Assembling habitat data layers for determining fish habitat suitability in areas impacted by water level change

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Assemblage des couches des bases de données sur l'habitat pour déterminer la qualité de l'habitat du poisson dans les zones touchées par les niveaux d'eau

by

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ABSTRACT

From 2001 to 2005, a five year study was undertaken by the International Joint Commission (IJC) to assess and evaluate water level regulation of the Lake Ontario–St. Lawrence River system. Thus, the nearshore habitat databases for Lake Ontario and the Upper St. Lawrence River was created to provide a structural basis to assess fish habitat suitability, supply and subsequent population responses to changes in water level regulation and climate. The databases also provided a valuable foundation for a broader scope of research and ecosystem assessments in Lake Ontario and the Upper St. Lawrence River. A Geographic Information System (GIS) was the framework in which to store, organize and model the spatial data. This report discusses the GIS data layers that were developed and loaded into the habitat databases, including wetland and shoreline segments, elevation profiles, substrate, fetch (for Lake Ontario) or velocity (for the St. Lawrence River), submerged aquatic vegetation, emergent vegetation and temperature zones.

RÉSUMÉ

De 2001 à 2005, une étude quinquennale a été entreprise par la Commission mixte internationale (CMI) afin d’évaluer la réglementation sur les niveaux d’eau du système du lac Ontario et du fleuve Saint-Laurent. Par conséquent, les bases de données sur l’habitat littoral du lac Ontario et du cours supérieur du fleuve Saint-Laurent ont été créées en vue de fournir un fondement structurel pour évaluer la qualité de l’habitat du poisson, l’approvisionnement et les réponses des populations aux changements relatifs au climat et à la réglementation sur les niveaux d’eau. Les bases de données ont également fourni des bases solides pour accroître la portée des recherches et des évaluations des écosystèmes dans le lac Ontario et le cours supérieur du fleuve Saint-Laurent. Un système d’information géographique (SIG) tenait lieu de cadre dans lequel les données spatiales étaient stockées, organisées et modélisées. Le présent

rapport traite des couches de données téléchargées dans les bases de données sur l’habitat, notamment les segments côtiers et les zones humides, les profils d’élévation, le substrat, la portée (pour le lac Ontario) ou la vitesse du courant (pour le fleuve Saint-Laurent), la végétation aquatique submergée, la végétation émergente et les zones de température.

1.0 INTRODUCTION

1.1 Lake Ontario-St. Lawrence River Water Levels Study

From 2001 to 2005, a study was undertaken by the International Joint Commission (IJC) to assess and evaluate water level regulation of the Lake Ontario–St. Lawrence River system (Figure 1). The aim of the IJC's Lake Ontario–St. Lawrence Study (LOSL) was to assess the impacts of planned water regulation changes at the Moses-Saunders Dam in Cornwall, Ontario on various environmental, economic and social endpoints relevant to stakeholders (LOSL Study Board 2006). To determine ecological effects on the ecosystem, various components of the ecosystem were investigated to assess the potential response to water level changes over time and different regulation scenarios.

An Environmental Technical Working Group (ETWG) was formed and charged with evaluating a suite of ecological performance indicators including wetland habitat quality and quantity, terrestrial fauna, fishes and fish habitat (Limno-Tech 2006). Projects within the ETWG served two main purposes: a) to identify mechanisms by which water flow regulations affect environmental features, and b) to build models to predict the responses of various biotic groups to changes in water regulation plans.

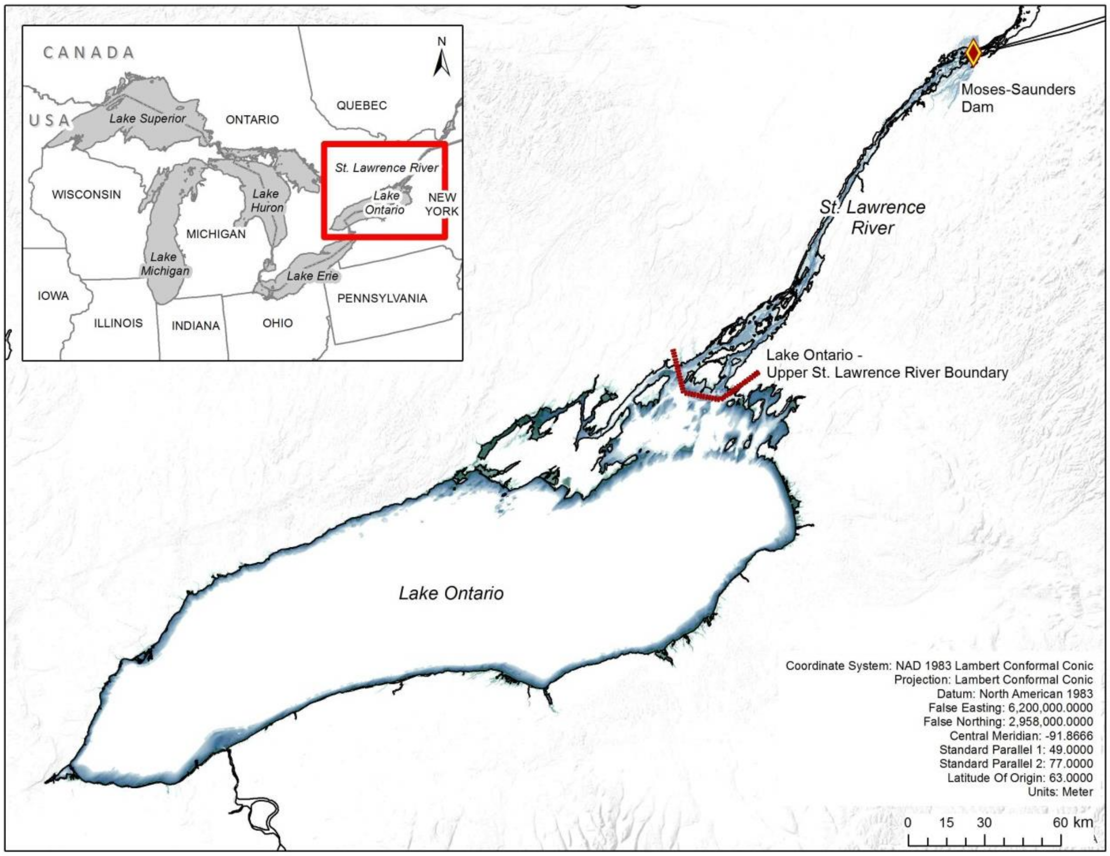

Figure 1. Study extent and the cut-off between Lake Ontario and the Upper St. Lawrence River

Within the ETWG, a Fish Subgroup was formed to assess the effects of water level changes on fishes and fish habitats in the system. The group was comprised of various agencies from Ontario, Quebec and the United States; however, the methods discussed in this report are specifically related to work done by the Fish Subgroup members from Fisheries and Oceans Canada (DFO) in Burlington, Ontario (herein referred to as the FSG). The FSG's goals were to a) examine water level impacts on fish habitat suitability in the nearshore, and b) identify fish habitat and population Performance Indicators (PIs) to be integrated into a holistic ecosystem modelling framework called the Integrated Ecological Response Model (IERM; Limno-Tech 2006). At a higher level, the IERM was integrated into a Shared Vision Model (the Lake

Ontario–St. Lawrence River Study's overall modelling framework), that incorporated all environmental, economic and social stakeholder PI responses (*Figure 1*Figure 2; LOSL Study Board 2006). The intention of the Shared Vision Model was to study the effects of various water level regulation plans on a host of PIs and determine an optimal regulation plan for the Lake Ontario–St. Lawrence River system. The intent of this report is to provide information regarding the assembly of Geographic Information System (GIS) data layers that supported the fish habitat modelling.

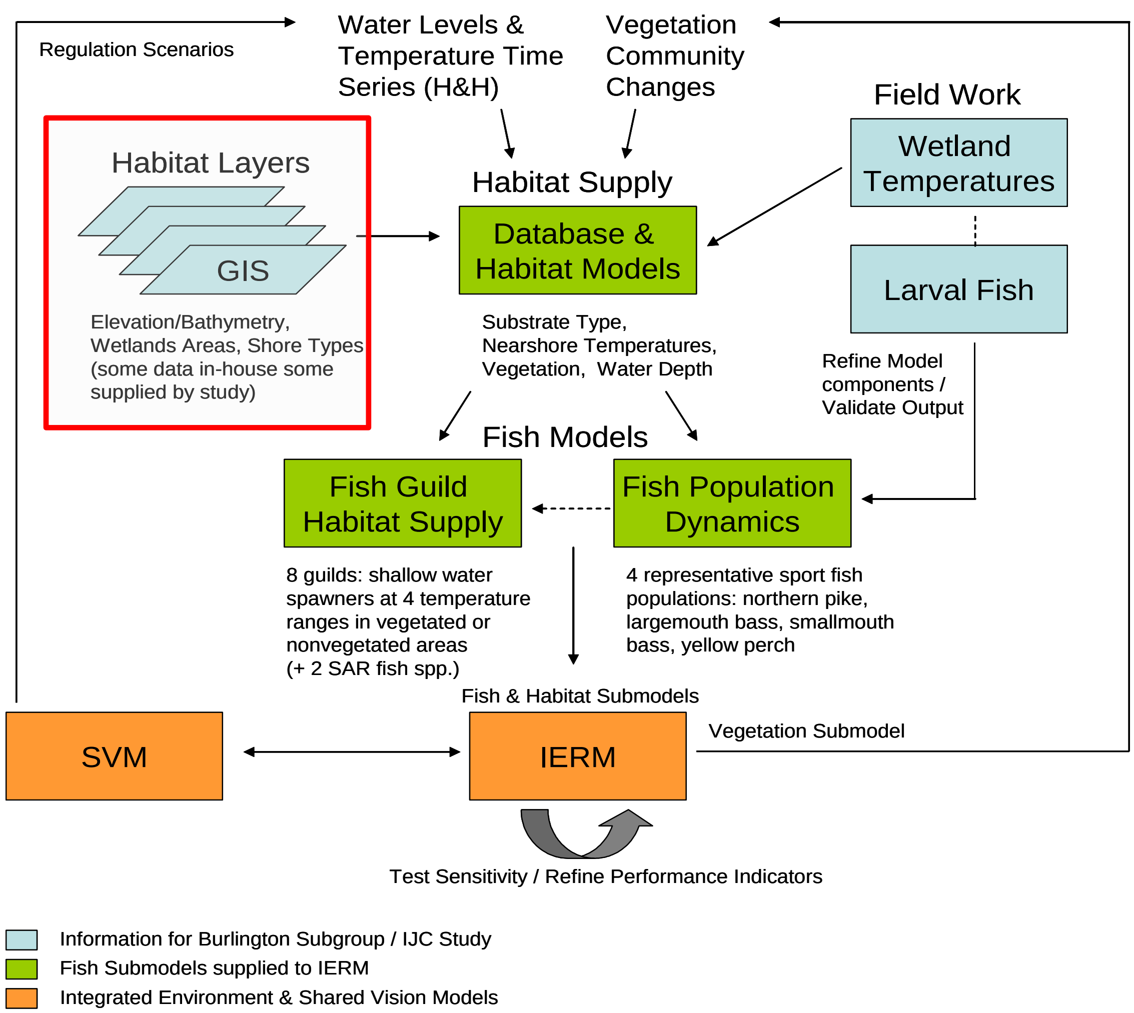

Figure 2. Diagram of the data flow, fish model development and relationships to the Integrated Environment Response Model (IERM) and the Shared Vision Model (SVM). GIS components highlighted by red box.

1.2 Habitat Databases

Two habitat databases, the Lake Ontario Habitat Database and the Upper St. Lawrence River Habitat Database, were designed and assembled by the FSG. Both databases were functionally similar; they differed only in their spatial extent (i.e., lake or river) and input variables used to calculate depth and vegetation. Given that fish habitat and ecosystem information are spatially explicit by nature, it was beneficial to develop methods that allowed for examination of questions related to fish habitat and ecosystems in a spatial framework. A GIS provided a framework within which to store, organize and model the data while maintaining the spatial integrity of the data. Data from the GIS and various intermediate habitat models were then compiled in Microsoft Access Lake Ontario and Upper St. Lawrence River databases for use by FSG researchers in the overall assessment.

The nearshore habitat databases for Lake Ontario and the Upper St. Lawrence River provided the architecture within which the FSG could achieve their goals of assessing fish habitat suitability and fish population responses to changes in water level regime. The habitat databases also provided a valuable foundation for a broader scope of research and assessments of ecosystems in Lake Ontario and the Upper St. Lawrence River. This report describes the process used to build the GIS components of the habitat databases.

2.0 METHODS

2.1 Study Areas

Lake Ontario

The Lake Ontario Habitat Database encompasses the entire nearshore area. The elevation of Lake Ontario's shoreline was set to 74.2 m above sea level at International Great Lakes Datum (IGLD85). At this elevation, water depth was considered to be equal to 0. The nearshore area of Lake Ontario was determined to be between 52 and 80 m above mean sea level; this represents 0-20 m water depth and approximately 10 km inland from the shoreline of Lake Ontario. The extent of this area was most likely to be affected by changes in water level regulation and encompasses water depths for all water level changes considered in the LOSL Study (*Figure 1*).

Upper St. Lawrence River

The Upper St. Lawrence River Habitat Database was built similarly to the Lake Ontario database. The Upper St. Lawrence River extended from Wolfe Island at the outlet of Lake Ontario and north-east to the Moses-Saunders Dam in Cornwall, Ontario (Figure 1). The study area for the Upper St. Lawrence River was bounded by an upper elevation of 80 m above mean sea level and a lower elevation corresponding to the deepest part of the river channel (approximately 10 m above mean sea level; *Figure 1*) to accommodate the river's elevation profile.

3.2 Database Structure

The nearshore area of Lake Ontario and all of the St. Lawrence River was initially formatted as a raster feature (cell size 25 x 25 m). However, given the immense size of the Lake Ontario-Upper St. Lawrence system being modelled, the number of cells made whole-system estimates impractical in terms of required model run times. It was necessary to aggregate the cells and associated attributes into a number of units that could be feasibly used in the ecological models. Further, the spatial coarseness of data for some data layers (e.g., substrate) supported the need to collapse the raster into larger, more manageable units to avoid interpolation and extrapolation errors.

To address data complexity and magnitude, a system was developed to reduce the GIS layers into a one-time static source of data in the final habitat databases. The entire shoreline of Lake Ontario and the Upper St. Lawrence River was divided into 1km reaches by the Coastal Technical Working Group (CTWG). Each reach was allocated a unique number that was primarily sequential but done in four parts: Lake Ontario Canada, Lake Ontario U.S., Islands and the St. Lawrence River.

These reach units were integrated into the habitat databases by the FSG with assigned habitat attributes: wetland or shoreline segment, elevation, substrate, fetch (Lake Ontario) or velocity (St. Lawrence River), submerged aquatic vegetation, emergent vegetation and temperature zone. The processes and decisions regarding these assignments are described below.

3.3 Spatial Data Layers

GIS data types consisted of base, sampled and modelled data (Doolittle et al. 2010). Base data was used for general mapping and included cartographic layers such as water polygons, shorelines and elevation contours. Sampled data represented data collected during field surveys and included point, linear transects and coverage data such as point samples for temperature, linear acoustics transects for macrophyte density and multi-beam imagery for bathymetry or substrate classification. Modelled data used base and sampled data to model and develop specific spatial layers required for the database's application. The final habitat databases were founded upon a simple set of derived habitat information comprised of modelled data:

1. Water depth

2. Substrate composition
3. Vegetation cover
4. Water temperature

For each of these four habitat layers, a significant amount of data manipulation and spatial modelling of the various GIS data types was required. All data layers were exported from ESRI ArcInfo® to the habitat databases as tabular attributes assigned to each reach. The attributes were:

1. Reach ID
2. Wetland or shoreline classification
3. Elevation
4. Substrate index
5. Fetch (Lake Ontario)
6. Velocity (Upper St. Lawrence River)
7. Vegetation
8. Temperature Zone

The methods used to create each data layer and summarize its information into attributes by reach are discussed further within the results section. Additional, more technical detail regarding the habitat database and accompanying software are described in “A Model of Nearshore Fish Habitat for Lake Ontario and the Upper St. Lawrence River: Software and Database Documentation” (J. Moore, unpublished report, 2005).

4.0 RESULTS

4.1 Reach

The entire Lake Ontario and St. Lawrence shoreline was divided into 1 km reaches. A reach was defined as the base unit of the habitat databases. To quantify habitat availability, various options were explored to assign area to each reach (e.g., buffer). The selected method was chosen because it maintained the reach's length; it did not overlap with neighbouring reaches; and was spatially true (all cells in the reach area are closest to the selected reach). Shoreline reaches were converted from vector to raster (25 x 25 m cells) and expanded as zones from the original shoreline cells thereby encompassing adjacent upland and water areas (Figure 3). The resulting raster extended far enough upland to accommodate the expected area that could be impacted by variation in water levels tested in the study and extended far enough into the water to include depths up to 20 m (defined as the nearshore). Maximum expansion distance was limited to 10 km (Lake Ontario) and 5 km (Upper St. Lawrence River) upland of the shoreline. Each reach varied in total number of cells despite the original consistent length of 1 km because of the nonlinear shape of the shoreline. Therefore, areas assigned to the reaches were not uniform or consistent. This was not inherently a problem but could make it difficult to directly compare fish habitat quantity across reaches. Raster cells within each reach were allocated the following attributes:

1. Elevation (Section 4.3)
    - Cell count by elevation interval from which depths and areas at a given water level (surface elevation) were inferred.
2. Substrate (Section 4.4)
    - Substrate composition

3. Effective fetch (in Lake Ontario) (Section 4.5) or flow velocity (in Upper St. Lawrence River) (Section 4.6)
    - Maximum effective fetch (Lake Ontario) or median velocities (Upper St. Lawrence River) were used as part of the vegetation cover modelling.
4. Temperature "zones" for the purpose of applying a depth-based temperature model (Section 4.8).

The reach approach substantially reduced the model run time and enabled the shoreline segments to be related to data from other Technical Working Groups in the LOSL Study by collapsing the spatial information without losing too much detail by changing to a coarser resolution.

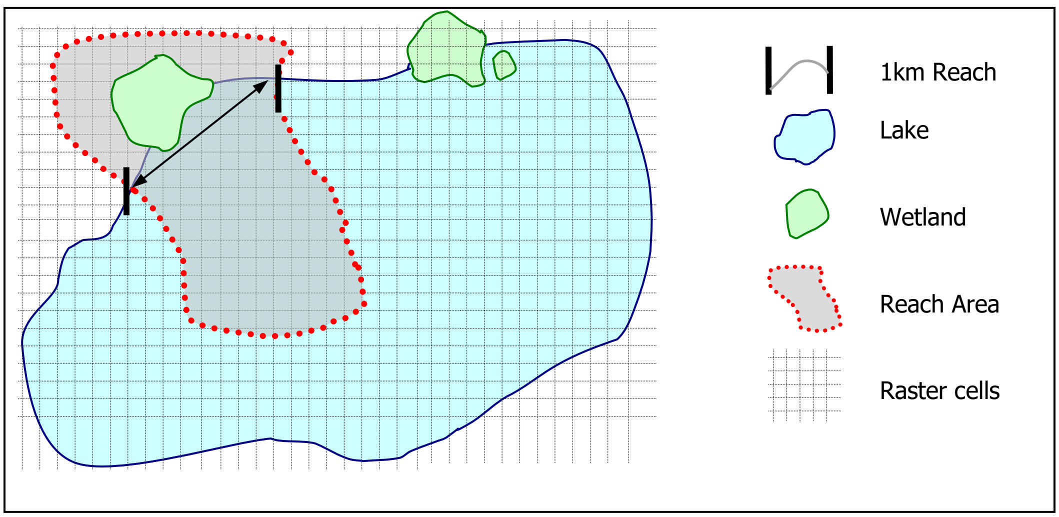

Figure 3. Schematic of reach areas and wetland polygons; Shoreline Reach (1 km) line expanded to "area" represented by multiple cells

The total number of reaches in the system was 3794, not including wetland polygons. There were 2455 shoreline reaches in Lake Ontario and 1339 in the Upper St. Lawrence River. Reach groups, in which reaches were combined based on geographic location or attributes, were developed for various modelling tasks. For example, fish population modelling; species-at-risk modelling (Figure 4); and temperature modelling.

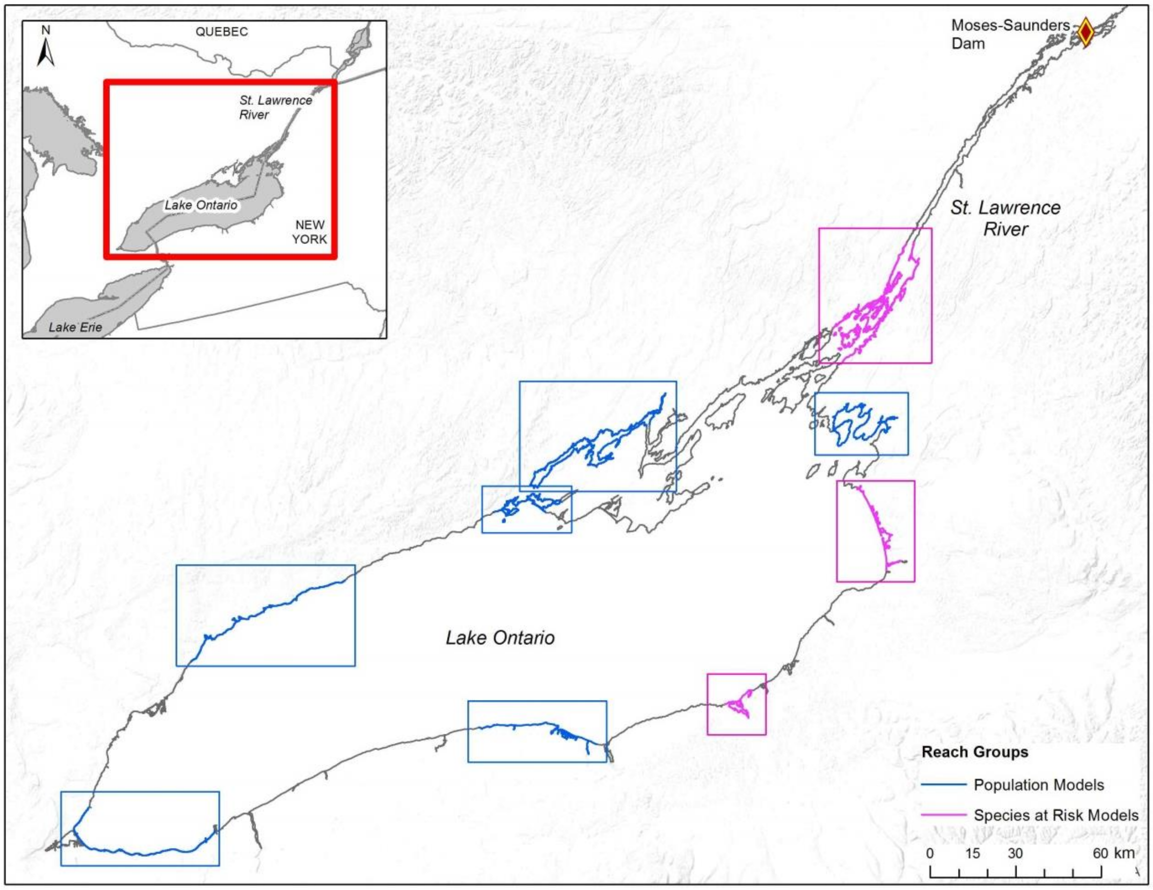

Figure 4. Reach groups for select fish population and species at risk habitat modelling

4.2 Wetlands

Wetlands were treated as a unique subset of reaches in the habitat databases because they provide distinctive habitats and ecosystem functions to fishes. Within the LOSL system, all cells in the nearshore area (52 to 80 m elevation) were identified as belonging to either a specific wetland or a shoreline reach. Wetland areas within 500 m of the shoreline and within the elevation range of the model were assumed to be accessible to fishes and, therefore, included in the model extent.

Wetlands were inventoried by the Habitat Quantity and Quality (Wetland) Subgroup of the ETWG (Ingram and Wilcox 2003) and provided as polygons (541 in Lake Ontario and 335 in the Upper St. Lawrence River) to the FSG. They were converted to a 25 x 25 m raster format and overlaid on the pre-configured reach areas. Where wetlands and shoreline reach areas overlapped, cells were re-assigned to the wetland. Wetlands, as a unique subset of reaches, have similar attributes to shoreline reaches (array of cell elevations, substrate index and temperature zone) and are treated as such within the habitat databases; however, wetland reaches were allocated an additional attribute of ‘wetland type’: Barrier Beach (BB), Drowned River Mouth (DRM), Open Bay (OB), or Protected Bay (PB).

All wetland polygons were given “Reach IDs” of >9000 to be easily identifiable as an inventoried wetland. Although some shoreline reaches were originally classified by the CTWG as “wetlands” (open shore or sheltered), these shoreline segments may or may not coincide with the wetland polygons as delineated by the Wetland Subgroup; because the CTWG provided only geological classification of these shore types, the data provided by the Wetlands Subgroup was used as the authoritative source of wetland data in the FSG application. Of the 876 wetlands, 32 were sampled in the field and, thus, have detailed elevation and vegetation data assembled by the Wetland Subgroup (Wilcox et al. 2005; Figure 5). From the detailed field data, schemes were derived (within the habitat databases) which allowed for the assignment of attributes to the “unsampled” wetlands within the habitat databases (i.e. elevation, vegetation and substrate).

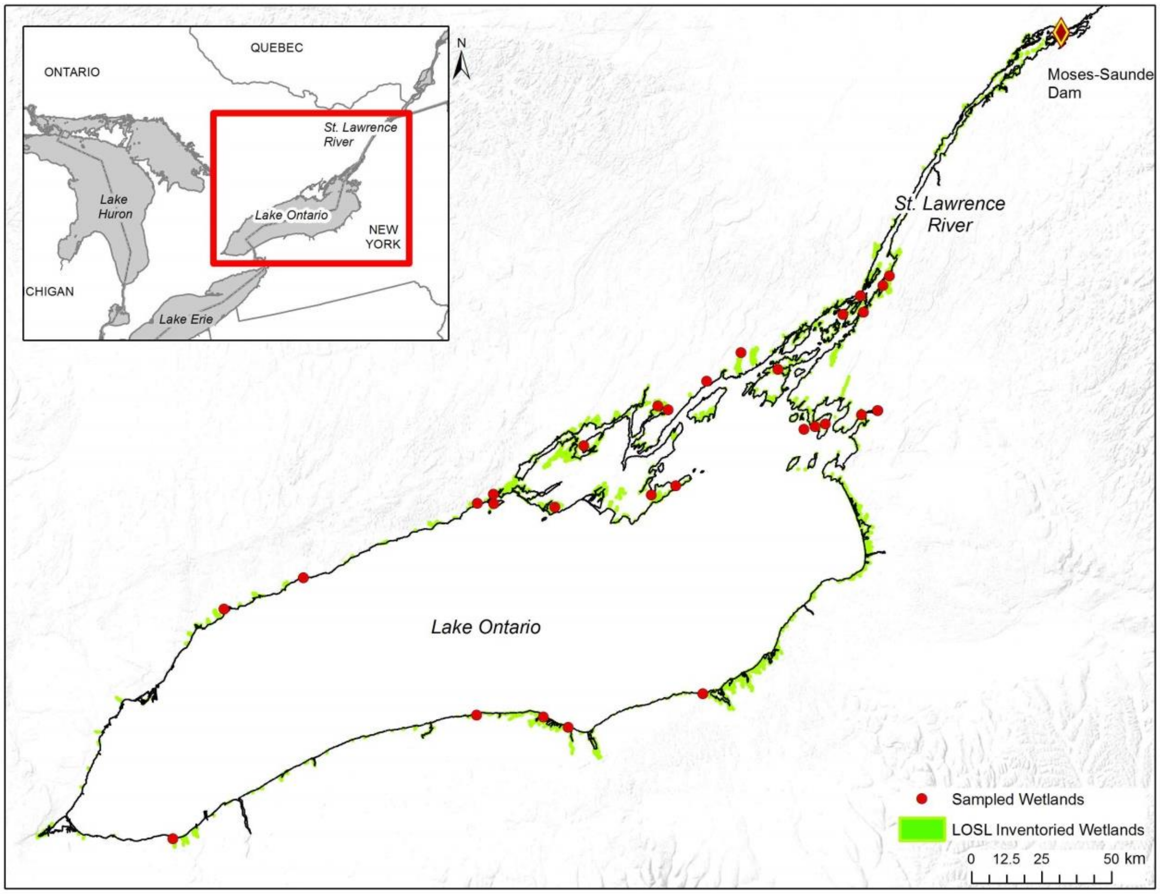

Figure 5. Location of wetland polygons and the 32 sampled wetlands

Wetland reaches in the habitat databases had fixed areal extents. Within these areas, wetland plant communities changed inter-annually and by water level scenario, as dictated by the Wetland Community Model (Hudon et al. 2006). Plant communities were not predicted outside of the reach areas; this may have been restrictive, but the expansion of wetlands beyond these fixed areas was unlikely due to lake morphometry, depth and exposure (Bain and Mills 2004).

Accessibility of wetlands to fishes was an important consideration when determining which wetlands should be included in the habitat databases. The accessibility of wetlands not immediately adjacent to the shoreline depended on the elevation of the associated reach in which the wetland occurred and the distance of the wetland from the shoreline. It was decided that all wetlands existing within 500 m of the shoreline and within the elevation range of the model would be accessible to fishes and were therefore included.

4.3 Elevation/Bathymetry

Within each reach, elevation was the foundational data requirement for all modelling of regulation effects. When combined with a water level scenario, it was used to calculate depth (elevation - daily water level = daily depth). Using literature information on depth preferences for fishes (Minns et al. 2001), elevations and water levels were used to quantify availability of suitable fish habitat based on water depth.

Elevation profiles were derived using data from several sources: the Coastal TWG provided shoreline data, the Ontario Ministry of Natural Resources and Forests (OMNRF) and United States Geological Survey (USGS) provided elevation data, and the Canadian Hydrographic Service (CHS) and National Oceanic and Atmospheric Administration (NOAA) provided bathymetric data. All data were fixed to the study's customized Lambert Conformal Conic projection and resampled to 25 m cell raster (0.0625 ha) before being processed into the final elevation layer that would be aggregated to elevation profiles by reach. The Lake Ontario shoreline was set to an elevation of 74.2 m above mean sea level at IGLD85.

For Lake Ontario, water levels reached a maximum level of 75.84 m on June 9, 1952 (1900-2000 Kingston daily water levels), CHS (T. Herron, unpublished data, 2005). It was, therefore, assumed that setting 80 m as the upper limit of the nearshore area was reasonable. The lower limit (52 m or approximately 20 m water depth) was chosen since the purpose of the FSG was to model habitat changes (generally most evident in shallow water) with water level fluctuation. To develop the elevation raster for Lake Ontario, the following processes were applied:

- The CTWG provided a GIS layer of the Lake Ontario shoreline (Stewart 2002). This shoreline was converted to a 25 m-cell size raster with elevation set to 74.2 m and merged with the digital elevation models (DEMs) described below. DEMs were available from the OMNRF and USGS. The DEMs varied in resolution and accuracy depending on their source and the geographic reference (+/- 10 m horizontal accuracy and reliable to +/-5 m vertical in southern Ontario; +/- 10 m horizontal accuracy and 2-5 m vertical accuracy for USGS data (Gesch 2007)). All DEMs were resampled to a 25 m cell size (OMNRF, NEDS Metadata regarding accuracy).
- Elevation data were provided by the LOSL Technical Working Group for many of the islands in Lake Ontario. The OMNRF and USGS DEMs were used to fill in island elevation where there were gaps.
- Bathymetry from NOAA's Lake Ontario dataset (National Geophysical Data Center) was converted from contours to points and interpolated, using an inverse distance weighted method, to raster (25 m cell size).
- Additional datasets used to update the bathymetry information were obtained from CHS field sheets for Hamilton Harbour, Toronto Harbour and the Bay of Quinte (CHS Burlington, unpublished data). Each of these datasets was resampled to 25 m cells.

As the Upper St. Lawrence River drains toward the Atlantic Ocean, its elevation above mean sea level declines from 74.2 (Lake Ontario) to 73.24 m (at Iroquois upstream of the Moses-Saunders Dam, a total difference of 0.96 m. To develop the elevation layer for the Upper St. Lawrence River, the following processes were used:

- The Coastal TWG provided geospatial data of the shoreline of the Upper St. Lawrence River. This shoreline was converted to a 25 m cell size raster with elevations corresponding to the elevation zone (Figure 6) of the region and merged with the DEMs described below.
- Similar to Lake Ontario, DEMs were available from the OMNRF and USGS. All DEMs were merged and resampled to 25 m cell size.
- Elevation data was sourced by the LOSL Study for some of the islands in the Upper St. Lawrence River. The OMNRF and USGS DEMs were used to fill in island elevation where it was missing.
- Channel bathymetry from CHS and NOAA was assembled by the Hydrologic & Hydraulic (H&H) TWG and shared with the FSG (Canadian data used with permission from CHS; Thompson and Moin 2003) (Figure 6). The data were converted to a 25 m raster using inverse distance weighted geoprocessing.

Using the above data, a final elevation layer was produced for the entire nearshore study extent. Cells in the raster were grouped into 10 cm elevation bins and were associated with the adjacent shoreline reach or wetland polygon between 80 m and the deepest part of the of channel (approximately 10 m above sea level).

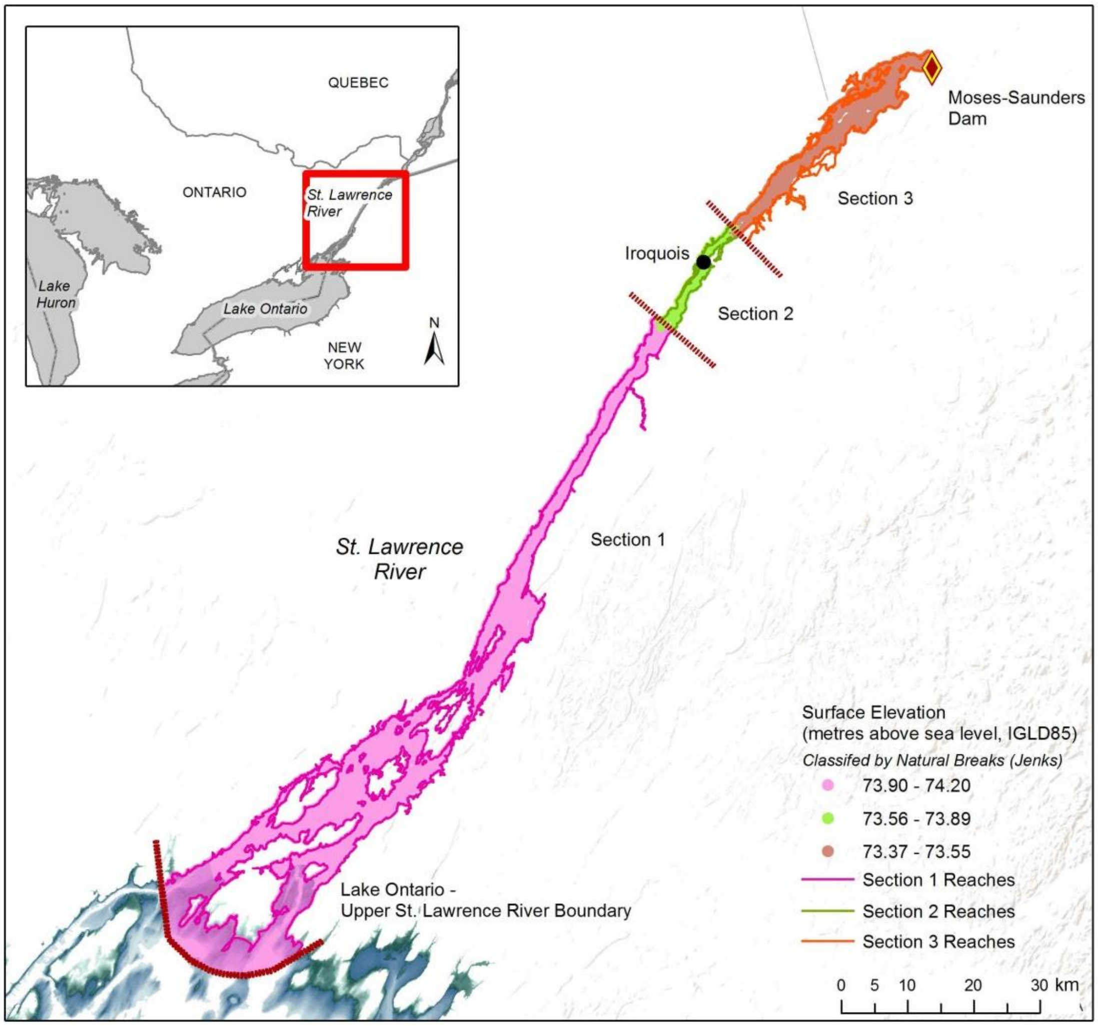

Figure 6. Map of Upper St. Lawrence River elevation divisions

Since several different data sources were used to produce the final elevation layer, issues arose from merging different data sets. A major assumption of the elevation layer was that there was enough vertical accuracy to determine which areas were wet and dry at a given water level. It was difficult to collect such high resolution data at the shoreline land-water interface. The interface was an important area of the merger of bathymetry and land elevation data; gaps between the water and land data layers sometimes existed and needed to be interpolated. Further, the vertical accuracy of the elevation and bathymetry sources vary from 10 cm to 5 m, and bathymetry data had different datums (CHS used IGLD85 and NOAA used IGLD55). Therefore, land elevations and different bathymetry sources had to be vertically adjusted to IGLD85 for the final elevation layer for the study area. Subsequent elevation-based calculations of water depth in the river depended on the slope of the riverbed. To accommodate the changing slope, the upper river was divided into three sections that were treated as though they were flat. These sections were derived from surface elevation points (N=82350) of the channel corrected to IGLD85 (CHS and NOAA). Surface elevation was divided into 3 classes using Natural Breaks (Jenks) method (Figure 6).

4.4 Substrate

Substrate is an important habitat feature for flora and fauna. Substrate data were not available for the entire nearshore area of Lake Ontario and the Upper St. Lawrence River; therefore it was necessary to devise a set of rules for extrapolating the data that were available to get a reasonable approximation. The Coastal TWG provided shore-type and nearshore geology classifications (based on aerial observation, nearshore geology, and morphology) for all reaches in the LOSL Study (Stewart 2002). These classifications were statistically linked to point substrate samples (Figure 7A) from Rukavina (1976) along the north shore of Lake Ontario and samples taken in the Bay of Quinte (Smith 1993; Environment Canada National Water Quality Data Bank (NAQUADAT) Database 2001; Minns et al. 2006) to derive a substrate classification scheme for the entire study area identified by unique substrate index values (Figure 7B). Each resultant substrate index was assigned a percent composition by substrate type: bedrock, boulder, cobble, rubble, gravel, sand, silt, clay and hardpan. Within each substrate index, substrate composition varied with depth interval (0-1 m, 1-2 m, 2-5 m, 5-10 m and 10-20 m) based on the sampled data.

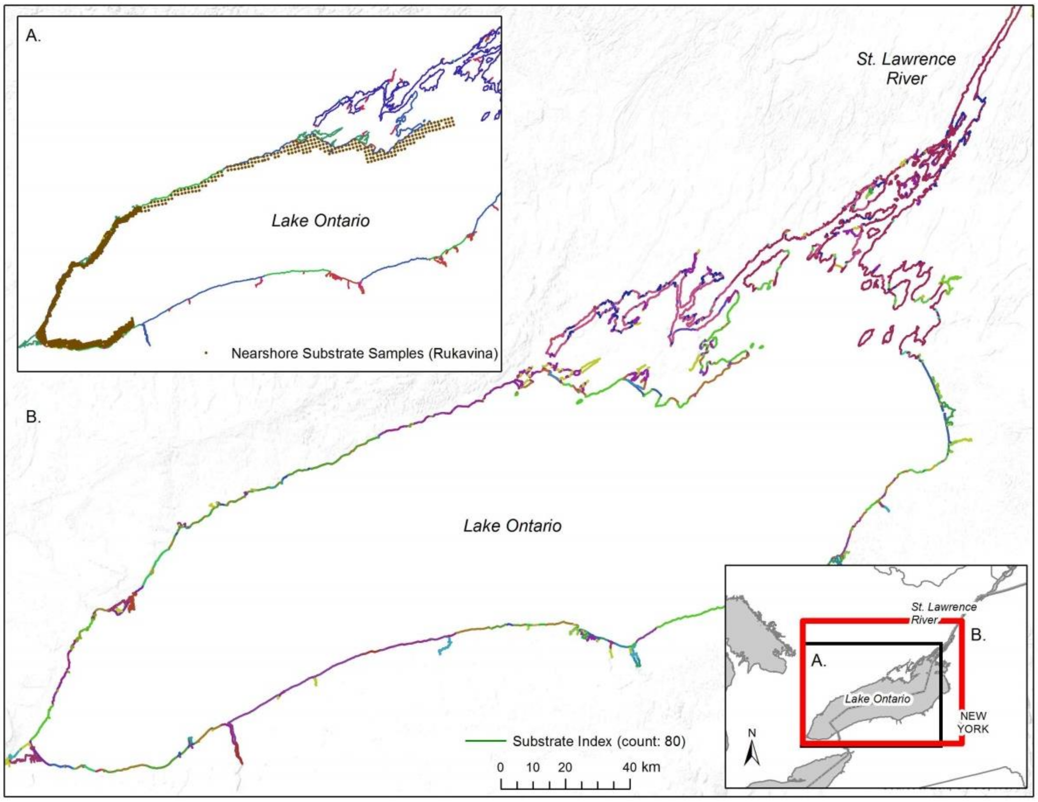

Figure 7. Substrate sample data locations (Rukavina, 1976) (A). Substrate Indices for Lake Ontario and Upper St. Lawrence River (B) based on substrate composition and depth

For the Upper St. Lawrence River, substrate data were not available for the nearshore area thus, the same substrate index system (based on shoreline features provided by the Coastal TWG) for Lake Ontario was applied. Not all islands in the Upper St. Lawrence River were attributed with shore-type and nearshore geology by the Coastal TWG. For these locations, the area was assigned to the same index as the nearest classified reach.

All wetland polygons were assigned a Substrate Index of 49 – wetland shore-type by sandy nearshore geology, a mixed, fine grain substrate type based on Rukavina (1976) samples.

4.5 Fetch

The fetch model was applied to Lake Ontario only. Fetch is the open distance over which wind can travel across water unimpeded. It affects currents and turbulence in the water, and affects where vegetation can grow. For Lake Ontario non-wetland shoreline reaches, effective fetch was used to determine whether it was vegetated or not. If the average effective fetch was ≤5 km, the reach would have submerged aquatic vegetation (SAV); otherwise it had no cover. This simple rule-based model for SAV resulted from data analysis in large, sheltered embayments with known distributions of SAV (Seifried 2002) as well as relationships between emergent wetland distributions in open embayments to the main lake using data generated from the Study (S. Doka, unpublished data, 2003).

Average effective fetch was calculated for a series of fetch points across the study system (Figure 8). Fetch points were generated at 500 m intervals in the nearshore areas of Lake Ontario. For each reach, a single point nearest the shoreline was selected. For this point, effective fetch was calculated by measuring the distance in 16 cardinal directions from the point to the shoreline (Scheffer 1992). Each reach was assigned the average effective fetch of the nearest 'fetch point'. The formula for calculating effective fetch is:

F = E(cos(a)*L(a))/E(cos(a) where:
a = angle to direction of wind: -45 through +45 degrees
L = Distance along direction

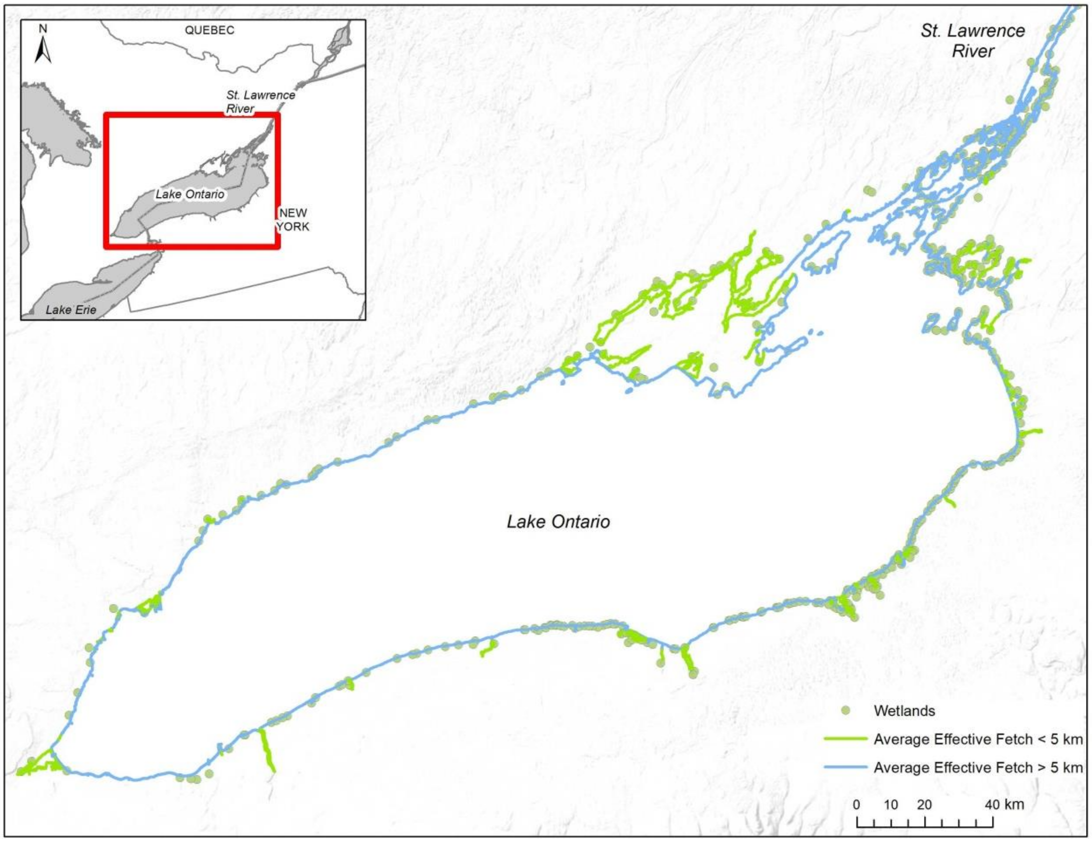

Figure 8. Map of Lake Ontario reaches with average effective fetch +/- 5 km.

The average effective fetch value associated with each reach was treated as a static attribute. Average effective fetch was used as a binary cut-off value for submerged aquatic vegetation presence (average effective fetch ≤5 km) or absence (average effective fetch >5 km). All wetlands were assumed to have a fetch ≤5 km.

4.6 Velocity

The velocity model was applied to the Upper St. Lawrence River only. Velocity in the riverine system, similarly to fetch in the lake system, affects where vegetation can grow. A cut-off velocity of 20 cm/s was used to determine submerged aquatic vegetation presence/absence in the Upper St. Lawrence River system (J. Morin, Environment Canada, unpublished data, 2005).

Velocity data for the Upper St. Lawrence were provided by the H&H TWG (Thompson and Moin 2003). The H&H TWG modelled river velocity from the long-term average water level of Lake Ontario to evaluate a base case, average water flow scenario. The long-term daily average water level (74.89 m) at Kingston, for the ice-free period between May to November from 1960 to 2003, was used as a boundary condition for the hydrodynamic modelling. An average outflow of 7580 m^3/s was calculated from the daily average Moses-Saunders outflow across the same time period (A. Thompson, unpublished data, 2005). The FSG used the velocity point data (mean point spacing of 85 m) from the hydrodynamic model and converted them to a 25 m raster using inverse distance weighting (IDW) interpolation. Median long-term velocity for cells within each reach area was calculated and assigned to each reach in the Upper St. Lawrence River (Figure 9). All wetland reaches were assumed to have a median velocity of ≤20 cm/s.

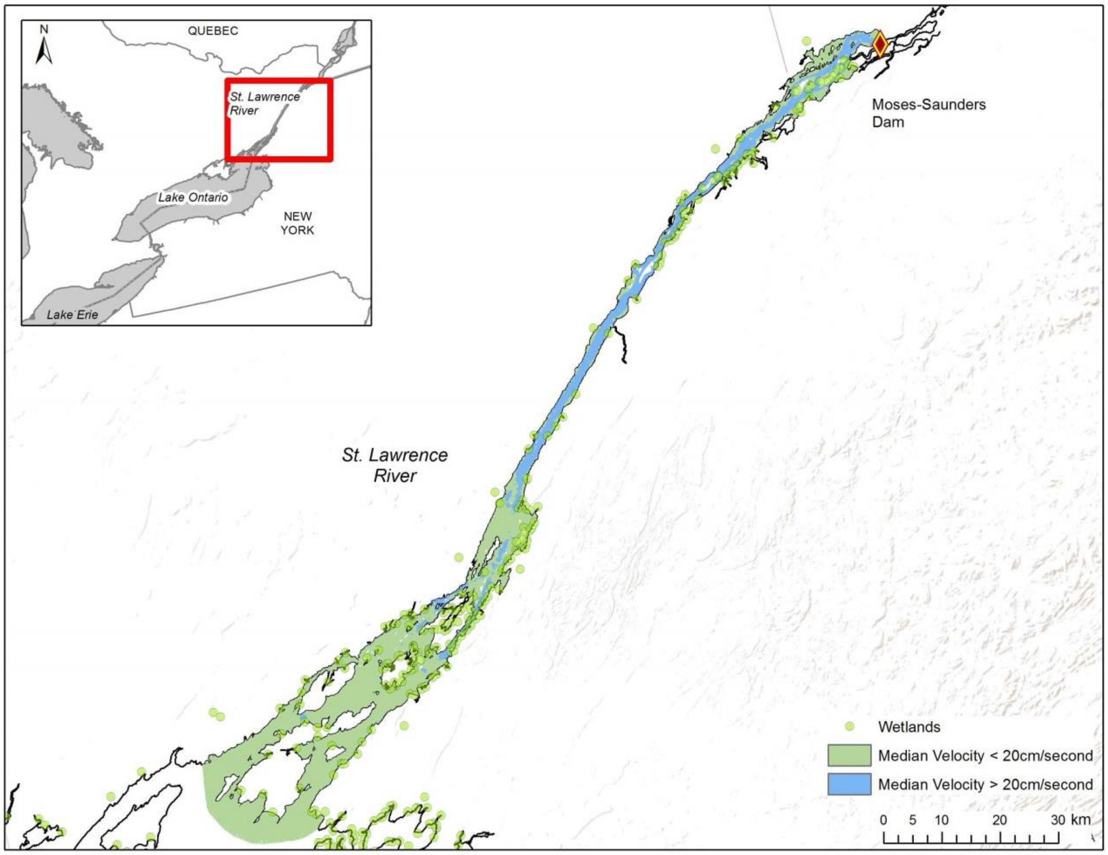

Figure 9. Areas in the Upper St. Lawrence River with a median velocity of +/- 20 cm/second

4.7 Vegetation

Emergent Vegetation

Emergent vegetation not generated as GIS layer for habitat databases by the Fish Subgroup. Emergent vegetation was considered to be present only in wetlands and was modelled externally to the habitat databases by the Coastal working group (Wilcox et al. 2005; Wilcox and Xie 2007) in an elevation-based Wetlands Vegetation Model (WVM). Four wetland types were modelled (barrier beach, drowned river mouth, open embayment, and protected embayment). Elevation bounds were defined for plant communities, each plant community had a fixed percent cover and a subset of types were used in the habitat database because of their potential usefulness as fish habitat (forbs, grasses, thin-stem emergent, broad-leaf emergent, floating leaf and thin-stem persistent emergent) (Moore 2005).

Submerged Aquatic Vegetation (SAV)

The presence and density of SAV in this study were modelled and depend upon emergent vegetation presence, water depth and fetch (Lake Ontario) or velocity (Upper St. Lawrence River).

For Lake Ontario, information on the extent and distribution of SAV across the system was not available from the LOSL Study or external sources. Therefore, the FSG developed a series of rules to model presence/absence and density of SAV.

Rule 1: no SAV exists at depths greater than 5 m:

- SAV growth depends on water clarity; for Lake Ontario, it was assumed that SAV growth occurs between 0 and 5 m and is constrained by the photic zone (secchi depth); (M. Bain, Cornell University, personal communication, 2004)
- Field data on SAV density across depth confirmed a similar 5 m cut-off for SAV growth in the Bay of Quinte area (Table 1; C. Chu, unpublished data, 2004; Doka et al. 2006)

Rule 2: SAV exists only where the reach's average effective fetch is less than 5 km

- Fetch cut-off for SAV presence was determined by Minns and Nairn (1999) and modified by analysis of wetland reaches (S. Doka, unpublished data, 2003).

Rule 3: SAV percent cover is depth-dependent, where:

- $SAV = 79.02 - 15.463 * z$

  z = mid-point of depth interval

- The relationship was determined using data from Seifried (2002) and as published in Doka et al. (2006) (Table 1; *Figure **10***).

Rule 4: If area is a wetland reach, the emergent vegetation model category takes precedence over the submergent model; for example:

- If 100% emergent vegetation cover; SAV cover is 0%
- If 50% emergent vegetation cover; SAV cover can be as much as 50% (given values produced by rules 1-3).
- If 0% emergent vegetation cover, apply SAV model (values produced from application of rules 1-3)

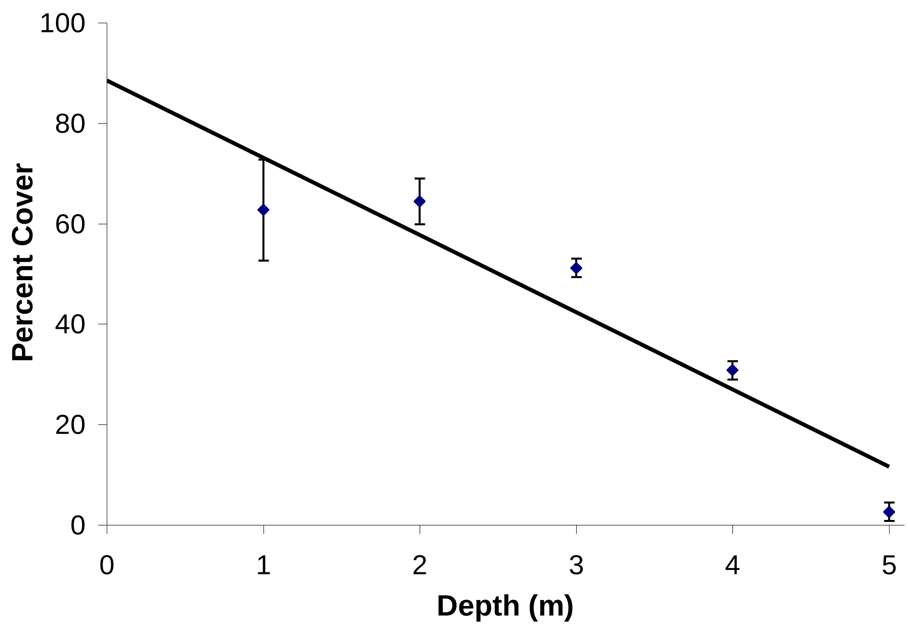

Figure 10. Graph of average SAV percent cover vs. depth for Lake Ontario (Seifried 2002).

Table 1. Summary statistics of submerged aquatic vegetation percent cover by depth for Bay of Quinte (Seifried 2002).

Depth (m)	Percent Cover	Standard Error	Count
0-0.5	62.69	10.083	12
0.5-1	64.41	4.550	65
1-2	51.15	1.828	487
2-5	30.77	1.860	475
5-10	2.61	1.857	41

For the Upper St. Lawrence River, SAV data were not available from the LOSL Study or external sources. Therefore, the FSG developed a series of rules to heuristically model the presence or absence and percent cover of SAV in the Upper St. Lawrence River:

Rule 1: no SAV exists at depths greater than 5 m (same rule as Lake Ontario)

Rule 2: SAV exists only where median reach velocity is less than 20 cm/s (J. Morin, unpublished, 2004)

Rule 3: SAV percent cover is depth-dependent (same rule as Lake Ontario)

Rule 4: If the area is a wetland reach, emergent vegetation model category takes precedence over the submergent model (same rule as Lake Ontario)

The cut-off of 20 cm/s for SAV growth in the Upper St. Lawrence River is conservative; however, this cut-off was used to avoid overestimating vegetation cover across the system. It is possible that in some areas (e.g., Lac St. Pierre), vegetation can withstand velocities greater than 20 cm/s (J. Morin, unpublished, 2004).

4.8 Temperature

Given that temperature varies greatly over space and time, the study area was divided into zones representing the general spatial deviations of temperature in the system. Temperature zones were established using Lake Ontario surface water temperature images derived from NOAA AVHRR (Advanced Very High Resolution Radiometer) satellite data collected between May 1990 and May 1991 (Schwab et al. 1992). The imagery was classified into 0.5 degree Celsius temperature deviation zones. A thermal zone was assigned to each shoreline segment used in the habitat database (Minns et. al. 2005).

Wetland temperatures generally behave similarly in all sheltered areas. Therefore, a Bay of Quinte 50 year time series of intake temperature data was used to represent, without modification, the Bay of Quinte and all wetland reaches in the Lake Ontario habitat database. All reaches were assigned a thermal zone attribute based on these classifications (Table 2; Figure 11).

Table 2. Thermal regimes in Lake Ontario based on surface temperature deviations in nearshore open waters from mid-lake temperatures (1-4) and sheltered areas.

Lake Ontario Temperature Zones	# Reaches	# Wetlands	Temperature Deviation (ºC)
Bay of Quinte and wetlands	478	545	0.0
1	792		-1.0 to -0.5
2	813		-0.5 to 0.0
3	859		0.0 to 0.5
4	330		0.5- to 1.0

For the Upper St. Lawrence River, Shen (2004) generated a 100-year time series of daily water temperatures using a compartment model. Statistical analysis of output node temperatures from the one-dimensional model revealed two thermally distinct sections of the river – one section influenced by lake temperatures downstream to the Thousand Islands area and one relatively isothermal riverine section between the Thousand Islands and the Moses-Saunders Dam at Cornwall (Figure 11). All Upper St. Lawrence River reaches were assigned one of these two thermal regions (Table 3).

Table 3. Characteristics of Upper St. Lawrence River regions

Elevation Section	Temperature Zone	# Reaches	# Wetlands
1	1	372	86
1	2	585	164
2	2	82	23
3	2	300	62

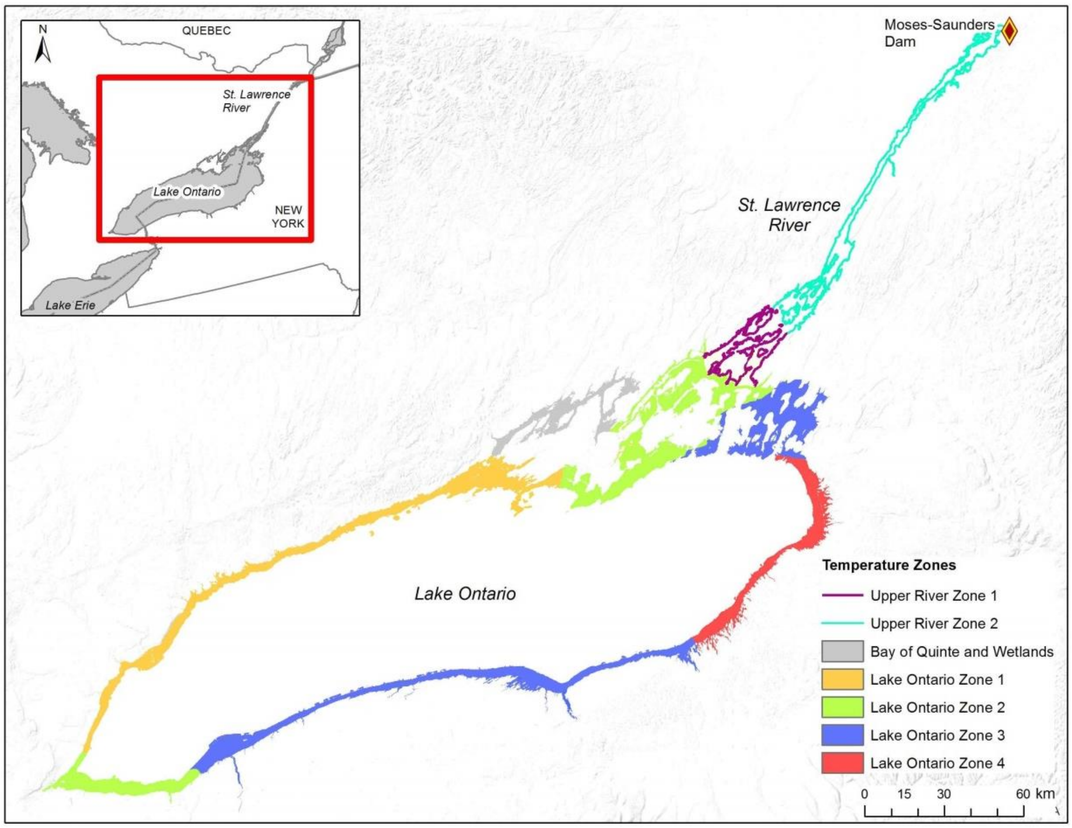

Figure 11. Map of temperature zones used in the Lake Ontario St. Lawrence habitat databases.

Some reaches had more than one temperature zone. In this case, the minimum deviation was used as the single value for the reach. The temperatures zones represent broad generalizations of the thermal patterns across the lake.

5.0 DISCUSSION AND CONCLUSIONS

Depth, substrate, vegetation and temperature are major factors affecting fishes and fish habitat (Minns et al. 2001). Despite their importance as habitat variables driving fish population and community dynamics, habitat data are often difficult to obtain at a large scale with adequate resolution. The two databases described in this report, the Lake Ontario Habitat Database and the Upper St. Lawrence River Habitat Database, provide valuable information for system-wide habitat and ecosystem assessments. The information in the databases allowed researchers to assess the effects of various water level regulation plans for the Lake Ontario–St. Lawrence River system on fish habitat and key fish populations over time. The databases supply a structural basis for answering other questions related not only to fish habitat and populations but also for other ecosystem applications (e.g. Chu et al. 2005). For example, with depth information in the Habitat Database, substrate properties could be resolved, vegetation cover could be inferred from models relating cover to fetch/velocity and depth, and temperature could be inferred from models based on depth and other properties of the reach.

A fish habitat suitability model was integrated into the habitat databases to facilitate the calculation of suitable habitat availability in the study area. This model is founded on a set of simple ideas. First, a reach (or a group of reaches) can be characterized as having the following habitat characteristics: depth, substrate, vegetation cover and temperature; each characteristic is recalculated when input water levels (surface elevations) are modified (Figure 12). A reach's weighted suitable area (WSA) is the product its suitability and its area. Computation of WSA available for a nearshore fish community (single reach) or summing in a selected reach group on a given day at a given water level constitutes the main products of the habitat databases.

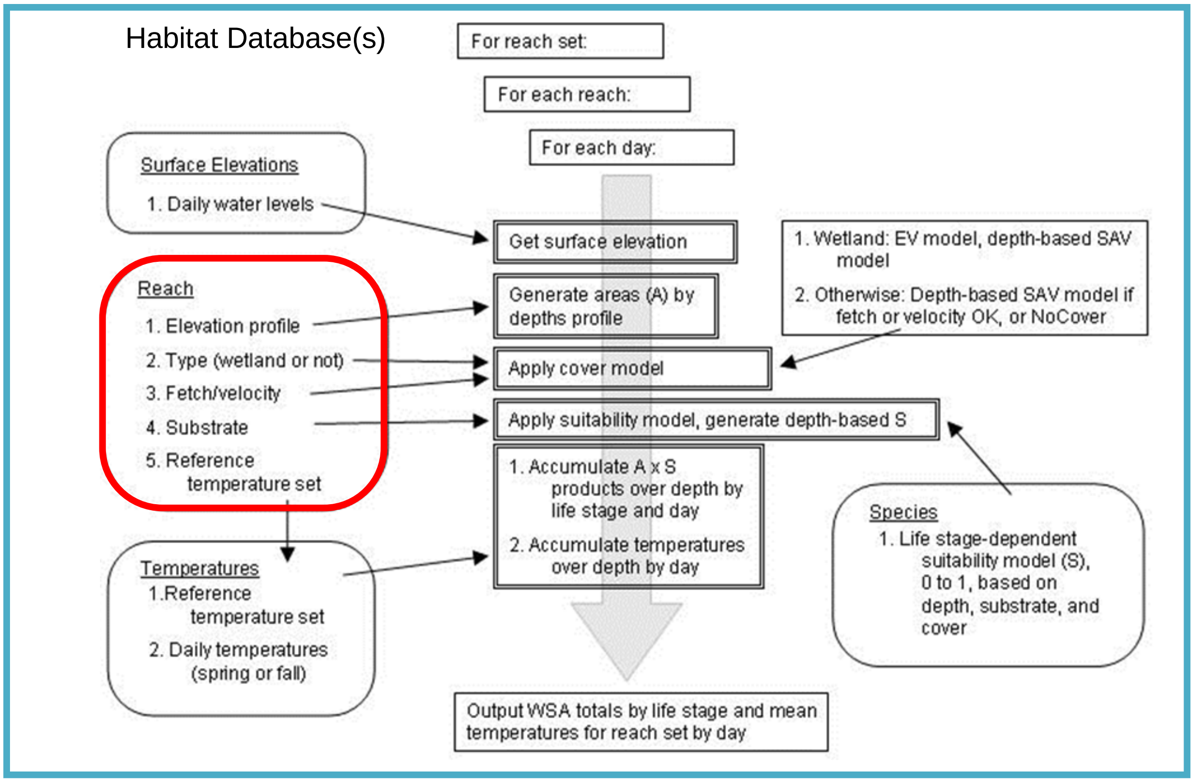

Figure 12. Flow diagram of GIS input (highlighted by red box) and habitat databases: data flow and model development approach.

The model outputs of water level dependent WSA can be compared between water level regulation plans and degree to which those plans impact the WSA available to nearshore fish communities. Similar assessments can be done for species-specific habitat and habitat-based population estimates (Chu et al. 2005).

Beyond the IJC water levels study fish habitat and population objectives, the reach-based structure allows new data to be added in an organized, hierarchical manner to expand the application to different ecosystem questions. For example, Chu et al. (2014) expanded upon the Lake Ontario database to include land use for each 1 km reach segment and incorporated these new data into an ecological classification model for the nearshore zone of Lake Ontario.

While the databases provide vital information for science assessments at a large spatial scale, several challenges and gaps remain. The main challenges encountered when developing the databases were related to computation requirements, data storage and data availability for a system of this large size. The concept of the ‘reach’ was developed to help overcome these challenges. First, because of the immense spatial scale of the Lake Ontario–Upper St. Lawrence River system and time scale required by the LOSL Study (100 years), developing a fully spatially explicit database was not feasible at the time. Summarizing the spatial data to the 1 km reach allowed for minimizing computation issues while still achieving the goal of assessing the effects of water levels over time.

Additionally, the reach concept allowed for incorporation of information from other TWGs in the study where spatial data was lacking. For example, although there was little substrate data available over the whole study area, the Coastal TWG developed a shoreline classification scheme at the reach scale. This scheme was correlated to point substrate sample data that were available to develop a proxy substrate classification scheme for the entire system at a reach scale. Likewise, temperature data was lacking across many parts of the system, however, broad scale temperature relationships were developed using satellite imagery and empirical model interpolation across the entire system. Despite overcoming several computation and data challenges, summarizing spatially explicit data by reach resulted in loss of potentially important spatial detail as some ecosystem changes occur at a finer spatial resolution than the reach (e.g., substrate and vegetation can be patchy at a fine spatial scale).

Overall, the habitat databases for Lake Ontario and the Upper St. Lawrence River provided a structural basis within which fish habitat suitability and population responses to changes in water level regime and climate could be assessed. The habitat databases will serve as a valuable base for a broader research and assessments of ecosystems.

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