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MODELING WETLAND PLANT COMMUNITY RESPONSE TO ASSESS WATER-LEVEL REGULATION SCENARIOS IN THE LAKE ONTARIO – ST. LAWRENCE RIVER BASIN

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Abstract. The International Joint Commission has recently completed a five-year study (2000–2005) to review the operation of structures controlling the flows and levels of the Lake Ontario – St. Lawrence River system. In addition to addressing the multitude of stakeholder interests, the regulation plan review also considers environmental sustainability and integrity of wetlands and various ecosystem components. The present paper outlines the general approach, scientific methodology and applied management considerations of studies quantifying the relationships between hydrology and wetland plant assemblages (% occurrence, surface area) in Lake Ontario and the Upper and Lower St. Lawrence River. Although similar study designs were used across the study region, different methodologies were required that were specifically adapted to suit the important regional differences between the lake and river systems, range in water-level variations, and confounding factors (geomorphic types, exposure, sediment characteristics, downstream gradient of water quality, origin of water masses in the Lower River). Performance indicators (metrics), such as total area of wetland in meadow marsh vegetation type, that link wetland response to water levels will be used to assess the effects of different regulation plans under current and future (climate change) water-supply scenarios.

Keywords: Lake Ontario, plant communities, St. Lawrence River, water level regulation, wetlands

1. Introduction

Water-level fluctuations are a natural phenomenon in the Great Lakes-St. Lawrence River system due to climatic variability (Magnuson *et al.*, 1997; Baedke and Thompson, 2000). The biological communities have, by necessity, evolved to adapt to a range of water depths and water-level changes that occur on several time scales, ranging from wind-driven tides or seiches that can occur several times daily, to seasonal changes each year, to longer episodes (Nilsson and Keddy, 1988; Wilcox, 1995, 2004; Bunn and Arthington, 2002).

The biological effects of water-level fluctuations in a lake or river system are most important in shallow water areas, where even small changes in water levels can result in the conversion of an aquatic environment to an environment in which sediments are exposed to the air, or vice versa. The localized effects of this variability are most evident in the relatively immobile plant communities that make up wetlands. The strong link between climate, hydrologic regime and composition and diversity of wetland plant communities has been well-documented for both lake (Wilcox and Meeker, 1991, 1995; Hill *et al.*, 1998) and river (Toner and Keddy, 1997; Ward *et al.*, 1999; Hudon, 1997, 2004, 2005) systems. Field data correlating vegetation to changes in water depth through time allow modeling and prediction of the effects of different water-level-fluctuation patterns on wetlands. Since wetlands represent major habitats for fish, water birds, and mammals, maintenance of diversified (in space and time) and well-connected wetlands also bring inherent benefits for aquatic fauna. The definition of sound, yet applicable environmental objectives is the first step towards sustainable management of natural resources.

Alteration of natural water-level cycles through regulation are known to affect wetland community dynamics, productivity, and function in general (Nilsson and Svedmark, 2002; Keddy, 2002). Although environmental effects of regulation are well documented and raise important concerns, only a small number of studies integrating environmental indices into regulation plans can be found in the published literature (Prowse and Conly, 1996; Millburn *et al.*, 1999; Marttunen *et al.*, 2001; Hellsten *et al.*, 2002). Since unaltered flow conditions represent the most desirable hydrological regime to sustain riparian systems (Petts, 1984; Wilcox and Meeker, 1991; Poff *et al.*, 1997), environmentally-conscious water-level management requires knowledge of how much regulated outflow can deviate from natural conditions without impairing wetland sustainability (Hill *et al.*, 1998; IJC, 1999).

The International Joint Commission (IJC) has recently completed a five-year study (2000–2005) to review the operation of structures controlling the flows and levels of the Lake Ontario – St. Lawrence River system. In addition to addressing the multitude of stakeholder interests, the regulation plan review also includes environmental sustainability, with an emphasis on wetlands. Understanding and quantifying the linkages between hydrology and wetlands in both Lake Ontario and the St. Lawrence River, and assessing the historical changes in wetland surface area and type lend support to the identification of water-level-regulation plans that respect wetland integrity and sustainability. However, since the constraints imposed on wetland habitats by level and flow regulation differ markedly between the lake and river systems, the general study approach needed to be adapted to each unique individual setting. This paper describes the scientific methodologies developed to quantify the response of wetlands to hydrology while accounting for regional differences in hydrology and confounding factors.

In addition to the assessment of regulation impacts on wetlands, results of the studies described in the present paper will serve as input to models used in evaluating regulation plans proposed by other interest groups. These models also include reference to seasonality of water-level changes as required by fish and wildlife, to the amplitude of water-level fluctuations that result in habitat development, and to the frequency of high and low water-level/flow events that determine cycling of habitat changes and result in habitat diversity. In the IJC Study, such quantitative relationships (metrics) linking various hydrologic to environmental and socio-economic characteristics were designated as "Performance Indicators" (PI). These PI allowed to compare the performance of different alternative regulation plans (in terms of relative gains or losses) with the current regulation plan.

Since releases of water from Lake Ontario and the Upper St. Lawrence River largely dictate conditions below the dam on the Lower St. Lawrence River, regulation-plan review must also account for the regional interdependency to ensure that any regulation-plan changes would not be detrimental to any region. Therefore, lake and river wetland study teams coordinated efforts in their approach to generate comparable results and compatible regulation options. The present study provides an example of the challenges involved in linking environmental objectives, scientific data acquisition and applied management considerations across a large and diversified watershed.

2. General Approach for Wetland Studies

Members of the Environment Technical Working Group (hereafter designated as ETWG) of the IJC study agreed upon the following working hypothesis and environmental objectives, defining the framework of the environmental studies to be carried out by the group members.

2.1. Working hypothesis

Hydrologic conditions affect the distribution, species composition, and biomass of emergent wetland plant assemblages.

2.2. Environmental objectives

The overall objective of the environmental studies was to ensure that all types of native habitats (floodplain, forested and shrub swamps, wet meadows, shallow and deep marshes, submerged vegetation, mud flats, open water, and fast flowing water) and shoreline features (barrier beaches, sand bars/dunes, gravel/cobble shores, and islands) were represented in sufficient abundance (surface area) to sustain critical biological populations and communities.

A corollary objective was to maintain hydraulic and spatial connectivity of habitats to ensure that fish and wildlife have access, temporally and spatially, to a sufficient area of all habitat types required to complete their life cycles. Specific types and degrees of anthropogenic alterations and degradation of water quality, which act as confounding factors since they also affect wetland surface area and general characteristics (Table I). Such regional differences needed to be accounted for in wetland studies carried out across the basin.

2.4. Hydrologic regime under current and unregulated conditions

Lake Ontario water levels and outflow to the St. Lawrence River at Cornwall–Massena have been regulated since 1963 using Plan 1958D (with deviations), under the conditions and criteria set out in the "Orders of approval for the regulation of Lake Ontario" of the International Joint Commission (Carpentier, 2003). Over the past century, climatic variability subjected Lake Ontario and the St. Lawrence River to alternating periods of low (1930s, the mid-1960s and the late 1990s) and high (1970s and mid-1980s) water supply. In addition to the effects of regulation, water level conditions have been increasingly modified over the last century by a variety of other human interventions, such as shoreline alteration, channel excavation and ice management. In order to isolate the impact of regulation, water level variations were simulated for the 1900–2000 interval using historical water supplies while maintaining the current channel configuration, structures and ice management regime. These simulated levels allowed us to compare water-level variations under unregulated (grey lines) and the present regulation plan (plan 1958D with deviations, black lines) for Lake Ontario and Lower St. Lawrence River at Sorel (Figure 2).

In Lake Ontario, regulation resulted in stabilization of long-term mean levels, elimination of decadal-scale periods of high levels and reduction of the overall range from >2 m to about 1 m (Figure 2, see also Wilcox and Whillans, 1999). More specifically, regulation reduced the amplitude and frequency of high water-level episodes to control flooding. In the downstream reaches of the Lower St. Lawrence River (Sorel), the effects of regulation were perceptible in the reduction of extreme high and low water level episodes in Sorel (Figure 2), but appeared dampened by the added influence of the Ottawa River and other tributaries. However, the seemingly small effects of regulation derived from simulated levels (Figure 2) markedly contrast with recorded level values (not shown), which show a 0.7 m reduction in overall range between 1912 and 1994 (Hudon, 1997). Such difference between simulated and recorded levels points out to the cumulative effects of regulation with other anthropogenic factors such as channel excavation, shoreline alteration and control of ice jams.

At the watershed scale, although water-level variations from year to year are largely controlled by climatic conditions (Magnuson *et al.*, 1997; Baedke and Thompson, 2000), regulation has modulated the timing and magnitude of levels and flow to suit the needs of the various interest groups, upstream and downstream of Moses-Saunders dam (IJC, 1999). The reduction in the range of Lake Ontario levels was achieved by increasing river discharge during periods of high water supply

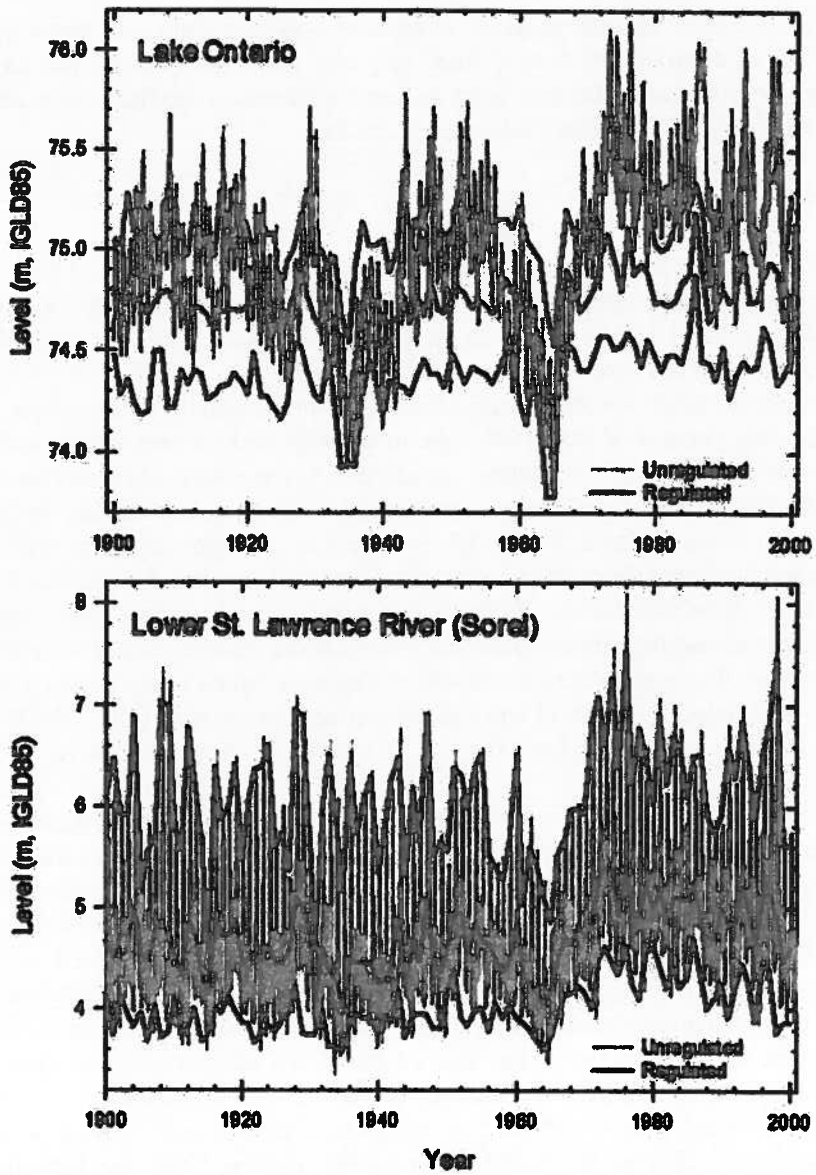

Figure 2. Comparison of water-level variations (1900–2000) in Lake Ontario (top panel) and in Lower St. Lawrence River at Sorel (bottom panel) simulated at a quarter-monthly time step for unregulated (grey line) and current regulation conditions (black lines indicate annual mean and range for Plan 1958D with deviations). All calculations are based on the historic sequence of water supplies to the basin while maintaining constant and using the structures presently in place, the present channel sizes and configurations and the present ice management regime. Water levels (m) are referenced to the International Great Lakes Datum of 1985 (IGLD85); note the difference in vertical scale between graphs. Data source: Environment Canada – Great Lakes – St. Lawrence Regulation Office, Ontario Region, Cornwall, unpublished data.

and by decreasing discharge to store water in the lake during periods of low water supply (Carpentier, 2003), thereby modifying the seasonal timing and increasing the short-term variability of river discharge and levels. This type of regulation induces major differences in the temporal scale of hydrological alterations for Lake Ontario (multi-decadal, long-term) and Lower St. Lawrence River (inter-annual, seasonal, short-term), which needed to be accounted for in the regional wetland studies.

2.5. General Approach and Study Design

The different effects of regulation in the upstream and downstream reaches of the study area prompted our use of different, regionally-adapted methodologies, albeit based on a common approach, to assess linkages between hydrology and wetlands in the Lake Ontario – Upper River and Lower St. Lawrence River regions. In both regions, historical variations in wetland surface area and community types were assessed from aerial photographs and remote sensing images. Several field study sites were selected in which plant surveys were conducted over a range of elevations and hydrologic conditions, serving as the basis for the elaboration of quantitative models linking wetlands in each region to hydrology, while accounting for potentially confounding effects (exposure, geomorphic type, and other factors). These models allowed us to generalize the study findings over broad geographical areas, after independent validation from the aerial photographs, remote sensing images or additional data. Finally, performance indicators (metrics) were developed to assess the response of wetlands to various regulation plans, applied to a 101-yr time series (1900–2000) using either historical, stochastic (wet and dry periods), or climate-change water-supply scenarios. The following two sections describe how the common approach was adapted to suit specific conditions in the Lake Ontario – Upper St. Lawrence River (Section 3) and in the Lower St. Lawrence River (Section 4) region. The technical solutions used at each step are contrasted between regions in Table II.

3. Lake Ontario – Upper River Wetland Studies

3.1. Data Acquisition for Model Development

3.1.1. *Selection of Field Study Sites*

Thirty-two wetlands were studied in Lake Ontario and the Upper St. Lawrence River. Twenty-five of the study sites are located along the Lake Ontario shoreline, and the remaining seven sites are in the Upper St. Lawrence River (Figure 1). Site selection was based on geomorphic type, wetland distribution, shoreline reaches for which topographic and bathymetric data were available or would be collected, and

Elevation Model, EC, 2003). Predicted wetland classes for each pixel were then identified from the combination of hydrologic conditions for the previous and current growing season over the 1961–2002 interval (Hudon *et al.*, 2005), which covers the period over which regulation took place.

4.2.3. *Validation of Model Spatial Generalization*

The validity of the prediction of spatial distribution of the nine wetland classes (Table IV) in Lake Saint-Pierre was assessed using three methods. First, we compared predicted habitats with remote sensing images for the same years, showing that the wetland assemblages coincided over 58% (1988) to 96% (1987) of the surface area.

Second, we compared the limits of continuous (>50% surface cover, dense and closed marshes) and sparse (<50% cover, scattered and open marshes) emergent plants surveyed in the field (2000–2002) with the limits of equivalent classes derived from the hydrology-based CART model and from remote sensing for the same years. The limits set by the airboat survey coincided generally with the mixed marsh plant assemblage, which represented the median marsh type in terms of plant cover.

Third, we verified the attribution of groups of quadrats derived from the hydrology-based model against the classes previously identified by the cluster analyses based solely on species' relative abundance, yielding a 71% (range of 24 to 84% depending on class) overall match.

4.2.4. *Analysis of Historical Changes in Wetland Plant Assemblages*

The distribution of the predicted wetland classes was mapped using a geographic information system (MapInfo version 6.5), which was then used to calculate the surface area of each class for each year (1961–2002). The 42-year sequence of changes in the surface area of wetlands classes was reduced from a nine-descriptor (surface of nine wetland classes) time series to a two-dimensional, state-space diagram. The new factors consisted of simple differences of wetland class areas and were identified by inspection of the first two principal components of the covariance matrix between the surface areas of the nine herbaceous wetland classes. The resulting diagram showed that Lake Saint-Pierre wetlands alternated between three major configurations, dominated by meadows and open marshes with floating-leaved vegetation (in the low-level period of the 1960s), scattered tall *Scirpus* marshes (during the high-water levels of the late 1970s), with a greater year-to-year variability and the appearance of closed marsh with aggressive emergents in the last decade.

5. Deriving Performance Indicators and Assessing Alternative Regulation Plans for Lake Ontario – Lower St. Lawrence River Wetlands

Several performance indicators (metrics) quantifying the relationships between various wetland characteristics and hydrologic conditions were derived from the above

studies for both regions, allowing a relative assessment of the effect of different regulation plans and water-supply scenarios on wetlands. Performance indicators linking hydrologic to environmental variables were derived from rules-based and regression models for the Lake Ontario and the Lower St. Lawrence River, respectively. The wetland habitat models incorporate seasonal water-level data to predict the annual distribution and abundance of various wetland plant communities. The performance indicators focus on general wetland plant community attributes such as estimated total area of wetland, area of meadow marsh, non-cattail dominated emergent marsh, and open marsh.

Wetland characteristics correspond to the type and magnitude of hydrological alteration experienced in each region. In Lake Ontario and Upper St. Lawrence River (region I), range reduction at the decadal scale resulted in the progressive expansion and colonization of cattail into meadow marsh and once diverse interspersed emergent marsh communities (Wilcox and Ingram, unpublished data). In Lake St. Francis (region III), stabilization of level resulted in colonization of meadows by shrubs (Jean and Bouchard, 1991), reduction of low marsh area (Jean *et al.*, 2002) and historically increasing submerged vegetation (Reavie *et al.*, 1998; Morin and Leclerc, 1998), compounded by other anthropogenic alterations (reduction in traditional fire-setting practices by aboriginal people, changes in land use, nutrient enrichment, shoreline encroachment, erosion, and armouring). In Lower St. Lawrence River wetlands (region IV), discharge regulation and associated channel excavation, ice control, and degradation of water quality resulted in the progressive drying out of wetlands, with a greater incidence of upland vegetation, aggressive or exotic taxa, and plants species indicative of eutrophic conditions (Jean *et al.*, 2002; Lavoie *et al.*, 2003; Hudon, 2004; Hudon *et al.*, 2005).

Studies linking wetlands and hydrology, including ours, underline the importance of natural water level variations (seasonal timing and annual range in level recurrence of high and low water levels over longer time spans) in sustaining wetland abundance and diversity. For socio-economic interest groups, the current regulation plan (1958D with deviations) represents the status quo option and is the plan against which the anticipated performance of alternative plans will be measured. For wetlands, however, the environmental sustainability of the current plan remains questionable in comparison with non regulated conditions, which must constitute the basic reference conditions for the environment. Allowing Lake Ontario level and discharge to fluctuate in phase with natural variations of water supplies to the basin would increase the range of lake levels while ensuring that discharge to the river follow a more natural pattern.

Both the current and alternative regulation plans must be examined on the basis of their lack of significant adverse effects on wetlands throughout the Lake Ontario – Upper St. Lawrence and Lower St. Lawrence River basin (CEAA, 1992). This general approach is also co-incident with the protection of endangered species (USFWS, 1973; COSEWIC, 2004) and the protection of fish habitat, based on the No Net Loss Guiding Principle (DFO, 1998). From an environmental standpoint, the selection of an alternative regulation plan to replace the one currently in use should proceed following the precautionary principle, seeking to reduce adverse environmental impacts from regulation. It is imprudent, based on the specific studies designed for this study, to recommend that any "benefits" will accrue to the natural environment based on water-level manipulation. Similarly, environmental "losses" anticipated (modelled) for given habitats or species cannot be traded against "gains" to other ecosystem components or against mitigation measures. The pursuit of environmental benefits and trade off for losses would require a much more comprehensive understanding of cause and effect relationships in the environment than our science now possesses.

6. Future Management Considerations

Historical changes in wetland plant assemblages related to regulation assessed in the studies described here may also be used back-track mapped vegetation types through time to correlate the signature of pre-regulation vegetation. For Lake Ontario, the estimate of the percentage of wetland occupied by the major vegetation types prior to regulation thus can provide generalized targets for wetland plant community assemblages that can be compared against proposed new regulation plans. For the Lower St. Lawrence River, regulation appears to be one factor among numerous others which exert cumulative impacts on wetland assemblages in Lake Saint-Pierre (Hudon *et al.*, 2005). For both lake and river regions, however, wetland monitoring is required to determine the effects of the new regulation plan on natural habitats quantity and quality through time. Such follow-up on model predictions would provide a unique opportunity to put adaptive management in practice, thus ensuring the sustainability of Lake Ontario – St. Lawrence River wetlands under the future regulation plan.

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