validity:** Largemouth bass recruitment is computed on an annual basis and is affected by daily habitat supply results. Each year the total surviving recruits or young-of-the-year are tallied. Currently, a ratio of largemouth bass recruitment between baseline (1958DD) and proposed regulation plans is calculated annually and then the ratios are averaged and a coefficient of variation is calculated over the 101-year simulation period to generate two metrics for comparison.

**Spatial Validity:** This largemouth bass performance indicator is valid for the following six contiguous groups, with the number of reaches and wetlands indicated:

- Bay of Quinte: 279 reaches and 56 wetlands
- Presquile: 139 reaches and 31 wetlands
- North Central Shore: 100 reaches and 19 wetlands
- West Shore: 83 reaches and 9 wetlands
- South Central Shore: 102 reaches and 33 wetlands
- Outlet Basin: 141 reaches and 51 wetlands

Each reach group was selected to represent temperature zones, sampled wetlands, and different geographic regions across Lake Ontario. The size of the reach group area is adequate for supporting distinct largemouth bass populations. Population estimates can be combined across reach groups, where appropriate, based on weightings determined by responsiveness to hydrologic changes. The population modeling reach groups were selected based on habitat variables such as temperature zone, presence of sampled wetlands and represent general geographic zones across the lake. The size of the reach group area is adequate for supporting distinct largemouth bass populations. WSAs can be combined across reach groups with a region, where appropriate, based on weightings determined by responsiveness of the PI to hydrology.


Upper Bay of Quinte
selected shoreline
and wetlands


Presqu'ile
Temperature Zones
1
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3
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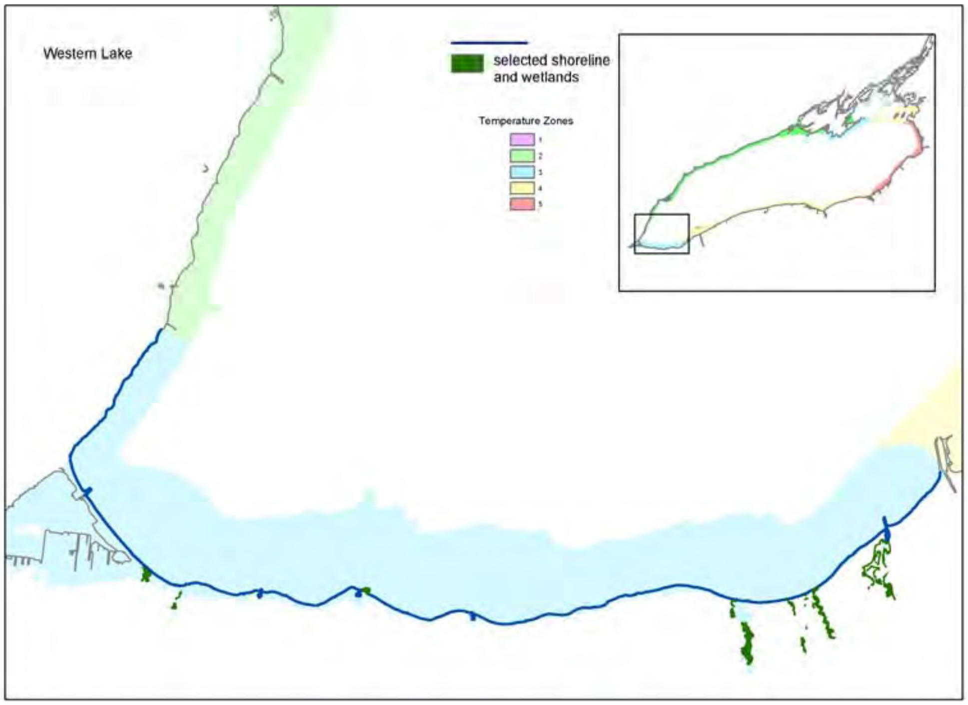
5
selected shoreline
and wetlands


Western Lake
selected shoreline and wetlands
Temperature Zones
1
2
3
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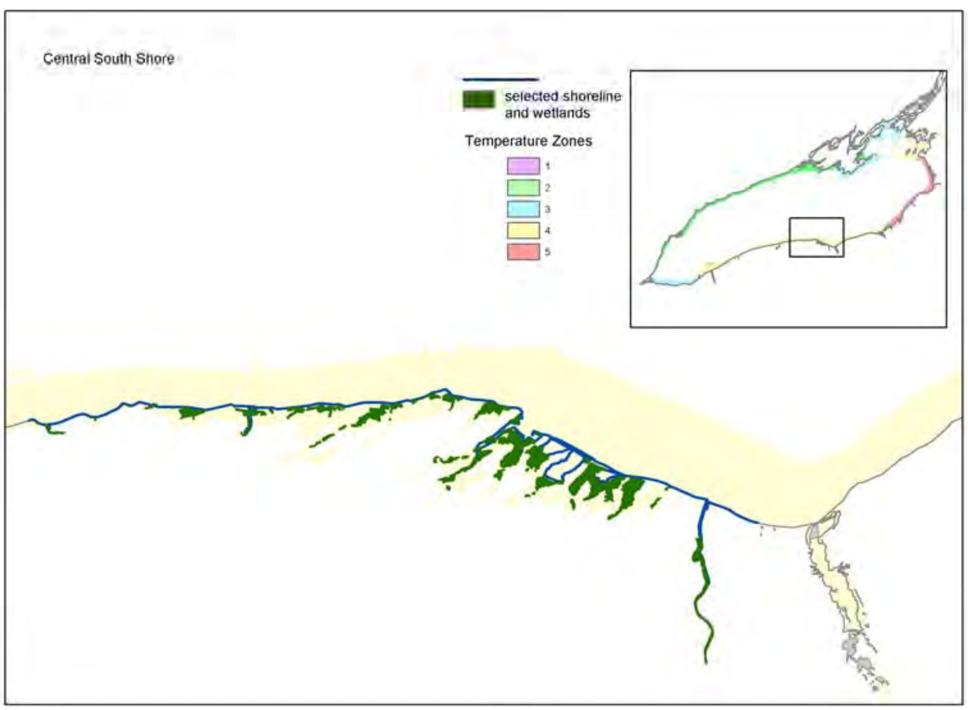
5


Central South Shore
selected shoreline and wetlands
Temperature Zones
1
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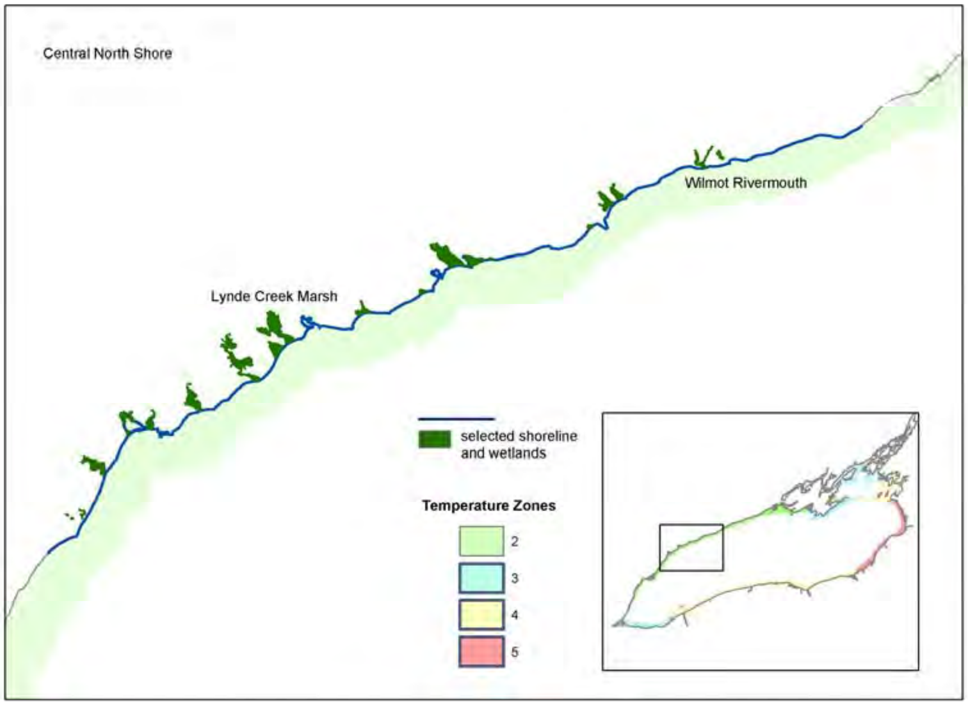
Central North Shore
Wilmot Rivermouth
Lynde Creek Marsh
selected shoreline and wetlands
Temperature Zones
2
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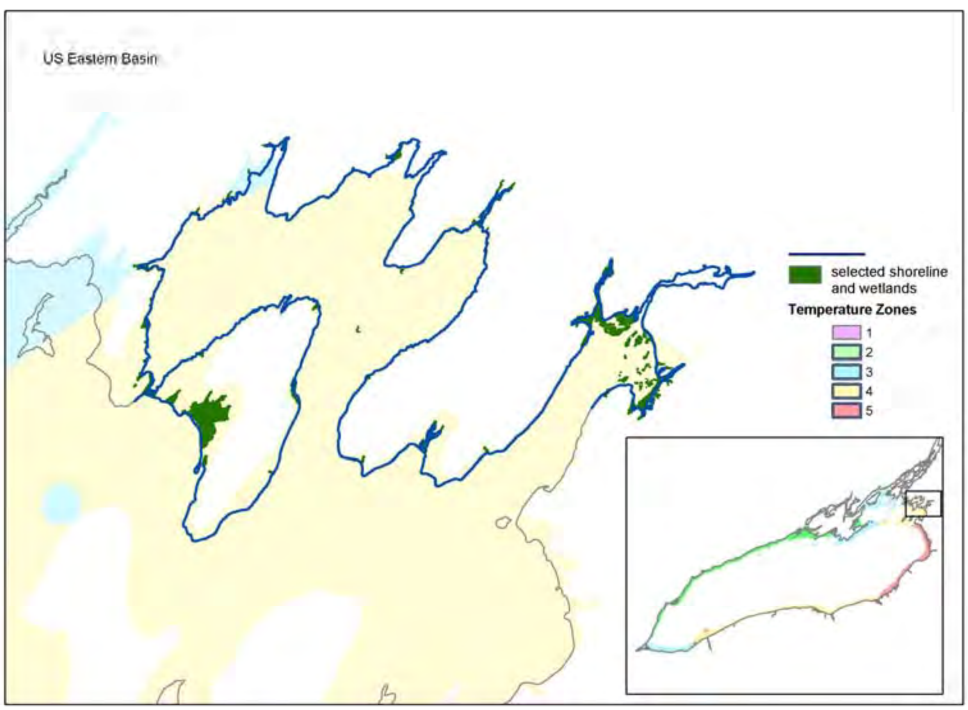
US Eastern Basin
selected shoreline and wetlands
Temperature Zones
1
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3
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**Hydrology Link:** Daily weighted suitable area, partly a function of hydrology, is used to calculate the density-dependent effects on growth and mortality of the appropriate life stages of largemouth bass in the selected study areas.

**Calibration Data:** No specific calibration data are available for largemouth bass recruitment, but the bioenergetic and mortality rates used are based on a large body of literature and information available on the species in the Great Lakes.

**Validation Data:** No specific validation datasets are available for weighted suitable areas. Temperatures used in the habitat supply calculations have been validated using simulated data from different thermal models for Lake Ontario or empirical datasets specific to the study areas, when available.

**Algorithm:** Specific equations and algorithms used in the calculation of weighted suitable areas have been documented in IJC Lake Ontario – St. Lawrence Study reports (available at ftp://wtoftpa.on.ec.gc.ca) and are too extensive to list here. The equations are part of a habitat supply submodel and database of the IERM for largemouth bass in Lake Ontario.

**Documentation & References:** The documentation and details of the algorithms used to calculate this PI are summarized in:

Minns, C.K.; S. Doka; C. Bakelaar; C. Chu; K. Leisti, and J.E. Moore. 2005. Year 4 Final Report for Burlington Fish Habitat & Modelling Group.

**Risk and Uncertainty Assessment:** Population models assume prey is abundant and growth is limited by density-dependent effects and temperature. Uncertainties exist in our density-dependent effects on growth, as currently growth decreases as densities increase. Currently cumulative uncertainties have not been estimated but errors and uncertainties exist at four levels of the analysis: spatial habitat information, habitat models, weighted suitable area calculations, and population models. The relative differences between scenarios should be equally affected by these cumulative uncertainties.

**PI Name/Short Description:** Virginia Rail (*Rallus limnicola*) - reproductive index in emergent marsh **[E7, E18, E24]**

**Technical Workgroup:** Environmental TWG

**Researched by**: Drolet,B., J. Ingram, J.-L. DesGranges
**Modeled by:** Drolet, B., J. Ingram, J. Morin, S. Martin, O. Champoux, T. Redder

**Performance Indicator Metric:** This PI represents an index of reproductive potential in emergent marsh during the breeding season, based on the carrying capacity, an annual estimate of the number of potential breeding pairs in emergent marsh weighted by water depth and water level increase and decrease, multiplied by an annual estimate of nest success, based on the probability that a breeding female will successfully hatch a nest, according to the magnitude of water level changes.

The PI response includes an aggregation of annual index values into a 2 year moving mean value. This smoothing technique was used to reduce extreme annual PI values and incorporate a lag in the response of the PI to changing habitat conditions. The aggregated 100 year plan scenarios are expressed by the percent of time that the PI index exceeds the first quartile value for plan 1958DD for the comparable water supply series (e.g. Historic, S1, S2 S3, etc). This metric will be used for plan evaluation by calculating a ratio of metrics between two plans.

**Ecological Importance/Niche:** The North American Bird Conservation Initiative (NABCI) considers the Lower Great Lakes/St. Lawrence plain (BCR 13) critical to the natural cycle of the Virginia Rail.

**Temporal validity:** Valid for the Virginia Rail breeding season from the second week of May to the end of July (QM 18 to QM 28). The PI does not consider cumulative effects from previous years.

**Spatial validity:** Valid for the Lake Ontario, Upper St. Lawrence River Unit 1 and 3, and the Lower St. Lawrence River to Lake Saint-Pierre (except Lake Saint-François and Laprairie Basin) where emergent marsh exists.

**Hydrology Link:** Virginia Rail construct nests close to the ground in emergent marsh vegetation, and prefer marsh habitat that is flooded, but will also breed in unflooded marsh vegetation near water. Emergent marsh habitat availability is directly linked to long term water supplies. The percentage of marsh habitat flooded or stranded, and the rate of water level change (rapid rise > 20cm) are also important annual hydrologic factors. During the nesting period, water levels increases can drown eggs and chicks. Water level decreases can increase ground predator access to nests.

**Algorithm:** This PI is influenced by hydraulic attributes responsible for emergent marsh surface area. More specifically, its algorithm was developed using Lower St. Lawrence hydrologic values based on a 2D water level and topographic model, for the carrying capacity values, and upon Ontario and Québec nest record data of nesting chronology, nest heights and water depths below the nest, for the nest success rate. Three hydraulic attributes were considered: *mean water depth*, the maximum *water level increase* and the maximum *water level decrease*.

The algorithm for the Virginia Rail reproduction success PI (index) is made from the multiplication of the carrying capacity values (estimated number of breeding pairs) and nest success rate.

***Carrying capacity:*** The algorithm is base on water depth relationship with the density of breeding pairs, weighted by a persistency rate of breeding activities due to water increase and/or decrease using a water increase and a water decrease index (Tab.1 and 2). The water increase and water decrease index were determined using 1) the highest increase index and the highest decrease index of water level (in meters) between two quarter-months during the breeding period, 2) the wetland transition before and after fluctuation and, 3) for water decrease index, the water depth after drop (Table 1 and 2).

Virginia Rail carrying capacity value = $(0.0690 + 0.3040 * WD – 0.1929 * WD^2) * P_{rate}$

Where: WD = water depth; $P_{rate}$ = Persistency rate calculated from the non linear relationship between breeding pair density and water increase index and (IN)/or water decrease index (DE): If IN = 0 and DE = 0 then $P_{rate}$ = 1; If IN = 0.2 and DE = 0 then $P_{rate}$ = 0.92; if IN = 0.4 and DE = 0 then $P_{rate}$ = 0.33; if IN = 0 and DE = 0.2 then $P_{rate}$ = 0.86; if IN =0 and DE = 0.4 then $P_{rate}$ = 0.31, if IN = 0.2 and DE = 0.2 then $P_{rate}$ = 0.79; if IN = 0.4 and DE = 0.2 then $P_{rate}$ = 0.28; if IN = 0.2 and DE = 0.4 then $P_{rate}$ = 0.28; if IN = 0.4 and DE = 0.4 then $P_{rate}$ = 0.10, and, if IN > 0.4 and/or DE > 0.4 then $P_{rate}$ = 0.; water depth algorithm lower and upper limits = -0.1metre to 1metre; null carrying capacity upper limits = 0.0032 ind./0.64ha.

***Table 1: Determination of water increase index (IN)***

| **Wetland transition** | **Increase of water level (meter)** | | | |
|---|---|---|---|---|
| | **0-0.2** | **0.21-0.50** | **0.51-0.70** | **>0.70** |
| **Wet-wet** | 0 | 0.4 | 0.4 | 0.6 |
| **Dry-wet** | 0.2 | 0.6 | 0.8 | 0.8 |
| **Dry-dry** | 0.6 | 0.8 | 0.8 | 0.8 |

***Table 2 : Determination of water decrease index (DE)***

| **Water depth after drop** | **Wetland transition** | **Decrease of water level (meter)** | | | |
|---|---|---|---|---|---|
| | | **0-0.2** | **0.21-0.50** | **0.51-0.70** | **>0.70** |
| **> 0.45 meter** | **Wet-wet** | 0 | 0.2 | 0.2 | 0.4 |
| **< 0.45 meter** | **Wet-wet** | 0 | 0.4 | 0.4 | 0.6 |
| **N/A** | **Wet-dry** | 0.2 | 0.6 | 0.8 | 0.8 |
| **N/A** | **Dry-dry** | 0.6 | 0.8 | 0.8 | 0.8 |

***Nest success:*** This rate is based on nest initiation estimates, nest height and water depth below nest data. Nest height data was adjusted to account for Virginia Rail specific nest resilience to flooding and stranding. Probability of nest loss estimates due to water level increases or decreases were determined based upon a statistical relationship between magnitude of water level change and probability of nest flooding or stranding. Water level change over a nest exposure period was calculated as the maximum water level increase and decrease from the quarter month of nest initiation over the preceding five quarter month period (Table 3). Either the probability of flooding or stranding was used depending of which had the higher probability value. The other reproductive variables included in the annual nest success rate equation, baseline nest success (in the absence of hydrologic impact) and the probability that a female will renest if the first nest attempt is unsuccessful (renesting rate) were held constant.

$$\text{Virginia Rail nest success rate} = n_1 + [(1- n_1) * rr * n_2]$$

Where: $n_1$ or $n_2$ = nest success attempt 1 or 2 where $n_i$ = BN * (1-PF) **or** BN * (1 - (PS * PSF)
BN = Baseline nest success = 0.5; PF = Prob. of nest flooding (see Tab. 3); PS = Prob. of nest stranding (see Tab. 3); PSF = Prob. of nest failure due to stranding = 0.5; rr = renest rate = 0.4

***Table 3: Virginia Rail nest flooding/stranding probability (PF/PS)***

| Rise of water level (RW; cm) | Decrease of water level (DW; cm) | Virginia Rail flooding/stranding probability |
|---|---|---|
| If RW <= 20 | and RW > DW | PF = 0 |
| If RW > 20 and RW < 78 | and RW > DW | PF = 0.4222 * Ln (RW) – 0.8359 |
| If RW >= 78 | and RW > DW | PF = 1 |
| If RW < DW | and DW <= 12 | PS = 0 |
| If RW < DW | and DW > 12 and DW < 67 | PS = 0.5853 * Ln (DW) – 1.4525 |
| If RW < DW | and DW >= 67 | PS = 1 |

**Calibration Data:** No data available

**Validation Data**: No external or internal validation was performed. The relationships between Virginia Rail and water level are biologically significant and were verified with scientific literature and expert opinion.

**Documentation and References**:

Jean-Luc DesGranges, Joel Ingram, Bruno Drolet, Caroline Savage, Jean Morin and Daniel Borcard (2005) Lake Ontario - St. Lawrence river water level regulation review: Use of wetland breeding bird evaluation criteria within an integrated environmental response model. IJC final wetland bird technical report (2000-2004).

**Risk and Uncertainty Assessment:**

This PI is based on the following assumptions:

- Breeding habitat supply and reproductive success are significant factors influencing the size and integrity of regional breeding populations.
- Sampling design and survey locations were representative of wetland habitats within the larger study area.
- Wetland habitat models are providing an accurate, relative estimate of emergent marsh habitat.
- Breeding bird density models developed from LSL data are representative of the larger study area.
- Quarter month hydrologic data is representative of real hydrologic conditions.
- Predicted bird response to hydrologic conditions based on statistical modeling is valid.

- Transformation from a 2D to 1D hydrologic model in the LSL is correct.

**Confidence Significance and Sensitivity:**

**1) Confidence rating:** We are confident in the associations between water levels and wetland bird PIs. Virginia Rails nest almost exclusively in wetland habitats and are thus sensitive to hydrologic alterations that impact wetland vegetation communities. Lake Ontario and St. Lawrence River specific research results and a moderate body of scientific literature document the close association between Virginia Rail occurrence, emergent marsh area and water depth. Thus we are confident that the PI allows for an accurate relative comparison of Virginia Rail breeding habitat availability and suitability among alternate water level and flow regimes within the study area. This is the first level of hydrologic association. The second is related to water depth and fluctuation within the various wetland vegetation habitats. Again, our research and publishes literature support the influence of water depth and fluctuation on the probability of wetland bird species presence and abundance for several species (PIs). Both the wetland habitat and breeding bird estimates are based upon hydrologic associations derived from a subset of study wetlands that are extrapolated to generate study area estimates.

Although hydrologic variables are strongly associated with habitat and bird density and occurrence, there is also a significant amount of variation not explained by hydrology. In order to assess 100 year water level scenarios, the predictive models necessarily ignore, or hold constant other important population variables (e.g. productivity, age and sexes distribution) and environmental variables (e.g. predation, food availability, pollution, exotic species) that can also impact reproductive success (habitat carrying capacity and nest success), and have an influence on regional Virginia Rail breeding populations. For these reasons, the PI values should only be considered as relative measures between plans (index).

**2) Significance of PI:** Although a regionally common species, the North American Bird Conservation Initiative (NABCI) consider the Lower Great Lakes/St. Lawrence plain (BCR 13) critical to the natural cycle of Virginia Rail. The Virginia Rail is also representative of a group of wetland breeding birds that require shallowly flooded emergent marsh habitats for breeding. The Virginia Rail is a surrogate species for American Bittern (*Botaurus lentiginosus*) and Sora (*Porzana carolina*), and also utilizes similar habitat to that of the Virginia Rail

**3) Sensitivity of PI:** Virginia Rail is retained as a Key PI because it clearly shows an important vulnerability and sensitivity to alternations in water levels and flows, and as such it should be used to evaluate potential environmental responses to alternative water regulation plans.

**PI Name/Short Description:** Least Bittern (*Ixobrychus exilis*) - reproductive index in emergent marshes **[E8, E29]**

**Technical Workgroup:** Environmental TWG

**Researched by**: Giguère, S., J. Ingram, B. Drolet, J.-L. DesGranges & P. Laporte
**Modeled by:** Morin, J., S. Martin, O. Champoux, for Lower St. Lawrence River, T. Redder for Lake Ontario and Upper St. Lawrence River


Clodin Roy

**Performance Indicator Metric:** This PI represents an index of reproductive potential in emergent marsh during the breeding season, based on the habitat supply, annual estimate of the number of potential breeding pairs using the study area, and annual estimate of nest success rate that is influenced by water levels fluctuations.

The PI response includes an aggregation of annual index values into a 2 year moving mean value. This smoothing technique was used to reduce extreme annual PI values and incorporate a lag in the response of the PI to changing habitat conditions. The aggregated 100 year plan scenarios are expressed by the percent of time that the PI index exceeds the first quartile value for plan 1958DD for the comparable water supply series (e.g. Historic, S1, S2 S3, etc). This metric will be used for plan evaluation by calculating a ratio of metrics between two plans.

**Ecological Importance/Niche:** Least bittern is designated as Vulnerable by Ontario Ministry of Natural Resources (OMNR) and Threatened by New York State Department of Environmental Conservation (NYSDEC), the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; Schedule 1), and the Species at Risk Act (SARA). Protecting the ecosystems of vulnerable, threatened, and endangered species is essential for species survival and the conservation and protection of biological diversity. The North American Bird Conservation Initiative (NABCI) considers the Lower Great Lakes/ St. Lawrence plain (BCR 13) as critical to the natural cycle of the Least Bittern.

**Temporal validity:** Valid for the Least Bittern breeding season from last quarter month of May to end of July (QM 19 –QM 28).

**Spatial validity:** Valid for the Lake Ontario, Upper St. Lawrence River (Unit 1), and the Lower St. Lawrence River to Lake Saint-Pierre (except Lake Saint-François and Laprairie Basin) where emergent marsh exists.

**Hydrology Link:** Least Bittern usually construct nests in emergent vegetation 20 cm to 80 cm above to water surface, and require marsh habitat that is flooded for nesting and feeding. Nests are typically located in emergent marsh with water depths ranging from 10 cm to 100 cm. Emergent marsh habitat availability is directly linked to long term water supplies. The percentage of marsh habitat flooded or stranded, flood amplitude, recurrence and duration, as well as the rate of water level change (rapid rise or drop > 20 cm) are also important hydrologic factors. During the nesting period, water levels increases can drown eggs and chicks, and water level decreases, increase ground predator access to nests.

**Algorithm:** This PI is influenced by hydraulic attributes responsible for nesting habitat availability and nest success rate. More specifically, the potential nesting habitat was developed for the Lower St. Lawrence River section, using 2D probabilistic modeling based on the combination of hydrodynamic (water depth) and emerging plants models. In Lake Ontario and Upper St. Lawrence River, the potential nesting habitat was developed using presence/absence modeling based on the same parameters as in the Lower St. Lower. For both regions, the nest success rate was based upon Ontario and Québec nest record data of nesting chronology, nest heights and water depths below the nest. Three hydraulic attributes were considered: *mean water depth*, the maximum *water level increase* and the maximum *water level decrease*.

The algorithm for Least Bittern reproductive success PI (index) is made from the multiplication of the carrying capacity values (estimated number of breeding pairs) and nest success rate.

***Carrying capacity value in Lower St. Lawrence River section*:** The algorithm gives the carrying capacity value of Least Bittern (estimated number of breeding pairs) based on the probability occurrence of Least Bittern nesting habitat within the study area [Eq. 1] multiplied by a fix density value [Eq. 2]. The estimated nesting habitat [Eq. 1] is based on water depth suitability (*pIXEX*) ; probability occurrence of Cattail (*pTYPHA_A* and *pTYPHA_L*) and of deep marshes vegetation (ex: *Scirpus fluviatilis*) (*pMp*). The parameters [Eq. 1] and the fix density [Eq. 2] were determined upon expert opinion and literature review.

**[Equation 1]** Least Bittern nesting habitat probability in Lower St. Lawrence River section =
presIXEX = (power(pIXEX,0.5) * power(pTYPHA_A,0.2) * power(pTYPHA_L,0.2 * power(pMp,0.1))
*where*: pIXEX = ((1/0.248*sqrt(2*π)))*exp(-0.5*(power(((depth-0.598)/0.248),2))))/1.6086
nesting habitat is considered as suitable if presIXEX > 0.5

**[Equation 2]** Least Bittern carrying capacity value (pair #/0.64ha) = presIXEX * 0.0384

***Carrying capacity value in Lake Ontario and Upper St. Lawrence River (Unit 1)*:** Suitable nesting habitat area was based on an annual estimate of emergent marsh habitat that contained an average of 10 to 100 cm of standing water during the breeding season. The area estimate was multiplied by a fix pair density (0.06 pairs/ha) to generate an annual carrying capacity estimate. The habitat parameters and density were determined upon expert opinion and literature review.

***Nest success rate:*** This rate is based on nest initiation estimates, nest height and water depth below nest data. Nest height data was adjusted to account for Least Bittern specific nest resilience to flooding. Probability of nest loss estimates due to water level increases or decreases were determined based upon a statistical relationship between magnitude of water level change and probability of nest flooding or stranding. Water level change over a nest exposure period was calculated as the maximum water level increase and decrease from the quarter month of nest initiation over the preceding five quarter month period (Tab. 2). Either the probability of flooding or stranding was used depending of which had the higher probability value. The other reproductive variables included in the annual nest success rate equation, baseline nest success (in the absence of hydrologic impact) and the probability that a female will renest if the first nest attempt is unsuccessful (renesting rate) were held constant.

**[Equation 3]** Least Bittern nest success rate = $n_1 + [(1- n_1) * rr * n_2]$

Where: $n_1$ or $n_2$ = nest success attempt 1 or 2 where $n_i$ = BN * (1-PF) **or** BN * (1 - (PS * PSF)
BN = Baseline nest success = 0.6; PF = Prob. of nest flooding (see Tab. 1); PS = Prob. of nest stranding (see Tab. 1); PSF = Prob. of nest failure due to stranding = 0.5; rr = renest rate = 0.6

***Table 1: Least Bittern nest flooding/stranding probability (PF/PS)***

| Rise of water level (RW; cm) | Decrease of water level (DW; cm) | Black Tern flooding/stranding probability |
|---|---|---|
| If RW <= 20 | and RW > DW | PF = 0 |
| If RW > 20 and RW < 82 | and RW > DW | $PF = -5E-05 * RW^2 + 0.0159 * RW$ |
| If RW > 82 | and RW > DW | PF = 1 |
| If RW < DW | and DW <= 29 | PS = 0 |
| If RW < DW | and DW > 29 and DW < 1.09 | PS = 0.7461 * Ln(DW) – 2.4948 |
| If RW < DW | and DW > =1.09 | PS = 1 |

**Calibration Data:** No data available

**Validation Data**: For Lower St. Lawrence River section, existing data were used for external validation of the potential nesting habitat (50 recorded observations). The rate of correct predicted even was 80%. No internal or external validation was performed for the carrying capacity value for Lake Ontario and Upper St. Lawrence River section and for the nest success rate.

**Documentation and References**: Giguère, S, J. Morin, P. Laporte and Mingelbier, M. (2005) Évaluation des impacts des fluctuations hydrologiques sur les espèces en péril. Tronçon fluvial du Saint-Laurent (Cornwall – Pointe-du-Lac). Rapport final déposé à CMI (2002 - 2005). Environnement Canada, Région du Québec, Service canadien de la faune

DesGranges, J.-L., J. Ingram, B. Drolet, C. Savage, J. Morin, and D. Borcard. (2005) Lake Ontario- St. Lawrence river water level regulation review: Use of wetland breeding bird evaluation criteria within an integrated environmental response model. IJC final wetland bird technical report (2000-2005).

**Risk and Uncertainty Assessment:**

This PI is based on the following assumptions:

- Breeding habitat supply and reproductive success are significant factors influencing the size and integrity of regional breeding populations.

- Predicted bird response to hydrologic conditions based upon literature review and experts opinion are valid.
- Wetland habitat models are providing an accurate, relative estimate of emergent marsh habitat.
- Quarter month hydrologic data is representative of real hydrologic conditions.
- Predicted bird response to hydrologic conditions based on statistical modeling is valid.
- Transformation from a 2D to 1D hydrologic model in the LSL is correct.

**Confidence, Significance and Sensitivity:**

**1) Confidence rating:**
This PI has a good confidence rating. It has been built from a good amount of literature information that was available from region of interest. The models have also been evaluated with the assistance of SAR experts, and the Lower St. Lawrence carrying capacity for Least Bittern has been validated with independent field data. A "precaution" principle has also been used in order to obtain a "conservative" type PI. Thus we are confident that the PI allows for an accurate relative comparison among alternate water level and flow regimes within the study area for: (1) Least Bittern breeding habitat availability and suitability and (2) impacts of water levels fluctuation on the nest success rate.

Although hydrologic variables are strongly associated with habitat and Least Bittern density and occurrence, there is also a significant amount of variation not explained by hydrology. In order to assess 100 year water level scenarios, the predictive models necessarily ignore, or hold constant other important population variables (e.g. productivity, age and sexes distribution) and environmental variables (e.g. predation, food availability, pollution, exotic species) that can also impact reproductive success (habitat carrying capacity and nest success), and have an influence on regional Least Bittern breeding populations. For these reasons the PI values should only be considered as relative measures between plans (index).

**2) Significance of the species:** The Least Bittern is designated as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The species is listed in the Schedule 1 of the Species at risk Act; the species and its critical habitat are legally protected under this Act. Critical habitat protection will be applied when it is identified within the Recovery Strategy or Action Plan. The North American Bird Conservation Initiative (NABCI) considers the Lower Great Lakes / St. Lawrence plain (BCR 13) as critical to the natural cycle of the Least Bittern.

**3) Sensitivity to water levels management:** The Least Bittern nest exclusively in wetland habitats. Lake Ontario and St. Lawrence River specific research results and scientific literature document the close association between Least Bittern occurrence and specifics hydrological condition. Least Bittern PI is retained as a Key PI because it clearly shows an important vulnerability and sensitivity to alternations in water levels and flows, and is listed as a Species at risk. As such it should be used to evaluate potential environmental responses to alternative water regulation plans.

**PI Name/Short Description:** Black Tern (*Chlidonias niger*) - reproductive index in emergent marshes **[E9, E26]**

**Technical Workgroup:** Environmental TWG

**Researched by**: Drolet, B., J. Ingram, J.-L. DesGranges
**Modeled by:** Drolet, B., J. Ingram, J. Morin, S. Martin, O. Champoux, T. Redder

**Performance Indicator Metric:** The Black Tern performance indicator represents an index of reproductive potential in emergent marsh during the breeding season, based on the carrying capacity, an annual estimate of the number of potential breeding pairs in emergent marsh weighted by water depth and water level increase, multiplied by an annual estimate of nest success, based on the probability that a breeding female will successfully hatch a nest, according to the magnitude of water level change.

The PI response includes an aggregation of annual index values into a 2 year moving mean value. This smoothing technique was used to reduce extreme annual PI values and incorporate a lag in the response of the PI to changing habitat conditions. The aggregated 100 year plan scenarios are expressed by the percent of time that the PI index exceeds the first quartile value for plan 1958DD for the comparable water supply series (e.g. Historic, S1, S2 S3, etc). This metric will be used for plan evaluation by calculating a ratio of metrics between two plans.

**Ecological Importance/Niche**: Black Tern is designated as Vulnerable by Ontario Ministry of Natural Resources (OMNR) and Endangered by New York State Department of Environmental Conservation (NYSDEC). Protecting the ecosystems of vulnerable, threatened, and endangered species is essential for species survival and the conservation and protection of biological diversity.The North American Bird Conservation Initiative (NABCI) considers the Lower Great Lakes/St. Lawrence plain (BCR 13) critical to the natural cycle of the Black Tern. Black Tern is a surrogate species for Pied-billed Grebe (*Podilymbus podiceps*) and wildfowl species that use emergent marshes as feeding and rearing habitats.

**Temporal validity:** Valid for the Black Tern breeding season from second week of May to the end of July (QM 18 to QM28). The PI does not consider cumulative effect from previous years.

**Spatial validity:** Valid for the Lake Ontario, Upper St. Lawrence River Unit 1, and the Lower St. Lawrence River to Lake Saint-Pierre (except Lake Saint-François and Laprairie Basin) where emergent marsh exists.

**Hydrology Link:** Black Tern construct nests on floating vegetation in emergent marsh vegetation, and require marsh habitat that is flooded for nesting and feeding. Emergent marsh habitat availability is directly linked to long term water supplies. The percentage of marsh habitat flooded or stranded, and the rate of water level change (rapid rise > 20cm) are also important annual hydrologic factors. During the nesting period, water levels increases can drown eggs and chicks. Water level decreases can increase ground predator access to nests.

**Algorithm:** This PI is influenced by hydraulic attributes responsible for emergent marsh surface area. More specifically, its algorithm was developed using Lower St. Lawrence hydrologic values based on a 2D water level and topographic model, for the carrying capacity values, and upon Ontario and Québec nest record data of nesting chronology, nest heights and water depths below the nest, for the nest success rate. Three hydraulic attributes were considered: *mean water depth*, the maximum *water level increase* and the maximum *water level decrease*.

The algorithm for the Black Tern reproductive success PI (index) is made from the multiplication of the carrying capacity values (estimated number of breeding pairs) and nest success rate.

***Carrying capacity value:*** The algorithm is base on water depth relationship with the density of breeding pairs, weighted by a persistency rate of breeding activities due to water increase using a water increase index (Table 1). The water increase index was determined using: 1) the highest increase of water level (in meters) between two quarter-month during the breeding periods and 2) the wetland transition before and after fluctuation (Tab. 1).

Black Tern carrying capacity value = $(0.1074 + 0.3979 * WD - 0.0590 * WD^{2}) * P_{rate}$

where: WD = water depth; $P_{rate}$ = Persistency rate calculated from the non linear relationship between breeding pair density and water increase index (IN): if IN = 0 then $P_{rate} = 1$; if IN = 0.2 then $P_{rate} = 0.74$; if IN = 0.4 then $P_{rate} = 0.09$ and if IN = >0.4 then $P_{rate} = 0$; water depth algorithm lower and upper limits = -0.26 meter to 1.8 meter; null carrying capacity upper limits = 0.033 ind./0.64ha.

***Table 1: Determination of water increase index (IN)***

| Wetland transition | Increase of water level (meter) | | | |
|---|---|---|---|---|
| | **0-0.2** | **0.21-0.50** | **0.51-0.70** | **>0.70** |
| **Wet-wet** | 0 | 0.4 | 0.4 | 0.6 |
| **Dry-wet** | 0.2 | 0.6 | 0.8 | 0.8 |
| **Dry-dry** | 0.6 | 0.8 | 0.8 | 0.8 |

***Nest success rate:*** This rate is based on nest initiation estimates, nest height and water depth below nest data. Nest height data was adjusted to account for Black Tern specific nest resilience to flooding. Probability of nest loss estimates due to water level increases or decreases were determined based upon a statistical relationship between magnitude of water level change and probability of nest flooding or stranding. Water level change over a nest exposure period was calculated as the maximum water level increase and decrease from the quarter month of nest initiation over the preceding five quarter month period (Tab. 2). Either the probability of flooding or stranding was used depending of which had the higher probability value. The other reproductive variables included in the annual nest success rate equation, baseline nest success (in the absence of hydrologic impact) and the probability that a female will renest if the first nest attempt is unsuccessful (renesting rate) were held constant.

Black Tern nest success rate = $n_1 + [(1- n_1) * rr * n_2]$

where: $n_1$ or $n_2$ = nest success attempt 1 or 2 where $n_i$ = BN * (1-PF) **or** BN * (1 - (PS * PSF)
BN = Baseline nest success = 0.5; PF = Prob. of nest flooding (see Table 2); PS = Prob. of nest stranding (see Tab. 2); PSF = Prob. of nest failure due to stranding = 1; rr = renest rate = 0.5

*Table 2: Black Tern nest flooding/stranding probability (PF/PS)*

| Rise of water level (RW; cm) | Decrease of water level (DW; cm) | Black Tern flooding/stranding probability |
|---|---|---|
| If RW <= 30 | and RW > DW | PF = 0 |
| If RW > 30 and RW < 69 | and RW > DW | PF = 0.3277 * Ln (RW) – 0.3838 |
| If RW > 69 | and RW > DW | PF = 1 |
| If RW < DW | and DW <= 36 | PS = 0 |
| If RW < DW | and DW > 36 and DW < 94 | PS = -0.0002 * $DW^2$ + 0.0453 DW – 1.3473 |
| If RW < DW | and DW > =94 | PS = 1 |

**Calibration Data:** No data available

**Validation Data**: No external or internal validation as been performed. Relationship between Black Tern and water level are biologically significant and were verified with scientific literature and expert opinion.

**Documentation & References**:

Jean-Luc DesGranges, Joel Ingram, Bruno Drolet, Caroline Savage, Jean Morin and Daniel Borcard. 2005. Lake Ontario- St. Lawrence river water level regulation review: Use of wetland breeding bird evaluation criteria within an integrated environmental response model. IJC final wetland bird technical report (2000-2004).

**Risk and Uncertainty Assessment:**

This PI is based on the following assumptions:

- Breeding habitat supply and reproductive success are significant factors influencing the size and integrity of regional breeding populations.
- Sampling design and survey locations were representative of wetland habitats within the larger study area.
- Wetland habitat models are providing an accurate, relative estimate of emergent marsh habitat.
- Breeding bird density models developed from LSL data are representative of the larger study area.
- Quarter month hydrologic data is representative of real hydrologic conditions.
- Predicted bird response to hydrologic conditions based on statistical modeling is valid.
- Transformation from a 2D to 1D hydrologic model in the LSL is correct.

**Confidence, Significance and Sensitivity:**

**1) Confidence rating**: We are very confident in the associations between water levels and wetland bird PIs. Black Terns nest almost exclusively in wetland habitats and are thus sensitive to hydrologic alterations that impact wetland vegetation communities. Lake Ontario and St. Lawrence River specific research results and a moderate body of scientific literature document the close association between Black Tern occurrence, emergent marsh area and water depth (i.e. if flooded emergent marsh habitat does not exist, the birds do not occur in the wetland). Thus we are confident that the PI allows for an accurate relative comparison of Black Tern breeding habitat availability and suitability among alternate water level and flow regimes within the study area. This is the first level of hydrologic association. The second is related to water depth and fluctuation within the various wetland vegetation habitats. Again, our research and published literature support the influence of water depth and fluctuation on the probability of wetland bird species presence and abundance for several species (PIs). Both the wetland habitat and breeding bird estimates are based upon hydrologic associations derived from a subset of study wetlands that are extrapolated to generate study area estimates.

Although hydrologic variables are strongly associated with habitat and bird density and occurrence, there is also a significant amount of variation not explained by hydrology. In order to assess 100 year water level scenarios, the predictive models necessarily ignore, or hold constant other important population variables (e.g. productivity, age and sexes distribution) and environmental variables (e.g. predation, food availability, pollution, exotic species) that can also impact reproductive success (habitat carrying capacity and nest success), and have an influence on regional Black Tern breeding populations. For these reasons the PI values should only be considered as relative measures between plans (index).

**2) Significance of PI**: The Black Tern is experiencing regional population declines (Ontario and New York State) and the North American Bird Conservation Initiative (NABCI) considers the Lower Great Lakes/St. Lawrence plain (BCR 13) critical to its natural cycle. The Black Tern PI is also a surrogate species for Pied-billed Grebe (*Podilymbus podiceps*) and Common Moorhen (*Gallinula chloropus*) and several wildfowl species that use deep emergent marshes as feeding and rearing habitats. The Black Tern and Pied-billed Grebe are listed by the NYSDEC as endangered and threatened respectively. The Black Tern is also listed as vulnerable by OMNR.

**3) Sensitivity of PI**: Black Tern PI is retained as a Key PI because it clearly shows an important vulnerability and sensitivity to alternations in water levels and flows, and as such it should be used to evaluate potential environmental responses to alternative water regulation plans.

**PI Name / Short Description:** Yellow Rail (CONO) - annual preferred breeding habitat coverage (Lake Ontario) **[E10]**

**Technical Workgroup:** Environmental TWG

**Researched By:** Lantry, Schiavone
**Modeled By:** LTI (DePinto, Redder)

**Performance Indicator Metric:** Basin level area estimate of the annual cover of preferred breeding habitat (ha).

**Ecological Importance/Niche:** Yellow rail is designated as Vulnerable by Ontario Ministry of Natural Resources (OMNR) and Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; Schedule 1), and the Species at Risk Act (SARA). Protecting the ecosystems of vulnerable, threatened, and endangered species is essential for species survival and the conservation and protection of biological diversity.

**Temporal Validity:** 2$^{nd}$ quarter of May through end of July.

**Spatial Validity:** Valid for Lake Ontario, where appropriate breeding habitat exists. Annual preferred breeding habitat coverage is simulated for "typical" open and protected embayment wetlands at elevations A-E. "Typical" open and protected embayment wetlands are characterized by bathymetry/topography and vegetative community responses that are intended to be representative of the entire collection of open and protected embayment wetlands on Lake Ontario (see calibration data). The generalized plant community and elevation models are assumed to be representative of all coastal wetlands of each geomorphic type located within all the Lake Ontario shore units and the Upper St. Lawrence RIV 1 shore unit (see PI Description for Area of Meadow Marsh and Calibration Data). As such, the model outputs are extrapolated to a complete coastal wetland database for Lake Ontario and the Upper St. Lawrence River to obtain a basin level annual estimate of preferred breeding habitat.

**Hydrology Link:** Water level regulation could change the availability of preferred breeding habitat in open and protected embayments. Predictions of this PI are generated from the wetland plant model developed by Wilcox and Ingram. Wetland plant community evolution is strongly dependent on the hydroperiod (i.e., flooding and dewatering history) at a particular elevation.

**PI Algorithm:** The wetland plant model uses flooding and dewatering intervals at specific elevations based on a 0.05-meter interval between 73.25 and 75.75 (meters IGLD85) to assign vegetative structural types, such as emergents (excluding *Typha*; A-E), to elevations on an annual basis. The wetland plant model is based upon field sampling completed for the IJC study (see wetland vegetation PI descriptions and reports for additional details).