EVALUATION OF WATER LEVEL REGULATION INFLUENCES ON LAKE ONTARIO AND UPPER ST. LAWRENCE RIVER COASTAL WETLAND PLANT COMMUNITIES

FINAL PROJECT REPORT
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Executive Summary

Water-level fluctuations are a natural phenomenon in the Great Lakes due to natural climatic variability, and Great Lakes biological communities, by necessity, have evolved to adapt to the range of water levels and water-level changes that occur on several scales. The biological effects of water-level fluctuations in the lakes are greatest in shallow water where even small changes in water level can result in conversion of a standing water environment to an environment in which sediments are exposed to the air, or vice versa. The localized effects of this change in the environment are most evident in the plant communities that occur in wetlands. In fact, water-level change patterns are the driving environmental force that determines the overall diversity and condition of wetland plant communities and the faunal habitats they provide. Previous studies showed that regulation of Lake Ontario water levels for more than 40 years resulted in considerable alteration of wetland plant communities.

The overall objectives of this study were to demonstrate quantitative changes in plant communities, to determine water-level patterns that best maintain habitat diversity as determined by plant community diversity, abundance, and distribution, and to develop predictive models and performance indicators to evaluate proposed new regulation plans for the lake. The specific tasks included evaluating and quantifying vegetation changes by assessing historic aerial photographs; completing a wetland inventory and classification for Lake Ontario and the Upper St. Lawrence River; sampling wetland plant communities along transects at specific elevations that represent unique hydrologic histories; developing bathymetric/ topographic models for each of four Lake Ontario wetland geomorphic types that relate plant communities and faunal habitats to water depths, as determined by lake levels; developing preferred environmental criteria for water-level regulation based on vegetation study results, bathymetric/topographic models, fish and wildlife habitat requirements, and long-term lake-level changes; and using bathymetric/topographic models and study results to develop predictive tools and performance indicators to assess the potential effects on wetlands of all proposed new scenarios for water-level regulation.

The 32 study sites selected for this work were distributed across the Lake Ontario – Upper St. Lawrence River area and included eight wetlands of each of four geomorphic types: open embayment, protected embayment, barrier beach, and drowned river mouth wetlands. Half of the sites for each geomorphic type were in Canada and half were in the United States. These sites are intended to represent a total of 879 geomorphically distinct wetlands, totaling 25,847 hectares, identified in the wetland inventory.

Interpretation and analysis of Lake Ontario water-level data and aerial photo sets revealed an often substantial increase in the area and percent cover of cattail (Typha)- dominated wetland vegetation communities since water-level regulation began in 1958. At most sites, the increase in Typha-dominated area did not result from lakeward expansion; it was the result of Typha invasion into existing meadow marsh communities at higher elevations. Lack of low water levels since the mid-1960s has seemingly allowed Typha, which has a greater requirement for water, to displace meadow marsh at higher elevations. As a result, it is estimated that greater than 50% of the meadow marsh wetland area that occurred within Lake Ontario – Upper St. Lawrence River during the mid- to late 1960s has been displaced by Typha-dominated emergent marsh. At many study sites, the loss in area of meadow marsh vegetation since the 1960s exceeds 80%.

Analyses of wetland plant community data, collected by sampling along transects that followed seven elevation contours with different water-level histories, identified four major vegetation types. Three transects at higher elevations contained plant species associated with meadow marsh; a slightly lower transect contained a mixed community with meadow and emergent marsh species, including

Typha; two transects below this were emergent marsh dominated by Typha; and the lowest transect contained mostly submersed and floating-leaf species.

Bathymetric and topographic data were used to create individual elevation maps for all study wetlands that could be compared with mapped vegetation types. GIS methodologies were then used to generate bathymetric/topographic models for each of the four wetland types. These models are meant to represent all wetlands of each specific type for use in predictive modeling efforts, but not any individual site.

Predictive wetland vegetation models were developed for each wetland geomorphic type. Within a GIS format, area by elevation contour data were used to calculate annual estimates of vegetation community distribution for each year in a sequence of 101 years of water-level data, as presented in potential new regulation plans. The result is a series of annual predictions of the area and percent of vegetation/time classes that will occupy the elevation range (73.0-75.75m) given in the models. Within the models, assignment of the four vegetation types to various elevation ranges is based on the number of years since last flooded or the number of years since last dewatered, as determined by rules generated by analyzing data from sampling along the transects.

The predictive models for each of the four wetland geomorphic types were tested using several potential regulation plans for Lake Ontario. The plans tested were 1958D with deviations (1958DD) and two plans developed by using 1958DD as a base and adding a higher lake level (75.65m) in 1947 when basin supplies were high and lower lake levels in the 1910s, 1930s, 1960s, and late 1990s when basin supplies were low. Neither high nor low lake levels exceeded those that actually occurred during post-regulation. Over the 101-year regulation plan period, test results showed an increase in the average percent of meadow marsh (ABC) vegetation from 1958DD to the plan with additional low lake-level years to the plan with even more low lake-level years, which is the expected result.

A wetland habitat performance indicator (Area of Meadow Marsh) was then developed using study results. This indicator was selected because it is sensitive to hydrologic change, it represents a habitat that supports the greatest diversity of plant species, it can contain a diversity of structural habitats that support a wide range of fauna, and it is the plant community shown to have been affected most by regulation of lake levels. To make the performance indicator more sensitive to the hydrologic conditions that promote meadow marsh expansion, the 101-year period of evaluation was scaled back to include analyses for only those years in which low total basin supplies provided an opportunity for meadow marsh to expand. The resulting performance indicator measures the comparative ability of regulation plans to generate the low lake levels required by the meadow marsh community during time periods when water supplies are low and low lake levels are possible. The regulation plans used to test the predictive models were then evaluated both by individual geomorphic wetland type models described above and by the IERM, in which percentages of meadow marsh community across all geomorphic types were converted to area of meadow marsh for the entire Lake Ontario/Upper St. Lawrence River basin. Again, the percent of meadow marsh vegetation type increased from plan 1958DD to the other plans with increasing numbers of low lake-level years.

The abundance of other predicted wetland vegetation communities is also important in alternate plan evaluation. These habitat predictions have been incorporated into several faunal models. Faunal models such as the Black Tern and Virginia Rail Reproductive Index performance indicators are being used to compare the relative supply of deep and shallow emergent marsh habitats among alternate water-level regulation plans.

Overall, study results indicate that moderation of water-level fluctuations since water-level regulation began has significantly restricted the long-term hydrologic environment important to the maintenance of coastal wetland meadow marsh communities. Moderation of long-term water-level fluctuations has also created hydrologic conditions that supported the expansion of aggressive, dominant emergent and submersed plant species, resulting in a reduction of plant species richness and emergent marsh habitat quality. The reduction in habitat quality has likely been further magnified in wetlands that have also been impacted by other stressors, such as increased nutrient and sediment inputs due to surrounding land uses. However, consistency in plant survey results and historic trends across study site wetlands, many with predominately forested watersheds support the conclusion that water-level moderation due to regulation is having a major impact on coastal wetland habitat quality.

The development of quantitative relationships between water levels and wetland plant communities, generalized geometric wetland elevation models, and estimates of wetland area within the study region provide powerful predictive tools to evaluate potential impacts of alternate water-level regulation plans on Lake Ontario – Upper St. Lawrence coastal wetland habitats. Manipulations of the current Plan 1958DD water-level regulation criteria clearly demonstrate that small changes in specific criteria can have dramatic impacts on coastal wetland plant communities. If the Study Board desires to ensure that any alternate water-level regulation plan recommended to the IJC not only has no additional environmental impact, but also incorporates criteria focused on reducing environmental impacts of the current plan, the results of this study, which have been incorporated into the IERM developed by the Environmental Technical Working Group, can provide valuable information.

The regulation plans used for testing predictive models were developed with recognition that the Study Board must evaluate the interests of all stakeholders and avoid undue impacts to any interest. Therefore, they are potentially viable options that do not exceed extreme lake levels that would otherwise be produced under the current regulation plan. Instead, they change the frequency of high and low lake levels in concert with total basin supplies and represent realistic opportunities to address problems facing this important and complex ecosystem.

Sommaire Exécutif

Les fluctuations des niveaux d'eau sont un phénomène naturel dans les Grands Lacs attribuable à la variabilité climatique naturelle, et les communautés biologiques des Grands Lacs, par nécessité, ont évolué pour s'adapter aux changements des niveaux d'eau qui se produisent sur plusieurs échelles. Les effets biologiques des fluctuations des niveaux d'eau dans les lacs sont les plus importants en eau peu profonde où même un petit changement du niveau d'eau peut entraîner la conversion d'un environnement d'eau stationnaire à un environnement où les sédiments sont exposés à l'air, ou vice versa. Les effets localisés de ce changement dans l'environnement sont les plus évidents dans les communautés végétales des terres humides. En fait, les régimes de changement de niveau d'eau sont la force motrice environnementale qui détermine la diversité globale et la condition des communautés végétales des terres humides et des habitats fauniques qu'elles offrent. Des études antérieures ont démontré que la régulation des niveaux d'eau du Lac Ontario depuis plus de 40 ans a modifié considérablement les communautés végétales des terres humides.

Les objectifs globaux de cette étude étaient de démontrer les changements quantitatifs dans les communautés végétales afin de déterminer les régimes de niveau d'eau qui maintiennent le mieux la diversité de l'habitat, tel que déterminé par la diversité, l'abondance et la distribution des communautés végétales, et de développer des modèles de prévision et des indicateurs de rendement pour évaluer les nouveaux plans de régulation proposés pour le lac. Les tâches spécifiques comprenaient l'évaluation et la quantification des changements à la végétation en examinant les photographies aériennes historiques, un inventaire des terres humides et la classification pour le Lac Ontario et le haut Saint-Laurent, l'échantillonnage des communautés végétales des terres humides le long de transects à des élévations spécifiques qui représentent un historique hydrologique unique, le développement de modèles bathymétriques et topographiques pour chacun des quatre types géomorphologiques de terres humides ayant trait aux communautés végétales et aux habitats fauniques par rapport aux profondeurs d'eau, telles que déterminées par les niveaux du lac, l'établissement de critères environnementaux pour la régulation du niveau d'eau d'après les résultats des études sur la végétation, les modèles bathymétriques et topographiques, les besoins d'habitat du poisson et de la faune, et les changements de niveau du lac à long terme, et l'utilisation des modèles bathymétriques et topographiques et des résultats des études pour développer des outils de prévision et des indicateurs de rendement permettant d'évaluer les effets sur les terres humides de tous les nouveaux scénarios proposés pour la régulation du niveau d'eau.

Les 32 sites de l'étude sélectionnés pour ce travail sont distribués tant tout le Lac Ontario et le haut Saint-Laurent et comprennent huit terres humides de chacun des quatre types géomorphologiques : enfoncement ouvert, enfoncement protégé, lido et terres humides d'embouchure submergées. Pour la moitié, les sites de chaque type géomorphologique sont au Canada et l'autre moitié aux États-Unis. Ces sites visaient à représenter un total de 879 terres humides distinctes au plan géomorphologique, totalisant 25 847 hectares, identifiées dans l'inventaire des terres humides.

L'interprétation et l'analyse des données sur les niveaux d'eau du Lac Ontario et des séries de photos aériennes ont révélé une augmentation souvent substantielle dans la zone et un couvert en pourcentage de communautés végétales dominées par la massette (Typha) depuis le début de la régulation du niveau d'eau en 1958. Pour la plupart des sites, l'augmentation de la zone dominée par la massette n'est pas le résultat de l'expansion du lac; elle est le résultat de l'invasion de la massette dans les communautés des marais à des élévations supérieures. L'absence de niveaux d'eau bas depuis le milieu des années 1960 a vraisemblablement permis à la massette, qui a un besoin d'eau supérieur, de déplacer les marais à des élévations supérieures. En conséquence, on estime que plus de 50 % de la zone de terres humides et de marais du Lac Ontario et du haut Saint-Laurent du milieu à la fin des années 1960 a été déplacée par les marais émergents dominés par la

massette. En de nombreux sites de l'étude, la zone de végétation des marais depuis les années 1960 dépasse 80 %.

Les analyses des données sur les communautés végétales des terres humides, collectées par l'échantillonnage le long de transects qui suivent sept contours d'élévation ayant des historiques de niveaux d'eau différents ont permis d'identifier quatre types de végétation principaux. Trois transects à des élévations supérieures contiennent des espèces végétales associées aux marais; un transects de niveau légèrement inférieur contient une communauté mixte d'espèces des prés et des marais émergents, dont la massette; deux transects sous celui-ci sont des marais émergents dominés par la massette, et le transects le plus bas contient surtout des espèces submergées et de potamot flottant.

Les données bathymétriques et topographiques ont été utilisées pour créer des cartes d'élévation individuelles pour toutes les terres humides de l'étude qui pourraient être comparées aux types de végétation cartographiés. Les méthodologies du SIG ont ensuite été utilisées pour produire des modèles bathymétriques et topographiques pour chacun des quatre types de terres humides. Ces modèles visaient à représenter toutes les terres humides de chaque type spécifique pour utilisation dans les efforts de modélisation prédictive, mais non pour chaque site.

Des modèles de végétation des terres humides prédictifs ont été développés pour chaque type géomorphologique des terres humides dans un format de SIG, les données de contour d'élévation ont été utilisées pour calculer les estimations annuelles de la distribution des communautés végétales pour chaque année dans une séquence des données sur les niveaux d'eau sur 101 ans, telles que présentées dans les nouveaux plans de régulation éventuels. Le résultat est une série de prédictions annuelles de la zone et un pourcentage des catégories de végétation qui occuperont la zone d'élévation (73.0-75.75m) donnée dans les modèles. Dans ceux-ci, l'affectation des quatre types de végétation aux diverses zones d'élévation est basée sur le nombre d'années depuis la dernière inondation ou le nombre d'années depuis le dernier assèchement, tel que déterminé par les règles générées en analysant les données de l'échantillonnage le long des transects.

Les modèles prédictifs pour chacun des quatre types géomorphologiques de terres humides ont été vérifiés à l'aide de plusieurs plans de régulation éventuels pour le Lac Ontario. Les plans vérifiés étaient de 1958D avec des dérivations (1958DD) et deux plans établis en utilisant 1958DD comme base et en ajoutant un niveau supérieur (75.65m) en 1947 lorsque l'alimentation du bassin était élevée et les niveaux du lac plus bas dans les années 1910, 1930, 1960 et à la fin des années 1990 lorsque l'alimentation du bassin est devenue faible. Ni les niveaux élevés ni les niveaux bas du lac n'ont dépassé ceux qui se produisent en réalité après la régulation. Au cours de la période du plan de régulation de 101 ans, les résultats des tests ont montré une augmentation du pourcentage moyen de végétation des marais (ABC) de 1958DD au plan avec des années de bas niveau du lac au plan même avec des années de niveau encore plus bas, ce qui est le résultat attendu.

Un indicateur de rendement de l'habitat des terres humides (zone des marais) a ensuite été établi à l'aide des résultats de l'étude. Cet indicateur a été choisi parce qu'il est sensible au changement hydrologique, qu'il représente un habitat qui soutient la plus grande diversité d'espèces végétales, qu'il peut contenir une diversité d'habitats structurels qui soutiennent un vaste éventail d'espèces fauniques et qu'il est représentatif de la communauté végétale ayant été le plus affectée par la régulation des niveaux du lac. Pour rendre l'indicateur de rendement plus sensible aux conditions hydrologiques qui favorisent l'expansion du marais, la période de l'évaluation de 101 ans a été reprise à la baisse pour inclure des analyses seulement pour les années où l'alimentation totale du bassin offrait une possibilité d'expansion des marais. L'indicateur de rendement en découlant mesure la capacité comparative des plans de régulation de générer les niveaux bas requis par la communauté végétale des marais durant les périodes où l'alimentation en eau est faible et où des niveaux bas du lac sont possibles. Les plans de régulation utilisés pour tester les modèles prédictifs ont ensuite été évalués par chaque modèle de type géomorphologique de terres humides susmentionnés et par la méthode IERN selon les pourcentages de communauté des marais de tous les types géomorphologiques ont été convertis en zone de marais pour l’ensemble du bassin du Lac Ontario et du haut Saint-Laurent. Encore là, le pourcentage de type de végétation de marais a augmenté à partir du plan 1958DD par rapport aux autres plans avec une augmentation du nombre d’années de niveaux bas du lac.

L’abondance des autres communautés végétales des terres humides est également importante dans l’évaluation d’un plan de rechange. Ces prédictions des habitats ont été intégrées à plusieurs modèles fauniques. Des modèles fauniques comme les indicateurs de rendement de l’indice de reproduction de la guifette noire et du râle de Virginie ont été utilisés pour comparer l’alimentation relative des habitats de marais émergents profonds et peu profonds parmi les plans de rechange de régulation des niveaux d’eau.

Dans l’ensemble, les résultats de l’étude indiquent que la modération des fluctuations du niveau d’eau depuis le début de la régulation a limité considérablement l’environnement hydrologique à long terme important pour le maintien des communautés côtières des marais. La modération des fluctuations du niveau d’eau à long terme a également créé des conditions hydrologiques qui ont soutenu l’expansion d’espèces végétales agressives, émergentes et submergées, entraînant une réduction de la richesse des espèces végétales et de la qualité de l’habitat des marais émergents. La réduction de la qualité de l’habitat a probablement été accrue les terres humides qui ont également subi l’impact d’autres facteurs de stress, par exemple une augmentation des éléments nutritifs et des sédiments attribuable aux utilisations des terres environnantes. Toutefois, l’uniformité des résultats de l’étude sur les plantes et des tendances historiques de l’ensemble des terres humides de l’étude, un grand nombre d’entre elles étant dominées par des bassins hydrographiques boisés, soutient la conclusion que la modération du niveau d’eau attribuable à la régulation a un impact majeur sur la qualité de l’habitat côtier des terres humides.

L’établissement de relations quantitatives entre les niveaux d’eau et les communautés végétales des terres humides, les modèles géométriques généralisés d’élévation des terres humides et les estimations de la superficie des terres humides dans la région de l’étude offrent des outils de prévision puissants pour évaluer les impacts éventuels d’autres plans de régulation des niveaux d’eau sur les habitats marécageux côtiers du Lac Ontario et du haut Saint-Laurent. Les manipulations des critères de régulation des niveaux d’eau du plan actuel 1958DD démontrent clairement que de petits changements à des critères spécifiques peuvent avoir des impacts spectaculaires sur les communautés végétales des terres humides côtières. Si le comité de l’étude veut s’assurer que tout autre plan de régulation des niveaux d’eau recommandé à la CMI non seulement n’a aucun impact environnemental additionnel, mais intègre les critères axés sur la réduction des impacts environnementaux du plan actuel, les résultats de cette étude, qui ont été intégrés au IERM développé par le groupe de travail technique environnemental, peuvent offrir de l’information valable.

Les plans de régulation utilisés pour l’essai des modèles prédictifs ont été mis au point en reconnaissant que le comité de l’étude doit évaluer les intérêts de tous les intéressés et éviter les impacts indus pour ceux-ci. Par conséquent, il y a des options éventuellement viables qui ne dépassent pas les niveaux extrêmes du lac qui auraient autrement été produites selon le plan de régulation actuel. Elles changent plutôt la fréquence des niveaux du lac hauts et bas de concert avec une alimentation du bassin total et représentent des possibilités réalistes de régler les problèmes de cet écosystème important et complexe.

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1.0 Introduction

1.1 Background and Rationale

Water-level fluctuations are a natural phenomenon in the Great Lakes due to natural climatic variability. For example, Lake Michigan was less than half its current size during the mid-Holocene warming period about 6,000 years ago and has experienced other extreme high and low lake levels approximately every 150-160 years (Thompson and Baedke 1997, Baedke and Thompson 2000). The biological communities of the Great Lakes have, by necessity, evolved to adapt to the range of water levels and water-level changes that occur on several scales, ranging from wind-driven tides or seiches that can occur several times daily, to seasonal changes each year, to longer episodes.

The biological effects of water-level fluctuations in the lakes are greatest in shallow water where even small changes in water level can result in conversion of a standing water environment to an environment in which sediments are exposed to the air, or vice versa. The localized effects of this change in the environment are most evident in the plant communities that occur in wetlands. In fact, the patterns of water-level change are the driving force that determines the overall diversity and condition of wetland plant communities and the habitats they provide for a multitude of invertebrates, amphibians, reptiles, fish, birds, and mammals (Keddy and Reznicek 1986, Wilcox 1995, Wilcox and Meeker 1995, Maynard and Wilcox 1997, Keough et al. 1999).

Due to Lake Ontario regulation, high lake levels normally experienced during high water-supply periods have been lowered and low lake levels during low water-supply periods raised. The long-term lake-level graph of mean August water levels clearly indicates this moderating effect (Figure 1). This elevation range has been compressed from approximately 1.5 meters to 0.7 meters, or half of what it was prior to regulation or would have been without regulation. The result of water-level moderation is that the total nearshore area that experiences a flooding and dewatering cycle is reduced and wetland plant communities change. Shrubs and upland plants become established in the soils above the high water line, aggressive canopy-dominating larger plants such as cattails crowd out other emergent plant species in shallow water, and a few competitive submersed species dominate in deeper water. High water levels are required to kill many of the shrubs and invading upland plant species. High water levels also result in die back and opening in the lower extent of cattails and other canopy-dominating emergents when water depth growing tolerances are exceeded. When water levels recede, bare sediments are exposed to the air, and seeds of many other emergent plants are able to germinate and grow. The dominate plant species also grow from seed and eventually regain dominance. However, the diversity of habitat provided by a diverse plant community remains for a number of years, the plants are able to complete their life cycles and replenish the seed bank, which awaits the next cycle of high and low water levels. Extreme low water levels expose deeper nearshore areas to the air and kill the competitive submersed plant species; emergent plants grow from the exposed seed bank. When water levels go up again, many of the emergent species eventually die, a variety of submersed plants returns, and the competitive submersed species eventually dominate again, but habitat diversity for fish and other aquatic fauna has been increased for a number of years, and the cycle of wetland rejuvenation has been repeated again (Working Committee 2 1993, Wilcox 1995, Maynard and Wilcox 1997).

1.2 Project Objective

The overall objective of the wetland-related studies within the environmental assessment framework is to maintain, enhance, and restore healthy and diverse wetlands. The objective of this project was to determine water-level patterns that best maintain habitat diversity as determined by plant community diversity, abundance, and distribution. This information was then linked to habitat requirements for wetland fish and wildlife communities. Together, the information gained enabled development of water-regulation criteria important to wetland communities and assessment models for use in evaluating alternate water-regulation scenarios.

1.3 Project Framework

This project draws on past studies conducted in the early 1990s under the direction of the Natural Resources Task Group of Working Committee 2 of the IJC Levels Reference Study. These studies concluded that different wetland plant communities have developed at different topographic elevations in Lake Ontario in response to water-level history. Plant communities at a higher elevation that had not been flooded since 1952 were dominated by grasses, old field plants, and shrubs; over half of the taxa growing at that elevation were upland species. Plant communities at a lower elevation that had not been dewatered since 1964 had the lowest species richness and were dominated by several submersed species. At elevations that were alternately flooded and dewatered on a more frequent basis, species richness of wetland taxa was greatest. However, many of the dominant taxa across all elevations were introduced species (exotics) or otherwise considered undesirable because of invasive, weed-like habits. The lack of high lake levels in recent years was cited as the likely cause for dominance by invasive emergent taxa; the lack of low lake levels was the likely cause for dominance of submersed species (Wilcox et al. 1992). Altered seasonality of water-level changes was also noted (i.e., exaggerated wintertime drawdowns resulting in springtime water levels too low to flood wetlands) and cited as a deterrent to fish access to wetlands for spawning in the spring.

The Natural Resources Task Group sought to develop a draft regulation plan for Lake Ontario that increased the frequency and amplitude of high and low lake levels to approximate natural conditions more closely and thus reduce environmental impacts of regulation. A preliminary recommendation for accomplishing this task was developed based on pre-regulation lake-level variability. Modeling of this regulation plan was based on actual past inflows and resulted in modeled lake levels in several years in the 1970s and 1980s that would likely be considered unacceptable by other interests. Therefore, another preliminary recommendation was developed that used the highest and lowest lake level constraints of the current regulation plan but added more variability in water levels between years. When potential responses of wetland plant communities to this proposed plan were compared with other regulation plans under evaluation, the proposed plan showed some improvement in increasing the area of wetland subjected to both flooding and dewatering conditions and thus increased habitat diversity. However, development and testing of this plan was based on biological and topographic data collection at a limited number of actual field sites and was not quantitative. In addition, the required frequency of high and low water-level events was determined from the modern record, which is too short to show long-term trends. The development process for the plan was also unable to address the seasonality problem, in which many wetlands remain dewatered during the critical seasons when they are used by fish and wildlife, because the topography information was not suited to the task.

This project addressed the limitations identified previously by completing the following activities:

1) evaluation and quantification of interactions between long-term lake levels and wetland communities, and effects of past water-level regulation by
    a) completing a historic vegetation change analysis through comparison of current air photos with pre-regulation and intervening air photos
    c) completing a wetland inventory and classification
    d) sampling wetland plant communities along transects at specific elevations that represent unique hydrologic histories.

2) developing bathymetric/topographic models for each of four Lake Ontario wetland geomorphic types that relate plant communities and faunal habitats to water depths, as determined by lake levels, and can be used to predict habitat changes associated with changes in the regulation plan;

3) developing preferred environmental criteria for water-level regulation based on vegetation study results, bathymetric/topographic models, fish and wildlife habitat requirements, and long-term lake-level changes; and

4) using bathymetric/topographic models and study results to develop predictive tools to assess the potential effects on wetlands of all proposed new scenarios for water-level regulation.

2.0 Study Design

2.1 Study Sites

Although lake-level fluctuations are a key factor in the distribution of wetland plant communities along an elevation gradient, several other environmental variables also influence the plant community distribution and abundance within a wetland. These include coastal dynamics, local geology, watershed inputs, and human influences on these environmental variables (Keddy 2000). The interactions among lake and watershed hydrology, and shoreline geomorphology result in a diverse array of coastal features and wetland types within the Great Lakes (Keough et al. 1999, Albert et al. 2005). Within Lake Ontario – Upper St. Lawrence River, four distinct hydrogeomorphic types are common and include wetlands protected from wave attack by barrier beaches, thus retaining organic sediments and developing a flatter topographic profile; protected wetlands in river mouths that are back-flooded by the lake and also have organic sediments and a flatter topographic profile; wetlands exposed to wave attack in open embayments, thus having predominantly inorganic sediments and a steeper topographic profile; and wetlands of intermediate wave exposure in protected embayments. Eight wetlands of each type were selected in the Lake Ontario basin for the completion of detailed site-level wetland plant community research. The 32 wetlands, half being located in each country, are considered to be representative of the other Lake Ontario - Upper St. Lawrence River wetlands. Hydrologic associations and predictive models developed using data from the study sites were extrapolated to a basin-level wetland database to allow estimation of basin-level trends.

2.2 Lake Ontario - Upper St. Lawrence Coastal Wetland Database

A seamless, digital, vector-based coastal wetland database was created for the entire Lake Ontario basin and Upper St. Lawrence using a combination of existing Ontario and New York wetland databases and photointerpretation. The Ontario Great Lakes Coastal Wetland Atlas (Environment Canada and Ontario Ministry of Natural Resources 2003) was used as a basis for development of the Canadian IJC study specific database. The majority of Canadian Lake Ontario and Upper St. Lawrence wetland atlas data was created from Provincial Wetland Evaluations that are based upon standard provincial protocols to map and evaluate Ontario wetlands (Ontario Ministry of Natural Resources 1993). Additional coastal wetlands were identified using the Ontario Ministry of Natural Resources (OMNR) Natural Resource Values Information System (NRVIS) waterpoly coverage digitized from the Ontario Base Mapping Program in combination with aerial photographs. For coastal wetlands that did not have suitable digital data, polygons were generated by delineating the wetland boundary using standardized air photo interpretation techniques (Owens and Hop 1995) and on-screen digitizing using ArcGIS 8.2. A combination of OMNR spot height elevation data and aerial photographs were used to identify wetlands that are hydrologically connected and influenced by lake levels.

For the U.S. component of the data series, Lake Ontario - Upper St. Lawrence coastal wetlands were extracted from the National Wetlands Inventory (NWI) of the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 1981-2001). Digital Elevation Models (U.S. Geological Survey 2001) were used to select wetlands situated at an elevation at least partially below historic high lake-levels, and infrared aerial photos (USACE 1988/1990) were interpreted to identify wetlands hydrologically connected to Lake Ontario by open-channel flow. Wetlands identified in aerial photos but not included in the NWI data set were identified and digitized using Digital Enhanced OrthoImagery (NYS Department of State 1999). The New York State Department of Environmental Conservation Regulatory Wetlands database was consulted as necessary (NYSDEC 1999).

Aerial photointerpretation was used to classify all wetlands in the coastal wetland database into one of the four hydrogeomorphic groups; barrier beach, drowned river mouth, open embayment, or protected embayment using a standard protocol (Albert et al.2005).

2.3 Historic Trends in Wetland Vegetation Abundance

Aerial photointerpretations of historic wetland vegetation patterns were made from pre-regulation to recent years (1930s – 2001). The aerial photo time series was used to map major vegetation types distinguishable through standardized photointerpretation techniques (Owens and Hop 1995) using a modified version of the southern Ontario Ecological Land Classification (Lee et al. 1998) and project specific guidelines (Appendix A). All vegetation maps were vectorized and orthorectified using ESRI products. The current time series vegetation map for each wetland study site was ground-truthed in 2002, and vegetation polygon classifications updated accordingly. Signatures of the current vegetation types were used to assist in interpretation of historic vegetation types by back-tracking through the photo time series.

2.4 Current Distribution of Wetland Vegetation along a Hydrologic Gradient

In 2002, transects perpendicular to the shore were established 50 m apart at each of two randomly selected locations along the perimeter of each study wetland. The topographic cross-sections along each of these perpendicular transects were surveyed using a laser transit. Since permanent benchmarks are generally not available near study sites, the current lake level was used to establish altitudes. Lake level at the recording station nearest the study site was obtained by telephone from offices of the National Oceanographic and Atmospheric Administration or Canadian Hydrographic Service on the morning of the survey. Specific elevations with ecological significance based on past water-level history were located along each transect by surveying, marking with flagged stakes, and GPS. Since the existing wetland vegetation in the lake developed in response to the history of high and low lake levels, the selected elevations reflect unique water-level histories. Surveyed elevations (IGLD85) were: 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 5 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. (Figure 2).

In late July- early August 2003, sampling was conducted at both plots within each study site. Ten 0.5 x 1.0 m quadrats were randomly placed along transects that follow the contours for each specific elevation (parallel to the shoreline) and running between the two transects surveyed in perpendicular to the shoreline. The quadrats were placed on the landward side of the contour transect lines. Such placement allowed the quadrats to adhere to the water-level history of each elevation according to the sampling design. In each quadrat, the plant species present were identified and percent cover estimations made by visual inspection. Plant taxonomy followed Gleason and Cronquist (1991). Substrate types and canopy cover were also noted or measured and recorded at each quadrat location. Importance Values (IV) were calculated for all taxa within each transect as the sum of relative frequency and relative cover ratings; these values were placed in Non-metric Multi-Dimensional Scaling (NMDS) ordinations. Correlation between specific elevations and accompanying plant communities were assessed across all wetlands sampled to determine the range of elevations in which the most diverse plant communities occur and to identify unique hydrologic associations of individual plant species, including invasive taxa. Any correlations with other physical habitat parameters were identified also.

2.5 Wetland Study Site and Generalized Elevation Models

The Information Management Working Group (formerly Common Data Needs WG) was identified to oversee collection of appropriate elevation data for the 32 wetland study sites. Topographic and bathymetric data for each study site were acquired using a combination of existing detailed Flood Damage Reduction Mapping, photo-interpreted topographic contours, airborne LIDAR, and boat-based sounding techniques. The bathymetric and topographic data were used to develop digital elevation models of each wetland study site within a GIS modeling framework. A variety of interpolation methods were evaluated for use with point elevation data from varying sources. A generalized digital elevation model for each of the four wetland types was created by integrating data from the eight study sites for each hydrogeomorphic wetland type. The generalized model and coastal wetland database were used to quantify estimates of change using the various wetland performance indicators and metrics.

3.0 Results and Discussion

3.1 Study Sites

Study sites were distributed throughout the Lake Ontario – Upper St. Lawrence River (Figure 3). Factors considered in selection of study sites included current distribution of wetlands, representative characteristics, accessibility, and topographic/bathymetric data collection limitations within the study. More study sites were located within the eastern half of the study area due to the fact that over 80 % of the current coastal wetland area occurs in this region (see Section 3.2) and acquisition of topographic/bathymetric data was restricted to certain reaches of the shoreline by the Common Data Needs Working Group. A total area of 4,108 hectares of wetland was mapped within the 32 study sites (Table 1). Study-site size varied significantly ranging from 7 to 543 hectares, with the mean wetland area for each wetland type ranging between 104 and 180 hectares (Table 1). Wetland area within the 32 study sites represents approximately 16% of the total estimated coastal wetland area within the Lake Ontario – Upper St. Lawrence River region.

3.2 Lake Ontario - Upper St. Lawrence Coastal Wetland Database

A total of 879 geomorphically distinct wetlands were identified within the Lake Ontario – Upper St. Lawrence River area, totaling 25,847 hectares (Appendix B). Drowned river mouth wetlands account for the largest area of wetland, followed by barrier beach, protected embayment, and open embayment (Table 2). Wetland size ranged from 0.02 to 1,157.2 hectares with an average size of 29.4 hectares. The availability of higher resolution wetland data in New York enabled identification of many wetlands less than 2 hectares in size (n=283). Ontario wetland data were typically not available to this resolution, and fewer small wetlands (<2.0 hectares) were identified on the Canadian side (n=56). Although the different resolutions do have an impact on the accuracy of current wetland distribution within the study, these wetlands have only a small influence on the total wetland area by type. The total wetland area was used to extrapolate study site based generalized models to basin-level impacts.

Distribution of wetlands along the shoreline is dictated by surficial geology, watersheds, and coastal processes. The eastern half of Lake Ontario (east of shoreline units CND8 and US3 to RIV1) supports over 21,000 ha of wetland or greater than 80% of the estimated current coastal wetland area (Figure 4). Within the eastern basin, shoreline units CND9, CND11, US4, US7, and RIV1, specifically, contain a geomorphology that supports a very high density of embayment and barrier beach wetlands (>18,000 ha) (Figure 4, 5).

Drowned river mouth wetlands make up the majority of wetlands that occur in the western basin of Lake Ontario. The highest concentrations of barrier beach wetlands are located along the southeastern shoreline of Lake Ontario (US4, US7, and US8) and outer shoreline of Prince Edward County (CND9), Ontario (Figure 5). The greatest densities of protected and open embayment wetlands occur within the Bay of Quinte (CND11), and within the island network occurring at the outlet of Lake Ontario and Thousand Island region within the St. Lawrence River (US8, RIV1).

3.3 Historic Trends in Wetland Vegetation Abundance

Interpretation and analysis of Lake Ontario water-level data and aerial photo series revealed an often substantial increase in the area and percent cover of *Typha*-dominated wetland vegetation communities since water-level regulation began in 1958. Aerial photo sets in the late 1950s and mid- to late 1960s revealed meadow marsh vegetation to be common in most study sites during this time period, which corresponds to low water levels in 1958-1959, and again in 1964-65. Over the course of this low water-level period, meadow marsh also expanded downslope, displacing emergent marsh at higher and dryer elevations in several locations (Figure 6). In other locations, the area of meadow and emergent marsh generally remained constant during this period. Since this low water period, there has been an often substantial increase in the area and percent cover of emergents and typically *Typha*-dominated wetland vegetation communities. At most sites, the increase in *Typha*-dominated area did not result from outward expansion of the wetland; it was the result of *Typha* invasion into existing meadow marsh communities (Figure 6, 7). The most dramatic increase in *Typha* was observed in the late 1970s photo set that was taken during a time of extended high-water levels. Lack of low water levels since the mid-1960s has seemingly not allowed meadow marsh to displace *Typha* at higher elevations. As a result, it is estimated that the greater than 50% of the meadow marsh wetland area that occurred within Lake Ontario – Upper St. Lawrence River during the mid- to late 1960s has been displaced by *Typha*-dominated emergent marsh. At many study sites, the loss in area of meadow marsh vegetation since the 1960s exceeds 80%. After the extreme highs in the mid-1970s, relatively static, moderate water levels in the 1980s and 1990s have maintained a somewhat constant area of meadow marsh. *Typha*, however, continued to expand into shallow pools and channels, resulting in a reduction in emergent habitat heterogeneity and emergent-open water edge (Figure 6). The floating-leaf communities have also increased in area at many sites since the 1970s due to the lack of extremely high or low water levels.

It should be noted that Great Lakes coastal wetlands have been impacted by a variety of human activities over the last 40 years. Surrounding land uses such as agriculture, have increased nutrient and sediment inputs, and are supporting the expansion of Typha in many Lake Ontario coastal wetlands. It is likely that degree of loss in habitat heterogeneity, diversity, and dominance of aggressive plant species such as Typha and other exotic species has been magnified in coastal wetlands that have experienced cumulative stresses. The moderation of water levels due to water regulation however, is a basin wide and significant stressor to the coastal wetland communities.

3.4 Current Distribution of Wetland Vegetation along a Hydrologic Gradient

Of the seven elevations that were sampled, the three transects at higher elevations (A, B, and C) had the most species in all four geomorphic types (Table 3). Differences in species richness between transects D, E, F, and G varied by geomorphic type and wetland. The number of wetland obligate species will be considered in future analyses.

When vegetation data were analyzed by species prominence and non-metric multidimensional scaling (NMDS), transects A, B, and C showed similarities across geomorphic types, and E and F were similar in all types except protected embayments. Data were analyzed to ascertain similarities among wetlands of the same geomorphic type for use in the model.

Open embayment.

Analysis of the most prominent species in open-embayment wetlands, determined by mean percent cover greater than 2.0 for at least one transect, showed similarities among transects A, B, and C in species composition consisting of sedges, grasses, and upland species (Table 4). In transect D, sedge and grass species, as well as emergent vegetation present in E and F (e.g., *Typha*), comprised the prominent species. Transects E and F showed similar species composition, largely *Typha*-dominated emergent vegetation, with some submersed species and sedges and grasses. In transect G, floating-leaf vegetation (e.g., *Nymphaea*) and submersed vegetation were more prominent than emergent vegetation, and sedges and grasses were not observed (Table 2). The NMDS ordination of species importance values provided a separate approach at analyzing the same open-embayment vegetation data. The initial ordination analysis (Wilcox et al. 2004) sorted the vegetation of each wetland transect according to similarities, dissimilarities, and co-occurrences. The transects largely fell into distinct groups having similarities to prominent species patterns observed in

Table 4. One study site (Robinson Cove) proved to be a partial outlier, and the transect D data point for that site was thus excluded from the D grouping within the ordination (see Wilcox et al. 2004). The resulting ordination diagram (Figure 8) showed transects A, B, and C in close proximity to each other and transect G isolated from others, an indication of unique species composition. Although a minor overlap was observed between the D- and E-transect groups, transects E and F fell very close to each other, whereas transect D fell farther away; it was apparent that the E and F transects had similar species composition, while the D transects had a dissimilar species composition (Figure 8). The prominent species calculations (Table 4) and the ordinations, although a separate means of analyzing the vegetation data, gave the same results. Accordingly, for open embayment wetlands, vegetation at transects A, B, and C was treated as one community; transect D vegetation was a second community; vegetation at transects E and F comprised a third community; and vegetation at transect G was a fourth. The four communities were used in subsequent analyses. For each vegetation structural category defined for faunal studies, a mean cover for the four transect groupings was calculated (Table 5). Forbs, grasses, trees/shrubs, and sedges had the highest mean cover values in the ABC community. Thin-stem persistent emergent vegetation was prominent in both the D and EF communities. However, forbs followed in prominence in the D community, whereas floating-leaf vegetation followed in the EF community. Submersed narrow-leaf vegetation dominated the G community. Unlike the ABC and G communities, the D and EF communities contained vegetation in most structural categories (Table 5).

Protected embayment.

Like open embayments, analysis of the prominent species in protected-embayment wetlands showed similar grass and sedge species composition in transects A, B, and C (Table 6). Transect D had sedges and grasses but was dominated by *Typha*. Transect G again was dominated by floating-leaf and submersed vegetation and lacked sedges and grasses. Unlike the open embayments, however, the protected-embayment wetland vegetation was distinct in transects E and F. Although *Typha* was most prominent in both transects, the presence of grasses differentiated E from F, and distinctions between D and E were due to greater prominence of trees and shrubs in D and floating-leaf vegetation in E (Table 6). The initial NMDS ordination of the wetland vegetation (Wilcox et al. 2004) showed similar results. Two study sites were identified as partial outliers. When the ordination was run again without Black River Bay South and the data point for transect E from Parrot Bay was excluded from the E grouping, transects A, B, and C overlapped almost completely, and the other four transects were mostly distinct (Figure 9). As in the open-embayment wetlands, the prominent species and ordination analyses produced similar results. For protected embayment wetlands, transects A, B, and C were treated as one community, and transects D, E, F, and G were considered four individual communities. These five communities were used in subsequent analyses. For the faunal study, mean cover of vegetation structural categories was calculated for the communities described, and calculations excluded Black River Bay south (Table 7). Forbs and trees/shrubs dominated the ABC community. Thin-stem persistent emergents and grasses were prominent in the D and E communities, with an increase in floating-leaf vegetation differentiating E from D. The F community was similar to E except that it had fewer grasses and more floating-leaf vegetation. Finally, submersed narrow-leaf, floating leaf, and algae dominated the G community.

Barrier beach.

Prominent species analysis of barrier-beach wetland vegetation indicated similarities between transects A, B, and C, whose predominant species composition consisted of grasses, ferns, and shrubs (Table 8). Although transects D, E, and F were dominated by *Typha*, transect D had more grasses than transects E and F, which had similar species compositions. Transect G was dominated by floating-leaf and submersed vegetation (Table 8). The initial NMDS ordination of transect vegetation (Wilcox et al. 2004) gave similar results, with transects A, B, and C overlapping and G a distinct group. Two study sites were partial outliers (Wilcox et al. 2004). The ordination was run again with the Port Britain data removed, and the data point for the E transect at Big Sand Bay was excluded from the E grouping. The resulting ordination diagram (Figure 10) showed transects A, B, and C overlapping, E and F overlapping, G distinct, and D mostly distinct. Thus, by prominent species and ordination analyses, transects A, B, and C were treated as one community in subsequent analyses. Transect D was considered a second community, combined E and F transects formed a third community, and transect G was the fourth. The mean cover for structural categories used in faunal studies was calculated for the four communities described above (Table 9). The ABC community was dominated by trees/shrubs, forbs, ferns, and grasses. Thin-stem persistent emergent species were dominant in the D and EF communities. However, the EF communities had more floating-leaf vegetation, whereas the D community had grasses. Prominent structural categories in the G community included narrow-leaf, floating leaf, and algae.

3.5 Wetland Study Site and Generalized Elevation Models

Topographic and bathymetric data formats and sources varied for the 32 study sites. An Inverse Distance Weighting (IDW) interpolation method with a power value of 2.4 and weighting value of 8 meters was used to create individual elevation surface maps for each of the study wetlands (Figure 12). This method was chosen as the best method to minimize jagged edges associated with bathymetric data collection methods and varying point density. To meet the needs of the IJC study, four models representing the four wetland geomorphic types were developed to provide the required predictive capability. The generalized models were developed by determining the relative areal proportion of each individual wetland that lies above, below, or between selected contour intervals (Table 12). ArcGIS 3D Analyst was used to generate generalized geometric models for each of the four wetland types studied based on the elevation surface maps from the groups of wetlands for each wetland geomorphic type. The resultant models for open embayment, protected embayment, barrier beach, and drowned river mouth wetlands are meant to represent all wetlands of each specific type but not any individual site (Figure 13a, b, c, d).

The uniqueness of the four wetland geomorphologies elevation profiles is evident within the cumulative percent area distributions along the model elevation range (Figure 14). Within the open and protected embayment geometric models lower elevation contours account for more of the total model area. Relative to the other wetland types, embayment wetlands are more exposed to wave attack and ice scour, which reduces the rate of organic sediment deposition. For this reason, embayment wetlands are expected to have a steeper topographic profile within the upper contour elevations and shallower slopes at lower elevation contours. Drowned river-mouth and barrier-beach wetlands are typically well-protected from wave attack. The river channel and beach barrier protection features allow for thick sediment accumulation and result in a shallower topographic profile within the upper elevation contours of the model range.

4.0 Predictive Models and Performance Indicators

4.1 Predictive Habitat Models for Assessing Alternate Water Regulation Plans

The predictive model was developed in the first year of this study using hypothetical topographic/bathymetric data. Within a GIS format, the model calculated the land-surface area between any selected elevation contour lines and converted such areas to percent of total wetland area using the following general procedures. Making use of the new regulation plan provided for evaluation, and starting with the most recent year in that plan, the hypothetical model used mathematical routines to **a**) identify the highest past lake level that occurs in the plan (e.g., 75.4m IGLD), **b**.) determine the wetland area (and percent wetland) between that elevation and the upper limit of the topographic/bathymetric model (75.75m), **c**) determine the number of years from the year being analyzed and the year in which the highest lake level (75.4m) occurred, and **d**) assign the area/percent wetland results to the appropriate vegetation/ time class (e.g., always dewatered, so *last flooded >30 years ago*).

Next, starting at the previously identified highest lake level (75.4m), the mathematical routines did the following: **a_1**) identify the next highest lake level shown in the regulation plan that occurs **after** the previously identified 75.4m high (e.g., 75.2m), **b$_2$**) determine the wetland area (and percent wetland) between that elevation and the 75.4m elevation, **c**) determine the number of years from the year being analyzed and the year in which the next highest lake level (75.2m) occurred, and **d**) assign the area/percent wetland results to the appropriate vegetation/ time class (e.g., last flooded 16 years ago, so last flooded *5-30 years ago*). The routine identified above is continued until the next identified high lake level is less than 5 years in the past, as determined in step **c**.

A routine similar to that identified above is then used to **a$_2$**) identify the lowest summertime peak lake level (e.g., 74.2m), **b$_2$**) determine the area and percent wetland between that elevation and the lower limit of the topographic/bathymetric model (73.0m), **c$_2$**) determine the number of years from the year being analyzed and the year in which the lowest summertime peak lake level (74.2m) occurred, and **d**) assign the area/percent wetland results to the appropriate vegetation/ time class (e.g., always flooded in summer, so *last dewatered in summer >40 years ago*). Routines similar to those above then continue to address low summertime peak lake levels until the next identified low summertime peak lake level is less than 4 years in the past. All wetland elevations (and corresponding areas/percents) that were flooded less than 5 years or dewatered less than 4 years in the past from the year being analyzed are assigned to the vegetation/ time class *flooded less than 5 years and/or dewatered in summer more recently than 4 years ago*.

The above steps are then repeated for the next most recent year shown in the regulation plan and continue sequentially backwards through the first year of the plan. When evaluating early years in a regulation plan, there are limited numbers of prior years from which to make calculations. This problem is overcome by attaching a copy of the regulation plan at the beginning of the plan under evaluation because the regulation plan is considered to be a repetitive sequence of lake-level patterns.

The hypothetical model output is annual predictions of the area and percent of vegetation/time classes that will occupy the elevation range (73.0-75.75m) given in the model. These predictions are then time-weighted by summing the areas/percents for each vegetation/time class and dividing by the number of years analyzed. The final output is time-weighted percent of wetland expected to fall into each vegetation/time class during the period portrayed by the proposed regulation plan. This model was tested and found to function according to design. However, it represented a hypothetical wetland and could not be used for actual predictions of wetland plant community response to regulation plans. Application of the four study generated geometric models representing the wetland geomorphic types required minor modifications of the hypothetical model because water-level data were presented in quarter-monthly (QM) form. As described in Section 3.4, the vegetation types were also defined more clearly, based on actual field data from sampling along transects.

Assignment of vegetation types (ABC, D, EF (E and F are separate for protected embayments only), or G) to various elevation ranges is based on the number of years since last flooded or the number of years last dewatered among the transect elevations used for sampling and grouped together as individual vegetation types. Professional judgment based on discussions among prominent Great Lakes wetland scientists was used to determine break points between classes.

Estimations of the number of years since last flooded and/or dewatered for each elevation increment are calculated based on the following process.

For "last flooded" determinations of A, B, C, D :

- All portions of elevation model above the highest peak identified across the entire regulation plan are never flooded by the lake and are automatically assigned to U (transition to Upland) up to 75.75m
- For other peaks, locate peak Quarter Month (QM).

- Identify 3 adjacent (4 total) highest QMs (doesn't matter which side of peak).
- Select elevation of the QM that is lowest of the 4.
- In most cases, this selects an elevation that has been flooded for 3 QMs.

IF: the most recent "last-flooded" peak year selected is <5 years ago and its elevation selected from the 4 highest QMs as described above is less than the most recent dewatered year elevation, then use the single peak QM for the "last flooded" elevation determination, rather than the elevation selected from the 4 highest QMs.

For "last dewatered in summer" determinations of D, E, EF, F, G :

- Use annual peak QM elevation.
- All portions of the elevation model below the lowest summertime peak identified across the entire regulation plan are continuously flooded and automatically assigned to G down to 73.0m.
- This procedure selects an elevation that largely remained dewatered during the entire growing season, although it could be flooded short term if the peak QM elevation reported did not represent the actual peak day. In addition, this elevation could periodically be flooded by seiches.

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)
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)
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)
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)
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 four new models were tested using several potential regulation plans for Lake Ontario. The plans were very similar, but differed in summertime peak water levels in certain years in a manner that would be expected to result in a change in model output for meadow marsh vegetation (ABC). The plans tested were 1958D with deviations (1958DD) (Figure 15), and two plans developed by using 1958DD as a base and adding a higher lake level (75.65m) in 1947 when basin supplies were high and lower lake levels in the 1910s, 1930s, 1960s, and late 1990s when basin supplies were low. Neither high nor low lake levels exceeded those that actually occurred during post-regulation.

Plan 0809c (Figure 16) added low summertime peak levels around 74.7m in 1910, 1911, 1934, 1935, 1964, 1965, and 1999 to provide the perceived opportunity for meadow marsh vegetation (ABC) to recolonize portions of the elevation gradient otherwise occupied largely by *Typha* (D, E, F, EF). Following those low summertime peak levels, intermediate summertime peak levels of about 74.8m were invoked in 1912, 1913, 1936, 1937, 1966, 1967, and 2000 to sustain the ability of the meadow marsh vegetation type (ABC) to occupy a wider elevation range.

Plan 0924 (Figure 17) was similar to plan 0809c except that the intermediate summertime peak levels of about 74.8m were extended to 1914, 1915, 1938, 1939, 1968, and 1969 to increase the ability to sustain the meadow marsh vegetation type (ABC). Thus, the expected response of model results would be an increase in ABC from plan 0809c to 0924, both of which should have more ABC than 1958DD.

When the regulation plans were tested by the models, the 101-year average for meadow marsh (ABC) vegetation increased from 1958DD to 0809c to 0924 in the drowned river mouth, barrier beach, and open embayment models. ABC results in plans 0809 and 0924 were equivalent in the protected embayment model but greater than results for 1958DD (Table 13). Full model results are presented in Appendix C and D.

4.2 Wetland Habitat Performance Indicators

Many aspects of the Lake Ontario - Upper St. Lawrence River coastal wetland flora and fauna are being evaluated by members of an Environmental Technical Working Group (ETWG). The ETWG used a variety of predictive models to develop metrics and Performance Indicators (PIs) for use in an environmental evaluation of alternate water regulation plans. Annual estimates of several unique wetland habitat types are being predicted as a percentage of the geometric wetland models (Figure 18). The percentage values were multiplied by wetland type total area estimates to generate basin level area estimates of wetland habitat types. The abundance of other predicted wetland vegetation communities are also important in alternate plan evaluation. These habitat predictions have been incorporated into several faunal models. Faunal models such as the Black Tern and Virginia Rail Tern Reproductive Index performance indicators, incorporate estimates of emergent marsh area that are flooded during the breeding season (DesGranges et al. 2005). As such, these two PIs are being used to compare the relative supply of deep and shallow emergent marsh habitats among alternate water regulation plans.

Analyses of historic aerial photos showed that the extent of meadow marsh plant communities decreased substantially following regulation of lake levels. Ensuring that meadow marsh plant communities are not additionally impacted under proposed alternate regulation plans is a specific priority of the wetland research. The following performance indicator was developed specifically for meadow marsh habitats. It uses the models described above and applies the results to total area of wetland in each geomorphic type, as determined by the wetland inventory.

Area of meadow marsh - Meadow marsh vegetation (ABC) typically develops between the maximum long-term high water level and the long-term mean. Plant species within this community are intolerant of prolonged flooding, but occasional flooding is required to prevent woody plant species from expanding down slope into the meadow marsh community. In addition, periodic low water levels are also required to stop the expansion of aggressive emergent plants upslope, and allow meadow marsh plant species to expand into elevations that are temporarily unsuitable to maintain emergent plants. Meadow marsh habitats support a very diverse group of meadow-specific plant species but 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 the greatest diversity of plant species and can contain a diversity of structural habitats that support a wide range of fauna. However, the meadow marsh occurs in a relatively narrow hydrologic range in comparison to the other wetland vegetation communities.

Water-level-regulation plans that maximize the expansion of meadow marsh in the 101-year average area estimates are considered better for the environment. However, when the extent of meadow marsh is averaged over the 101-year period, the data include years with high total basin supplies, which should result in high lake levels not amenable to meadow marsh expansion. A performance indicator based on the 101-year period would not represent the actual potential for meadow marsh expansion. Therefore, the performance indicator was scaled to include analyses for only those years in which low total basin supplies provided an opportunity for meadow marsh to expand. The resulting performance indicator measures the comparative ability of regulation plans to generate the low lake levels required by the meadow marsh community during time periods when water supplies are low and low lake levels are possible.

The periods selected for analyses under this performance indicator were determined by analyzing total basin supplies during the pre-regulation period and comparing them with the actual lake levels that occurred during the same time period. The quarter-monthly total basin supplies for January to June were then summed for those years and averaged. As a result of this procedure, the performance indicator measures meadow marsh response in the years following a low supply period in which the January-June quarter month net total supply is less than 6,792 m3/s and continues until the year when the same average exceeds 7,917 m3/s).

Regulation plans 1958DD, 0809c, and 0924 were then evaluated both by individual geomorphic wetland type models described above and by the IERM, in which percentages of meadow marsh community across all geomorphic types were converted to area of meadow marsh for the entire Lake Ontario/Upper St. Lawrence River basin. Again, the percent of meadow marsh vegetation type increased from plan 1958DD to 0809c to 0924 in models for all geomorphic types (Table 14). Within the IERM, the total area of meadow marsh in the basin increased from 5,225 ha for plan 1958DD to 5,897 ha for plan 0809c to 6,327 ha for plan 0924.

5.0 Conclusions

Intensive plant community surveys within coastal wetlands representative of the study area confirm previous conclusions that the distribution of plant communities in Lake Ontario – Upper St. Lawrence River coastal wetlands is highly correlated to water-level history (Wilcox et al. 1992). The wetland plant community type observed at specific elevations was consistent among sites within and across the wetland geomorphic types. Analyses of historic aerial photographs also confirm that plant communities have responded to interannual water-level cycles, with communities shifting up- and down-slope, based upon hydrologic preferences, during high and low water-level cycles, respectively. Study results also indicate that moderation of water-level fluctuations since water regulation, has significantly restricted the long-term hydrologic environment important to the maintenance of coastal wetland meadow marsh communities. Moderation of long-term water-level fluctuations has also created hydrologic conditions that supported the expansion of aggressive, dominant emergent and submergent plant species, resulting in a reduction of plant species richness and emergent marsh habitat quality. It is likely that the reduction in habitat quality has also been influenced and magnified in wetlands that have been impacted by increased nutrient and sediment inputs due to surrounding land uses. However, intensive surveys and historic aerial photo evaluations provide very similar results across all of the study sites, including sites with largely natural (forested) watersheds. The consistency in study results support the conclusion that water-level moderation due to water regulation is having a major impact on coastal wetland habitat quality.

The development of quantitative relationships between water levels and wetland plant communities, generalized geometric wetland elevation models, and estimates of wetland area within the study region provide powerful predictive tools to evaluate potential impacts of alternate water-level regulation plans on Lake Ontario – Upper St. Lawrence coastal wetland habitats. Manipulations of the current Plan 1958DD water regulation criteria clearly demonstrate that small changes in specific criteria can have dramatic impacts on coastal wetland plant communities. If the Study Board desires to ensure that any alternate water-level regulation plan recommended to the IJC not only has no additional environmental impact but also incorporates criteria focused on reducing environmental impacts of the current plan, the results of this study, which have been incorporated into the IERM developed by the Environmental Technical Working Group, can provide valuable information. The regulation plans shown in Figures 16 and 17 were developed to test the wetland plant community model, but they were developed with recognition that the Study Board must evaluate the interests of all stakeholders and avoid undue impacts to any interest. Therefore, they are potentially viable options that do not exceed extreme lake levels that would be produced under the current regulation plan. Instead, they change the frequency of high and low lake levels in concert with total basin supplies and represent realistic opportunities to address problems facing this important and complex ecosystem.

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Tables

Table 1. Size characteristics of the 32 Lake Ontario - Upper St. Lawrence River wetland study sites.

Wetland Type	**Count**	**Total Area (ha)**	**Mean Area (ha)**	**Min. Area (ha)**	**Max. Area (ha)**
Barrier Beach	8	836.8	104.6	11.9	178.3
Drowned River Mouth	8	1,442.7	180.3	27.4	543.1
Open Embayment	8	880.6	110.1	7.7	346.0
Protected Embayment	8	948.3	118.5	15.3	371.1
Total	32	4,108.4			

Table 2. Estimate of Lake Ontario - Upper St. Lawrence River coastal wetland area (hectares) by shoreline unit and wetland type. Barrier beach (BB), drowned river mouth (DRM), open embayment (OE), and protected embayment (PB) geomorphic types.

SHL UNIT	**BB**	**DRM**	**OB**	**PB**	**SHL UNIT TOTAL**
CND1	-	190	5	-	195
CND3	-	226	-	-	226
CND4	11	46	-	-	57
CND5	4	-	-	14	18
CND7	323	529	-	-	852
CND8	187	139	-	-	326
CND9	1,197	997	473	634	3,301
CND10	23	71	63	11	168
CND11	67	3,059	695	2,184	6,004
CND12	543	781	-	73	1,397
Subtotal	**2,356**	**6,038**	**1,236**	**2,915**	**12,545**
US1	33	184	0	-	218
US2	587	551	162	94	1,393
US3	-	8	1	-	9
US4	880	626	0	443	1,950
US5	82	14	3	-	99
US6	149	4	0	-	154
US7	1,954	324	0	305	2,584
US8	361	249	218	96	924
Subtotal	**4,046**	**1,961**	**386**	**938**	**7,331**
R1	431	1,163	1,392	1,580	4,566
R2	-	56	103	156	315
R3	39	69	220	762	1,090
Subtotal	**470**	**1,288**	**1,714**	**2,498**	**5,971**
TOTAL	**6,872**	**9,287**	**3,337**	**6,352**	**25,847**

Table 3. Species richness by transect for each wetland study site.

Geomorphic Type	Site	Transect						
		A	B	C	D	E	F	G
Barrier beach	2. Lynde Creek	32	33	37	15	7	8	2
	4. Port Britain	27	27	27	13	9	4	-
	6. Huycks Bay	22	18	16	20	20	24	12
	8. Big Sand Bay	38	38	38	26	29	16	-
	26. Lakeview Pond	53	53	52	30	17	18	19
	27. South Colwell Pond	48	39	38	20	14	27	29
	29. Maxwell Bay	40	46	43	24	18	15	13
	30. Round Pond	23	25	28	19	6	9	17
Drowned river mouth	1. Jordan Station	32	23	18	16	7	3	8
	3. Wilmot Creek	28	26	26	14	11	12	6
	10. Hay Bay north	35	39	36	20	16	16	17
	13. Little Cataraqui	27	35	30	22	16	23	14
	17. Crooked Creek	40	57	61	42	23	21	25
	21. Kents Creek	50	44	32	11	7	9	16
	25. Stony Creek	40	48	39	21	14	15	24
	32. Brush Creek	38	28	22	9	6	8	14
Open embayment	7. South Bay	32	29	21	13	15	14	6
	9. Robinson Cove	20	25	21	11	13	16	14
	11. Hay Bay south	42	40	39	17	18	10	11
	15. Button Bay	49	50	39	15	11	15	11
	20. Eel Bay	54	61	65	33	27	24	21
	22. The Isthmus	45	39	34	13	27	17	14
	23. Black River Bay north	67	65	62	24	13	35	20
	31. Braddock Bay	33	26	33	16	14	18	12
Protected embayment	5. Presqu'ile Bay	37	41	34	27	26	18	15
	12. Parrot Bay	34	39	42	24	16	24	17
	14. Bayfield Bay	27	32	31	32	24	25	16
	16. Hill Island East	39	38	37	31	27	33	20
	18. Goose Bay	48	54	45	23	16	16	25
	19. Point Vivian Bay	23	33	29	23	16	10	15
	24. Black River Bay south	32	28	27	17	9	13	18
	28. north North Pond	37	38	31	16	17	27	17

Table 4. Most prominent species among open-embayment wetlands by mean percent cover for all transects.

TAXA	MEAN % COVER						
	A	B	C	D	E	F	G
Calamagrostis canadensis (Michx.) P. Beauv.	12.89	12.82	12.06	2.42	0.09	0.12	
Anemone canadensis L.	5.32	5.50	1.98				
Viburnum lentago L.	4.80	3.92	2.23				
Cornus sericea L.	3.98	2.27	0.58				
Rubus idaeus L.	2.60	1.09	0.58				
Lathyrus pratensis L.	2.31	0.69	0.02				
Impatiens capensis Meerb.	2.23	3.85	5.85	8.44	0.25	0.18	
Phalaris arundinacea L.	2.21	5.41	10.00	10.52	7.03	4.49	
Vitis riparia Michx.	2.18	1.04	2.63				
Carex stricta Lam.	2.12	3.91	4.92	0.15			
Lonicera x*bella* Zabel	2.10	0.94	0.15				
Lysimachia nummularia L.	2.00	3.19	3.16	0.09			
Onoclea sensibilis L.	1.44	2.78	0.39			0.03	
Cornus racemosa Lam.	1.38	1.31	3.21	0.65			
Typha x*glauca* Godr.	0.09	1.09	3.81	16.19	12.03	6.11	0.04
Typha angustifolia L.	0.01	0.06	0.09	11.12	13.84	23.94	0.42
Typha spp.		0.04	0.18	2.19			
dead *Typha* spp.			0.01	32.32	20.20	9.57	
Lemna minor L.				2.43	0.89	3.98	0.01
Hydrocharis morsus-ranae L.				1.22	9.33	5.07	0.63
Sparganium eurycarpum Engelm.				0.25	1.26	3.33	0.42
Lemna trisulca L.				0.19	1.94	5.49	0.32
Vallisneria americana L.				0.02	0.16	0.84	11.02
Ceratophyllum demersum L.					0.30	1.01	5.18
Potamogeton pusillus L.					0.21	0.70	2.78
Chara spp.					0.17	2.41	10.08
Myriophyllum spicatum L.					0.10	0.06	3.82
Najas flexilis (Willd.) Rostkov and Schmidt					0.02	0.64	8.19
Potamogeton zosteriformis Fern.						0.12	3.96
Potamogeton pectinatus L.						0.01	4.48

Table 5. Open-embayment wetland mean cover by combined transects for unique structural groups.

Structural Category	**A,B,C MEAN COVER (*480 quads*)**	**D MEAN COVER (*160 quads*)**	**E,F MEAN COVER (*320 quads*)**	**G MEAN COVER (*160 quads*)**
Broad-Leaf Emergent	0.49	0.58	1.73	0.10
Thin-Stem Emergent	0.81	0.38	2.33	0.77
Thin-Stem Persistent Emergent	2.17	40.98	42.11	2.54
Submerged Broad-Leaf	0.00	0.00	0.01	1.52
Submerged Narrow-Leaf	0.00	0.02	3.50	44.24
Floating Leaf	0.00	3.84	13.73	2.16
Algae	0.00	1.38	2.03	3.53
Grasses	22.39	6.48	6.00	0.04
Sedges	9.24	1.99	0.22	0.00
Forbs	24.15	10.51	0.90	0.01
Moss	0.10	0.00	0.00	0.00
Ferns	1.79	0.45	0.02	0.00
Trees/Shrubs	17.85	0.67	0.02	0.00
Vines	5.70	1.85	1.48	0.00
Miscellaneous	3.48	0.07	0.00	0.00
Total Mean Cover	88.18	69.18	74.09	54.91

Table 6. Most prominent species among protected-embayment wetlands by mean percent cover for all transects.

TAXA	**MEAN % COVER**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Onoclea sensibilis L.	7.04	5.33	2.69	0.03	0.13		
Calamagrostis canadensis (Michx.) P. Beauv.	6.26	4.42	7.82	10.49	9.66	2.40	0.04
Lysimachia ciliata L.	3.82	3.43	1.75				
Cornus sericea L.	3.06	3.37	1.43	3.63			
Impatiens capensis Meerb.	2.62	1.65	3.69	1.19	0.06	0.003	
Solidago spp.	2.29	2.09	1.13				
Viburnum lentago L.	2.21	2.18	0.95				
Viburnum spp.	2.20	1.33	1.42				
Cornus drummondii C. A. Meyer.	1.44	1.20	3.03				
Carex stricta Lam.	1.34	2.23	5.24	0.97	0.28	1.20	
Thelypteris palustris Schott	1.02	2.25	3.42	3.32	0.37		
Carex spp.	0.88	1.58	3.77	2.02	0.68	0.07	
Cornus racemosa Lam.	0.40	0.46	2.03	0.13			
Phalaris arundinacea L.	0.21	0.36	0.28	1.87	2.26	2.23	
Typha x*glauca* Godr.	0.19	0.32	0.61	8.06	7.41	3.01	
Typha angustifolia L.		0.03		8.67	19.10	23.02	5.88
dead *Typha* spp.			0.06	21.10	31.66	20.10	0.25
Hydrocharis morsus-ranae L.				3.11	9.08	23.84	1.46
Lemna minor L.				0.58	1.96	8.24	2.03
Sagittaria latifolia Willd.				0.17	1.13	1.29	3.56
Potamogeton pectinatus L.				0.11		0.11	9.71
Lemna trisulca L.					1.18	4.04	2.72
Nymphaea odorata Aiton					0.08	0.48	9.13
Ceratophyllum demersum L.					0.06	1.01	6.07
Utricularia vulgaris L.						1.16	4.86
Vallisneria americana L.						0.34	6.39
Potamogeton pusillus L.						0.02	5.37
Najas flexilis (Willd.) Rostkov and Schmidt						0.01	9.00
Chara spp.							6.47
filamentous algae							2.93
Zosterella dubia (Jacq.) Small							2.13

Table 7. Protected-embayment wetland mean cover by combined transects for unique structural groups (excludes South Black River Bay).

Structural Category	**A,B,C MEAN COVER (*420 quads*)**	**D MEAN COVER (*140 quads*)**	**E MEAN COVER (*140 quads*)**	**F MEAN COVER (*140 quads*)**	**G MEAN COVER (*140 quads*)**
Broad-Leaf Emergent	0.1738	1.5643	2.3929	3.2036	6.0321
Thin-Stem Emergent	0.36	1.15	1.29	1.70	0.21
Thin-Stem Persistent Emergent	0.82	30.10	45.25	46.36	7.01
Submerged Broad-Leaf	0.00	0.00	0.00	0.00	2.25
Submerged Narrow-Leaf	0.00	0.13	0.14	3.98	51.21
Floating Leaf	0.00	4.34	14.39	41.86	16.20
Algae	0.00	0.00	0.00	0.00	9.99
Grasses	9.04	18.20	16.05	5.59	1.15
Sedges	9.31	6.10	3.13	1.56	0.00
Forbs	22.65	4.23	1.63	2.16	0.04
Moss	0.45	0.00	0.00	0.00	0.00
Ferns	5.30	3.62	0.56	0.00	0.00
Trees/Shrubs	14.35	7.41	0.04	0.00	0.00
Vines	3.17	1.95	1.07	0.71	0.00
Miscellaneous	4.89	0.48	0.00	0.00	0.00
Total Mean Cover	70.51	79.27	85.93	107.14	94.08

Table 8. Most prominent species among barrier-beach wetlands by mean percent cover for all transects.

TAXA	MEAN % COVER						
	A	B	C	D	E	F	G
Calamagrostis canadensis (Michx.) P. Beauv.	7.32	6.33	8.74	5.12	1.13	0.23	
Onoclea sensibilis L.	6.88	10.82	8.69				
Phalaris arundinacea L.	5.91	4.36	3.27	5.22	2.82	0.34	
Rosa multiflora Thunb.	5.00	4.47	1.36				
Cornus sericea L.	4.51	5.09	5.43	0.26	0.19		
Impatiens capensis Meerb.	3.47	6.00	6.58	0.53	0.04	0.003	
Dryopteris carthusiana (Villars) H. P. Fuchs	3.41	2.06	0.25				
Toxicodendron radicans (L.) Kuntze	2.33	1.87	0.04				
Rubus idaeus L.	1.95	2.18	0.69				
Alnus serrulata (Aiton) Willd.	1.66	2.13	1.83	0.16			
Rhamnus frangula L.	1.39	2.07	2.78				
Cornus racemosa Lam.	1.33	3.15	0.08				
Spiraea alba Duroi	1.03	2.31	2.15	0.53			
Typha angustifolia L.	0.20	0.23	0.43	1.17	2.06	4.57	
Typha x *glauca* Godr.	0.03	0.31	2.64	19.85	22.13	12.83	0.15
Lythrum salicaria L.		1.62	1.81	0.96	2.75	1.32	
dead *Typha* spp.			2.97	24.77	26.66	8.52	
Sparganium eurycarpum Engelm.			0.22	4.71	5.20	2.68	0.03
Lemna minor L.			0.06	7.03	7.42	16.85	5.81
Sagittaria latifolia Willd.			0.01	1.48	2.13	1.55	
Hydrocharis morsus-ranae L.				11.73	8.31	3.84	0.003
algae				2.34	5.48	2.63	
Eleocharis palustris L.				0.63	0.28	2.09	
Utricularia vulgaris L.				0.29	0.45	0.56	2.41
Nymphaea odorata Aiton				0.16	1.38	6.43	9.37
Ceratophyllum demersum L.				0.12	0.74	2.36	4.50
Chara spp.				0.01		2.14	8.20
Pontederia cordata L.					0.07	0.35	2.95
Zizania palustris L.					0.03	0.30	2.31
Najas flexilis (Willd.) Rostkov and Schmidt						0.61	2.20
Nuphar variegata Durand							5.75
filamentous algae							5.23

Table 9. Barrier-beach wetland mean cover by combined transects for unique structural groups (excludes Port Britain).

Structural Category	**A,B,C MEAN COVER (*420 quads*)**	**D MEAN COVER (*140 quads*)**	**E,F MEAN COVER (*280 quads*)**	**G MEAN COVER (*140 quads*)**
Broad-Leaf Emergent	0.14	3.67	3.73	3.38
Thin-Stem Emergent	0.60	7.31	6.30	0.18
Thin-Stem Persistent Emergent	0.57	46.83	43.71	0.47
Submerged Broad-Leaf	0.00	0.00	0.02	0.35
Submerged Narrow-Leaf	0.00	0.49	6.16	16.85
Floating Leaf	0.02	10.95	17.54	16.88
Algae	0.00	0.47	4.51	16.13
Grasses	10.45	11.55	2.76	2.65
Sedges	1.30	1.34	1.28	0.00
Forbs	20.88	2.93	0.50	0.05
Moss	0.00	0.00	0.00	0.01
Ferns	12.85	0.21	0.01	0.00
Trees/Shrubs	27.72	3.69	0.46	0.00
Vines	1.52	1.27	0.27	0.00
Miscellaneous	0.57	0.04	0.23	0.02
Total Mean Cover	76.62	90.76	87.48	56.96

Table 10. Most prominent species among drowned river-mouth wetlands by mean percent cover for all transects.

TAXA	**MEAN % COVER**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Cornus sericea L.	6.17	7.14	6.94	2.33			
Calamagrostis canadensis (Michx.) P. Beauv.	5.72	4.18	8.49	2.37	1.27	0.67	
Impatiens capensis Meerb.	5.59	7.32	10.22	0.76	0.003	0.03	
Cornus racemosa Lam.	4.48	4.74	1.37	0.58			
Carex stricta Lam.	4.27	3.47	4.77	0.88	0.06	0.03	
Equisetum arvense L.	2.83	0.04					
Lysimachia nummularia L.	2.80	3.70	1.98	2.53			
Anemone canadensis L.	2.64	1.69	1.09				
Vitis riparia Michx.	2.40	2.68	2.18	0.60			
Aster spp.	2.19	2.14	0.83	0.01			
Phalaris arundinacea L.	1.55	2.59	5.39	4.82	7.88	5.60	
Cornus drummondii C. A. Meyer.	0.39	1.01	2.48	0.48			
Typha x*glauca* Godr.	0.21	1.16	1.47	12.25	15.65	12.08	0.25
Typha angustifolia L.		0.16	0.49	7.91	12.67	12.67	0.07
dead *Typha* spp.				31.32	38.06	26.18	0.05
Lemna minor L.				4.67	16.04	13.86	5.62
Hydrocharis morsus-ranae L.				2.90	13.99	27.79	1.99
Spirodela polyrhiza (L.) Schleiden				0.11	0.40	1.94	5.58
Ceratophyllum demersum L.						0.61	4.66
Potamogeton pectinatus L.						0.08	25.65
Nymphaea odorata Aiton						0.01	2.92
Potamogeton zosteriformis Fern.						0.01	2.70
Potamogeton pusillus L.						0.003	3.19
Chara spp.							10.58
filamentous algae							6.25
Vallisneria americana L.							4.21
Najas flexilis (Willd.) Rostkov and Schmidt							2.60

Table 11. Drowned river-mouth wetland mean cover by combined transects for unique structural groups (excludes Crooked Creek).

Structural Category	**A,B,C MEAN COVER (*420 quads*)**	**D MEAN COVER (*140 quads*)**	**E,F MEAN COVER (*280 quads*)**	**G MEAN COVER (*140 quads*)**
Broad-Leaf Emergent	0.21	0.37	0.41	0.19
Thin-Stem Emergent	2.97	0.25	0.39	0.02
Thin-Stem Persistent Emergent	1.42	50.91	39.36	0.55
Submerged Broad-Leaf	0.00	0.00	0.00	0.55
Submerged Narrow-Leaf	0.00	0.00	0.64	36.67
Floating Leaf	0.00	8.68	25.73	20.99
Algae	0.00	0.00	0.00	21.18
Grasses	13.71	8.19	8.19	0.09
Sedges	7.96	1.96	0.26	0.00
Forbs	28.74	4.77	0.57	0.00
Moss	0.07	0.00	0.00	0.01
Ferns	1.16	0.00	0.00	0.00
Trees/Shrubs	18.99	3.78	0.07	0.00
Vines	5.29	0.78	0.84	0.00
Miscellaneous	1.39	0.82	0.04	0.00
Total Mean Cover	81.92	80.51	76.49	80.26

Table 12. Percentage of total generalized area in 5 cm intervals across the model elevation range (73.0-75.75 meters IGLD) for barrier beach (BB), drowned river mouth (DRM), open embayment (OE), and protected embayment (PE) geomorphic models.

Contour Interval	Wetland Type			
	BB	DRM	OE	PE
73.00-73.05	0.3%	0.3%	0.2%	0.3%
73.05-73.10	0.4%	0.2%	0.5%	0.3%
73.10-73.05	0.6%	0.2%	0.8%	0.3%
73.15-73.20	0.8%	0.2%	1.1%	0.4%
73.20-73.25	2.8%	0.3%	1.4%	1.8%
73.25-73.30	1.4%	0.2%	1.2%	1.1%
73.30-73.35	1.5%	0.2%	1.4%	1.1%
73.35-73.40	1.6%	0.2%	1.6%	1.2%
73.40-73.45	1.8%	0.3%	1.7%	1.2%
73.45-74.50	1.9%	3.7%	1.9%	1.3%
73.50-73.55	1.0%	0.7%	1.9%	1.3%
73.55-73.60	1.0%	0.7%	2.1%	1.4%
73.60-73.65	1.1%	0.7%	2.2%	1.4%
73.65-73.70	1.1%	0.7%	2.4%	1.5%
73.70-73.75	1.1%	0.7%	2.5%	1.5%
73.75-73.80	0.8%	1.0%	2.1%	2.2%
73.80-73.85	0.8%	1.2%	2.2%	2.2%
73.85-73.90	0.8%	1.2%	2.3%	2.3%
73.90-73.95	0.8%	1.0%	2.4%	2.4%
73.95-74.00	0.9%	1.2%	2.5%	2.5%
74.00-74.05	0.8%	2.4%	3.0%	3.3%
74.05-74.10	0.8%	2.4%	3.1%	3.5%
74.10-74.15	0.8%	2.4%	3.2%	3.6%
74.15-74.20	0.8%	2.6%	3.3%	3.8%
74.20-74.25	0.8%	2.4%	3.5%	3.9%
74.25-74.30	0.7%	1.4%	2.1%	1.7%
74.30-74.35	0.8%	1.4%	2.2%	1.7%
74.35.74.40	0.8%	1.6%	2.2%	1.8%
74.40-74.45	0.8%	1.4%	2.3%	1.8%
74.45-74.50	0.8%	1.4%	2.3%	1.8%
74.50-74.55	0.9%	0.9%	0.6%	0.6%
74.55-74.60	0.9%	0.9%	0.6%	0.6%
74.60-74.65	0.9%	0.7%	0.6%	0.6%
74.65-74.70	0.9%	0.9%	0.6%	0.6%
74.70-74.75	0.9%	0.9%	0.6%	0.6%
74.75-74.80	1.2%	2.4%	0.5%	0.7%
74.80-74.85	1.2%	2.6%	0.5%	0.7%
74.85-74.90	1.2%	2.6%	0.5%	0.7%
74.90-74.95	1.2%	2.6%	0.5%	0.7%
74.95-75.00	1.2%	2.4%	0.5%	0.7%
75.00-75.05	3.1%	3.7%	3.4%	1.5%
75.05-75.10	3.2%	3.5%	3.5%	1.5%
75.10-75.15	3.3%	3.7%	3.6%	1.5%
75.15-75.20	3.4%	3.5%	3.7%	1.5%
75.20-75.25	3.5%	3.7%	3.7%	1.5%
75.25-75.30	4.3%	3.3%	2.3%	4.2%
75.30-75.35	4.5%	3.3%	2.3%	4.3%
75.35-75.40	4.6%	3.5%	2.3%	4.4%
75.40-75.45	4.8%	3.3%	2.4%	4.5%
75.45-75.50	4.9%	3.5%	2.4%	4.6%
75.50-75.55	3.7%	2.8%	0.7%	1.8%
75.55-75.60	3.8%	2.8%	0.7%	1.8%
75.60-75.65	3.9%	2.8%	0.7%	1.8%
75.65-75.70	4.0%	2.8%	0.7%	1.8%
75.70-75.75	4.1%	2.7%	0.7%	1.8%