# Effects of water level regulation on shoreline marshes: a predictive model applied to the Great Lakes



Scott Painter and Paul Keddy
NWRI, Environment Canada
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## Introduction

Water levels in the Great Lakes, as in all lakes, fluctuate within a year as well as between years in response to water supplies and demands. Lakes Ontario and Superior are regulated according to a prescribed plan for each lake and those plans are being revised. The water levels in the other lakes are not directly regulated but due to property damage during high water events, pressure is regularly applied on governments by the affected property owners to consider regulation of the other lakes as well. The IJC Phase II Water Levels Reference Study was established to evaluate any proposed measures to alleviate the impact of fluctuating water levels including schemes to regulate the water levels of each lake.

The proposed revisions to the existing regulation plans and any possible projects to regulate the water levels of the other lakes would have to be assessed under the Canadian Fisheries Act to ensure no net loss of productive capacity of fish habitat. The Canadian Fisheries Act requires that fish habitat be conserved and that there be no net loss of productive capacity of habitats. The policy applies to all projects and activities, large and small, in or near the water, that could alter, disrupt or destroy fish habitats, by chemical, physical or biological means.

At the beginning of the Phase II study, the following principles, which reflect the spirit of the Canadian Fisheries Act, were established:

> That existing and future beneficial uses be considered and that the fundamental character of the Great Lakes - St. Lawrence River System will not be adversely affected;
>
> That any recommendations for action be environmentally sustainable and respect the integrity of the Great Lakes - St. Lawrence ecosystem;
>
> That any actions to address the adverse consequences of fluctuating water levels should not be implemented unless they produce a net benefit to the Great Lakes - St. Lawrence River system and not result in undue hardship to any particular group.

In response to these principles, the Study Board adopted the following study planning objectives:

> Avoid adverse impacts to wetlands in the Basin as the result of fluctuating water levels and flows and their extremes;
>
> Avoid adverse impacts to fish and wildlife as the result of fluctuating water levels and flows and their extremes.

Wetlands were chosen as the indicator of ecosystem health; the assumption being that if wetland quantity and quality were unaffected by proposed actions then the integrity of the Great Lakes - St. Lawrence River ecosystem would be unaffected. Coastal wetlands are the most productive and diverse component of the Great Lakes - St. Lawrence ecosystem. The productivity, biological composition, and size of Great Lakes wetlands are a reflection of the long-term water level regime. Coastal wetlands are an important fish and wildlife habitat in the Great Lakes system and these areas are where the lake level changes have the greatest ecological effect.

Wetlands are widely recognized for their importance to waterfowl, wildlife and fish habitat. The majority of fish species found in the Great Lakes - St. Lawrence River system are dependent on coastal wetlands and other near shore habitat for critical parts of their life cycle. In a study of coastal marshes in the Toronto area of Lake Ontario, Stephenson (1990) concluded that 32 of 36 (89%) fish species encountered utilize these coastal marshes for some aspect of reproduction. The fish species encountered included 18 game and commercial fish species such as northern pike, largemouth bass and yellow perch. Of the U.S. commercial fishery landings in 1985, approximately 77% of the fish catch was estimated to be estuarine-dependent species (Chambers, 1991). Raphael and Jaworski (1979) estimated the economic value of coastal marshes in Michigan at approximately $3000 per hectare per year (1992 $) of which ~$1700 was attributed to fisheries related activities and only ~$200 was attributed to waterfowl related activities. We speculate that most people would consider wetlands as predominately waterfowl habitat and attribute very little importance to wetlands for fish and yet the reverse seems to be the case.

The economic value of wetlands to the Great Lakes ecosystem has been an item of much discussion and several estimates have been made. Raphael and Jaworski (1979) estimated the recreational value of Michigan wetlands to be $810/ha/yr (1992 $). Kreutzwiser (1981) however, estimated the value of Point Pelee marsh and found that the recreational value was $3071/ha/yr (1992 $). If one combined Kreutzwiser's and Raphael and Jaworski's estimates then the fishing, hunting and recreational value of Great Lakes wetlands would be $6000 per hectare per year (1992 $). Neither estimate included the other functional values of wetlands such as a natural filter for nutrients and toxics; flood storage; primary and secondary production areas for the nearshore Great Lakes communities; recharge areas for groundwater; habitat and nursery areas for biota; and shore protection. If these values had been included, the true value of a Great Lakes coastal wetland would be considerably more (Burton, 1985).

In an analysis of the economic value of wetlands to the Great Lakes ecosystem, an estimate of the areal extent would be desirable. The Ontario Ministry of Natural Resources began a wetland inventory program in 1983 and to date have classified 160 coastal wetlands from the Ontario/Quebec border to Severn Sound in Georgian Bay, Lake Huron. These 160 wetlands in the lower Great Lakes on the Canadian shore total approximately 40,000 hectares (Glooschenko, et al. 1991). The upper Great Lakes Canadian shoreline has not been inventoried, but the regional biologists from the Ontario Ministry of Natural Resources was asked in 1992 to provide a map of known locations of wetlands in their area. A further 212 wetlands on the Canadian shoreline from north of Severn Sound in Lake Huron to the Canadian/American border in Lake Superior were identified by the regional biologists. Therefore, more than 370 wetlands on the Canadian shoreline are known to exist and the area of less than half has been quantified.

The United States completed an inventory of wetlands on their coastline in 1978 (Herdendorf et al. 1981) and a total of 1370 wetlands with a total area of 120,844 hectares have been identified. Therefore, on the coastline of the Great Lakes, we have greater than 1740 wetlands occupying greater than 200,000 hectares with an economic value of greater than 600 - 1200 million (1992 US$) per year.

The areal estimate of coastal wetlands in the Great Lakes is very crude in that ¼ has yet to be surveyed and ½ of the shoreline is 15 year-old data. The economic value underestimates the true value; however, we find ourselves in the unfortunate situation of having to justify perserving a natural resource based on the economic value of its consumptive uses by people. In spite of their value, conversion of wetlands to other land uses such as agriculture has resulted in an estimated loss of over 50% of the original wetland habitat in North America by the mid 1970s (Chambers, 1991). Snell (1986) estimated the loss of wetlands in southern Ontario at 68% and over 90% in southwestern Ontario. Estimates of wetland loss in the Great Lakes have been summarized by Bedford (1990) and range from 11 to 100% with 70-90% being typical. The economic value of the original wetlands of the Great Lakes could be estimated at greater than 6 billion $ per year (1992$) and through our various activities we have lost at least 4.8 billion $ per year. Our belated recognition of the importance of wetlands to the ecological sustainability and integrity of the ecosystem of the Great Lakes has resulted in many recent initiatives to protect wetlands and achieve no net loss of habitat ( ie. Great Lakes Wetlands Conservation Action Plan)..

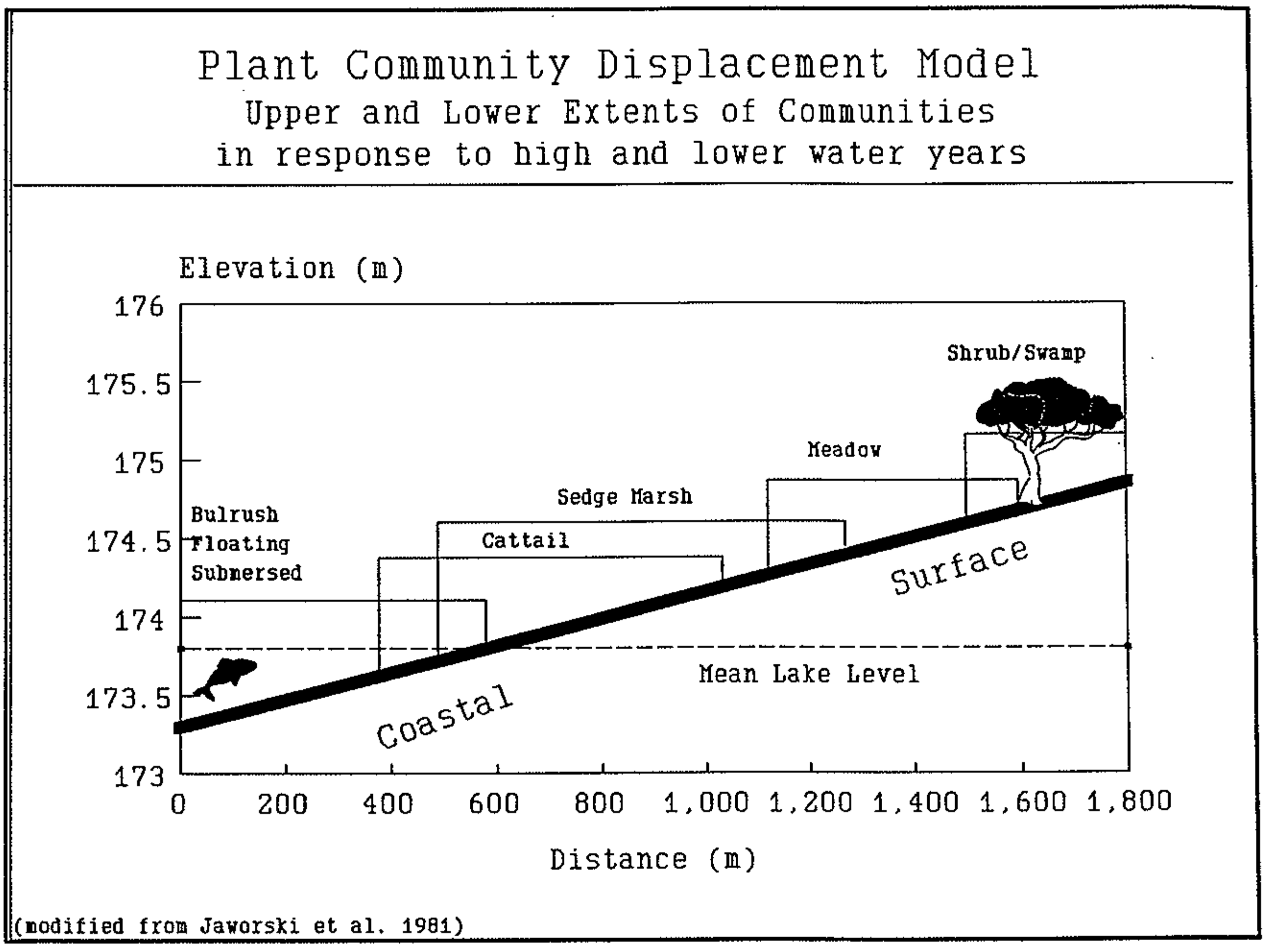
Most of the losses that have occurred have been due to conversion to other land uses; however, an overlooked impact on wetlands is the practice of reducing the amplitude of water level fluctuations in lakes. Any regulation of water levels which reduces the within or between year amplitudes in water levels would have a negative impact on wetland area and diversity in the coastal wetlands of the Great Lakes. A predictive model of emergent marsh plant response to water level fluctuations can be developed based on our present understanding of plant community response to water level cycles.

We chose to model the emergent marsh community response because their integrity and diversity are dependant on fluctuating water levels. Stuckey (1975) observed that "the greatest diversity of vegetation zones and greatest diversity of species within zones occur in that part of the marsh where the water level fluctuated the most throughout the season." The model can then be used to evaluate the various regulation schemes' impact on emergent marsh area as a preliminary analysis of their potential impact. If a proposed scheme is recommended at the conclusion of the Phase II study and that scheme has been initially determined to have a negative impact on marsh area, then a full environmental assessment under the Fisheries Act will be necessary.

## The Biology behind the Model

Cowardin et al. (1979) have employed the concept of a continuum of physical environmental conditons at the aquatic/terrestrial interface to illustrate their definition of wetlands. Wetlands are lands where "the water table is at, near, or above the land surface long enough to promote the formation of hydric soils or support the growth of hydrophytes." The deep water end of the continuum is marked by the growth limit of emergent macrophytes. It grades into "deep-water habitats," which are dominated by submerged aquatic macrophytes. The upland limit is exceeded when soils are no longer " hydric" in classification, and the predominating vegetation is terrestrial rather than hydrophytic. Wetland systems are broad and extensive where this continuum is long, and the degree of environmental change along its extent is gradual. They are limited in occurence and extent where environmental gradients are steep or truncated.

The water level regime is the primary environmental factor which influences the location, areal extent and diversity of wetland communities. The primary influence of the water level regime on wetland community composition has allowed Gilman (1976) to successfully construct a gradient model using the annual mean water depth to illustrate the effect of water depth on the preferred location of emergent and submergent species along the continuum. Jaworski et al. (1979) developed a plant community displacement model for Lake St. Clair to predict vegetation responses to changing water levels and Herdendorf and Duffy (1987) modified the model for western Lake Erie (Figure 1). These plant community gradient models are based on an understanding of the tolerance ranges or niche width of wetland plant species.




Keddy and Reznicek (1986) also developed a model which linked water levels and shoreline vegetation. The transition between forest or upland plant communities intolerant of hydric soils and wet meadow vegetation was determined by high water events experienced during previous years. High water levels kill off the woody shrubs and allow meadow species to re-establish. In the absence of disturbance by flooting, woody plants can displace herbaceous species through competitive exclusion by shading. Low water levels allow seed germination of woody shrubs and, over time, the eventual exclusion of the wet meadow.

The transition between emergent marsh species and deep-water submergents is determined by the minimum water level experienced during previous years. Some emergents can survive flooding for several consecutive years, however, seedling germination usually requires an exposed lake bottom. Busch and Lewis (1984) observed a response in emergent vegetation to the average water level in the preceding five years. If water levels were high during the preceding five year period, emergent marsh species would recede and be replaced by submergent plants.

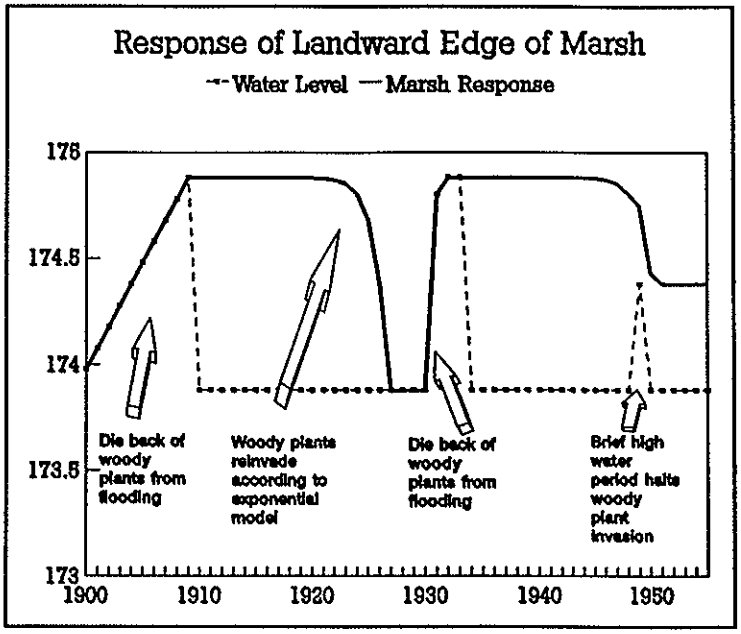
In order to predict the effects of water level regulation on wetlands, we must know the response of communities to high and low water events over various time scales. Frequency, duration and seasonality of flooding strongly influence species compostion. Different wetland plants withstand various degrees of inundation depending on when and for how long the flooding occurs. Lyon et al. (1986) determined that Typha occurrs at depths that are flooded for 50-85% of the time from mid-June to mid-August and is excluded from depths that are flooded for longer periods. Most shrub and tree species and most emergent plants need a period of lower water levels or very limited flooding during the growing season, but can withstand prolonged inundaton in the dormant season (Hammer, 1992). Oxygen limitation to the roots during the active growing season could cause stress and eventually mortality. Some tree species can endure fairly long periods of shallow flooding whereas others are vulnerable to any inundation beyond 4 to 5 days during the growing season. Most tree seeds will not germinate under flooded conditions, so even though established trees can survive a period of flooding, no new recruitment of seedlings will occur until water levels recede.

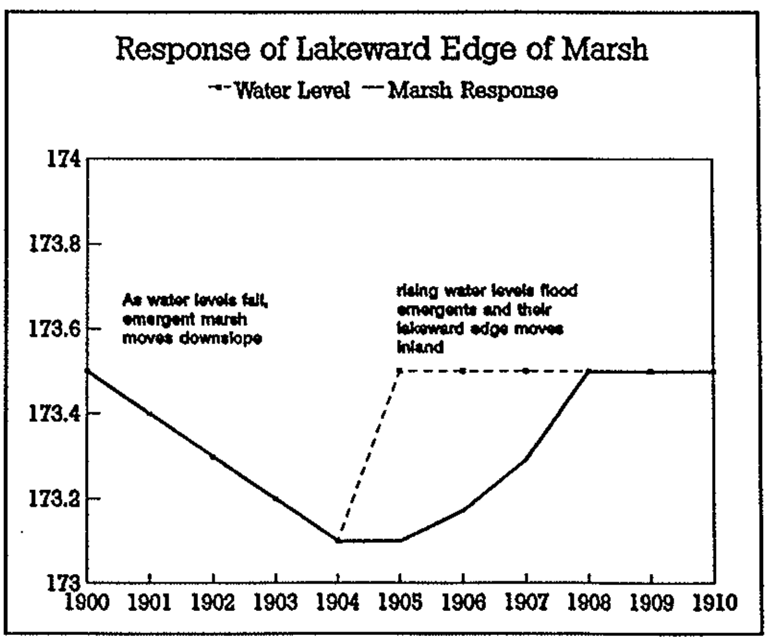
## The Model

Our model of emergent marsh plant response to fluctuating water levels was developed to incorporate our limited understanding of general plant community response to seasonal as well as previous years' water levels. Emergent plants respond to water level events as well as competitive forces between themselves and other plant communities such as trees and shrubs which are upslope and aquatic plants which are downslope.

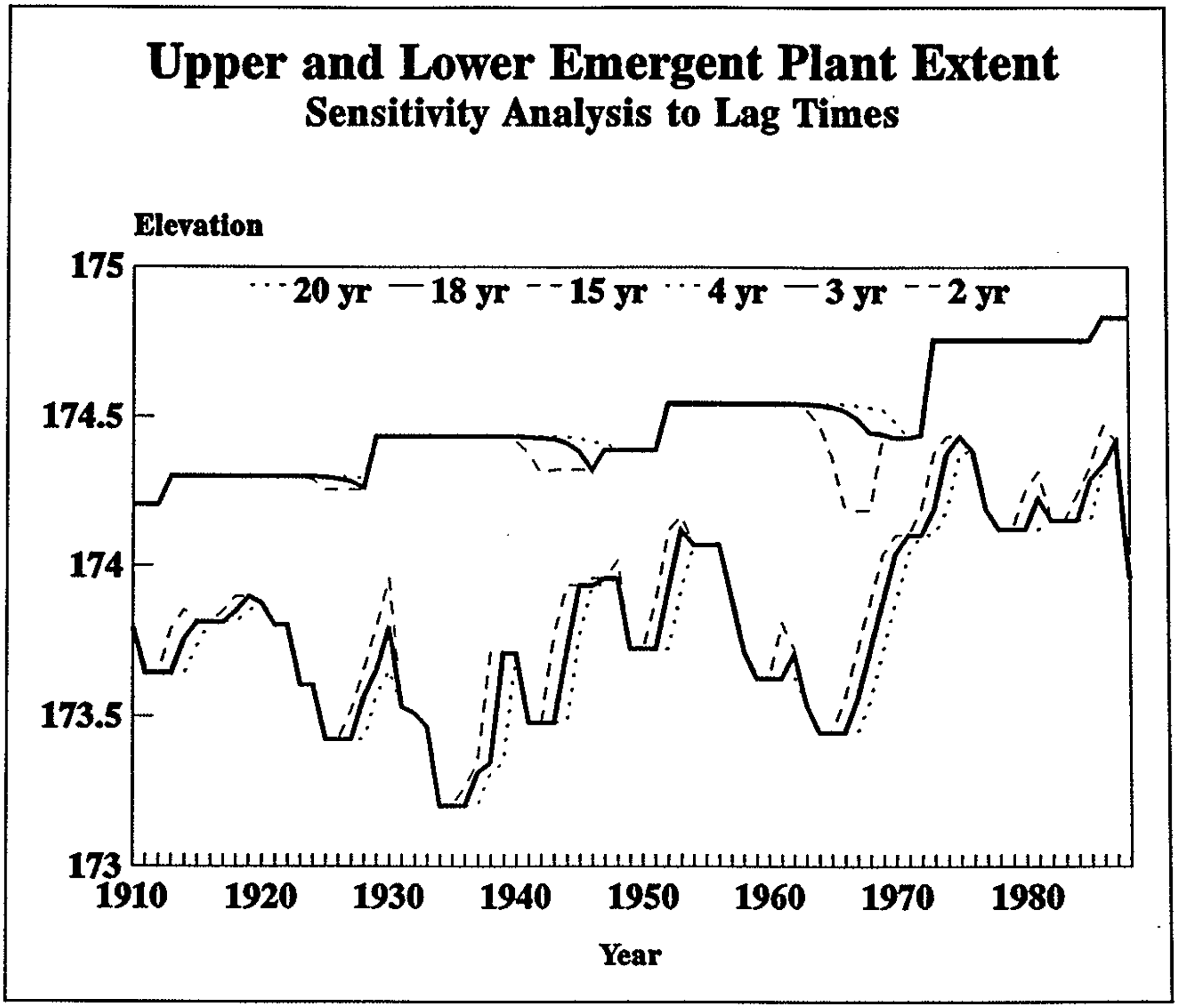
The landward upper edge of the marsh is determined by high water events. The three months surrounding the peak during the growing season were chosen as the critical time period which would influence the location of the woody plant\marsh transition. For example, in Lake Ontario, the peak normally occurs in June so the average water level from May, June and July was determined. The upper edge migrates inland as woody plants nearest the water die in response to a single season of high water but migrates back downslope slowly as trees and shrubs re-invade when lower water levels return. The competitive exclusion of marsh emergents by trees and shrubs begins slowly and escalates over time as the marsh plants are excluded by shading from the tree canopy (Figure 2). The model also scans back in time to ensure that the new location for the landward edge is sensitive to minor high water events (right hand portion of Figure 2).

The lakeward lower edge of the marsh is determined by low water events. The lower edge moves lakeward in response to a single season of low water as muds become exposed and annual marsh plant seeds sprout. Regeneration from buried seeds is a well documented phenomenon in wetlands in general (Van der Valk, 1981) and on shorelines in particular (Keddy and Reznicek, 1982,1986). The mean water level for September was chosen as the critical time period which would determine the transition between emergent marsh plants and submergent plants. When high water returns, the lower edge migrates upslope after a few years of flooding (Figure 3).



Various time delays were tried to determine the sensitivity of the model. For the landward transition, 15, 18, and 20 year delays, and for the lakeward transition, 2, 3, and 4 year delays were examined. The predicted marsh response varied by +/- 10% between the various combinations (ie 15/2 vs 20/4, Figure 4). An 18/3 delay combination was chosen.



The model is sensitive to:

the within year water level difference from the peak in the spring or early summer to the September water level;

and

the year to year comparisons of the water level during the spring/summer peak being compared to the previous 18 years location of the peak and the September water level being compared to the last 3 years September water level;

and

the timing of the peak because the within year difference between the peak and the water level in September would be affected, with a earlier peak being beneficial and a later peak being detrimental.

Dr. Doug Wilcox investigated wetland plant community response to water level regulation in Lakes Superior and Ontario as part of this Phase II IJC Water Level study. A comparison of his results with the model predictions was performed during the development of the model. The linear extent of Dr. Wilcox's plant groups 2 and 3 on Lake Ontario and plant groups 2,3 and 4 on Lake Superior (sedge marsh, emergents) compared very favourably to the model predictions ($r^2 = 0.86$, regression slope = 0.9, df=7). The model appears to perform satisfactorily when compared to Dr. Wilcox's observations. The model results of the various scenarios under discussion also provide a relative comparison between scenarios so that the scenarios can be ranked using their relative impact on the emergent marsh plant community.

## Results

The model analysis to predict the emergent marsh landward and lakeward extents was performed on the following scenarios:

Baseline conditions and sensitivity analysis:

| | |
|---|---|
| Pre-reg. | - Pre-regulation of the Great Lakes |
| BOC | - the present regulation of Ontario and Superior but beginning in 1900 |
| Wet/Dry | - 77Amod & 58D/28B with wet and dry supplies |

Lake Superior Plans:

| | |
|---|---|
| 77Amod | - Lake Superior's plan modified |
| 77A no C | - Superior's present plan no Criterion C |
| Superior -half/foot | - Superior lowered by half a foot |

Lake Ontario Plans:

| | |
|---|---|
| 58D/28B | - Ontario's plan with modification 28B |
| 58D-35P | - Ontario's plan with modification 35P |
| 58D-35Z | - Ontario's plan with modification 35Z |
| SO Environment | - Ontario's plan modified to address wetland concerns |

Lake Ontario and Superior Plans:

77A-58D-35P - Superior and Ontarios' plans modified

Three Lake Regulation Plans:

SEO combined - a 3 lake regulation plan

SEO Extended - a 3 lake regulation plan

Five Lake Regulation Plans:

5 Lake opt. - an water level scenario which tries to optimize water levels throughout the basin from various interest groups perspectives

Riparian +/- 1 ft. - a plan requested by the committee representing the riparians from the basin

The analysis of the various scenarios examined the long term average water level; the average within year water level range; the 90 year maximum and minimum and the difference; the timing of the peak; the dominance of the peak occuring in any one month; the location of the emergent marsh upper extent and lower extent; and the average elevation difference between the upper and lower extents. The elevation differentials for the upper and lower emergent marsh extents are reported in Table 1. In comparing any scenario to another, the study requested that the comparisons be made to the Basis of Comparison (BOC) hydrograph which assumed the present regulation plan had gone into effect in 1900 with the historical rainfall supply. However, the present regulation plan (BOC) has had an impact on wetlands in Lakes Ontario and Superior, and we felt compelled to compare the various scenarios to the pre-regulation hydrograph as well. People would see that their not just losing a little bit (ie 5%) but that they were deciding to continue to allow the present loss and a little bit more (30% + 5%). Table 1 compares the elevation differentials of the various scenarios to the pre-regulation and the BOC hydrograph.

The present regulation plans (BOC) for both Lakes Superior and Ontario are having serious negative impacts on emergent marsh area in Superior and Ontario; and minor impacts on Michigan, Huron, St. Clair and the St. Lawrence (Figure ?). In Lake Superior, the model predicts a loss of 26%; and in Lake Ontario, the loss is predicted to be 30% compared to pre-regulation.

The regulation plan for Lake Superior is under review. Emergent marsh area in Lake Superior would experience a loss of 26%, 18% and 16% compared to pre-regulation with scenarios 77A no C, 77A mod. and Superior -½ ft., respectively (Figures ?,?,?).

The regulation plan from Lake Ontario is also under review. Lake Ontario would experience a 36%, 30% and 28% loss of emergent marsh area under the modified plans 28B, 35P and 35Z, respectively (Figures ?,?,?).

The combined scenario for modification of the plans for Lakes Superior and Ontario (77A-58D-35P) resulted in an 18% loss in Lake Superior and a 39% loss in Lake Ontario.

The 2 three lake regulation plans experienced serious losses on Lakes Superior, Michigan/Huron, St. Clair, Erie and Ontario (Figures ?,?).

The 5 lake optimized plan results in serious losses on all lakes (Figure ?).

The SHMEO riparian +/- 1 foot plan would result in 26%, 59%, 39%, and 25% losses in emergent marsh area in Lakes Superior, Michigan/Huron, St. Clair and Erie, respectively (Figure ?).

## Discussion

Regulation of water levels which compresses the amplitude of the within-year and between-year highs and lows has a serious impact of wetland communities. The present regulation plans for Lakes Ontario and Superior and their modifications are having a serious impact of wetland integrity and diversity in Lakes Ontario and Superior and to some extent in the downstream lakes as well. These plans and their modifications need to be reviewed. The other scenarios that were evaluated have very serious impacts on wetlands in all the Great Lakes. They must not be considered.

To perform a full environmental assessment of the impact of the present plans and their modifications or the other scenarios, detailed elevation data of the shorelines of the Great Lakes would be necessary. The contour interval for the detailed elevation data would have to be at least 10 cm for the assessment to be sensitive to the scenarios being analyzed. Such information is virtually impossible to collect.

Table 1

Elevation Differentials For Upper and Lower Emergent Marsh Extents (metres)

| | St. Louis | Ontario | Erie | St. Clair | Mich/Huron | Superior |
|---|---|---|---|---|---|---|
| Pre-Reg. | 1.27 | 0.89 | 0.65 | 0.63 | 0.67 | 0.38 |
| BOC | 1.21 | 0.62 | 0.65 | 0.65 | 0.66 | 0.28 |
| 77A Mod. | 1.31 | 0.61 | 0.64 | 0.64 | 0.64 | 0.31 |
| 58D-28B | 1.21 | 0.57 | NA | NA | NA | NA |
| Wet/Dry | 1.23 | 0.60 | 0.65 | 0.65 | 0.66 | 0.33 |
| 5 Lake Optimized | 1.24 | 0.56 | 0.35 | 0.39 | 0.56 | 0.25 |
| Riparian +/- 1 ft. | 2.16 | 0.96 | 0.48 | 0.39 | 0.27 | 0.28 |
| SEO Combined | 1.61 | 0.43 | 0.33 | 0.48 | 0.74 | 0.26 |
| 77A no C | 1.21 | 0.62 | 0.64 | 0.64 | 0.69 | 0.28 |
| 58D-35P | 1.17 | 0.62 | NA | NA | NA | NA |
| 58D-35Z | 1.14 | 0.64 | NA | NA | NA | NA |
| Sup-half foot | 1.17 | 0.64 | 0.65 | 0.63 | 0.67 | 0.32 |
| 77A-58D-35P | 1.21 | 0.54 | 0.64 | 0.64 | 0.67 | 0.31 |
| SO Environment | 1.15 | 0.60 | NA | NA | NA | NA |
| SEO Extended | 1.57 | 0.45 | 0.43 | 0.58 | 0.56 | 0.36 |

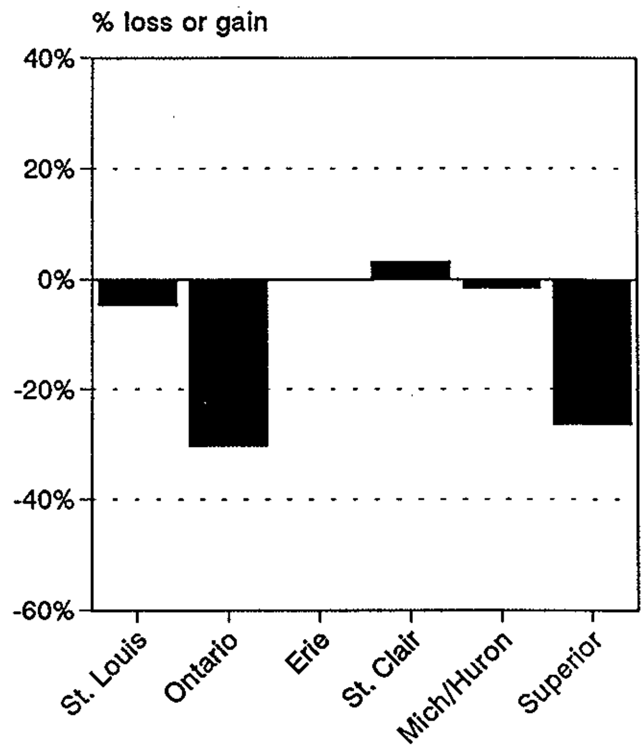
Comparison of Elevation Diff. to Pre-Regulation (%)

| | St. Louis | Ontario | Erie | St. Clair | Mich/Huron | Superior |
|---|---|---|---|---|---|---|
| Pre-Reg. | 0% | 0% | 0% | 0% | 0% | 0% |
| BOC | -5% | -30% | 0% | 3% | -1% | -26% |
| 77A Mod. | 3% | -31% | -2% | 2% | -4% | -18% |
| 58D-28B | -5% | -36% | NA | NA | NA | NA |
| Wet/Dry | -3% | -33% | 0% | 3% | -1% | -13% |
| 5 Lake Optimized | -2% | -37% | -46% | -38% | -16% | -34% |
| Riparian +/- 1 ft. | 70% | 8% | -26% | -38% | -60% | -26% |
| SEO Combined | 27% | -52% | -49% | -24% | 10% | -32% |
| 77A no C | -5% | -30% | -2% | 2% | 3% | -26% |
| 58D-35P | -8% | -30% | NA | NA | NA | NA |
| 58D-35Z | -10% | -28% | NA | NA | NA | NA |
| Sup-half foot | -8% | -28% | 0% | 0% | -1% | -16% |
| 77A-58D-35P | -5% | -39% | -2% | 2% | 0% | -18% |
| SO Environment | -9% | -33% | NA | NA | NA | NA |
| SEO Extended | 24% | -49% | -34% | -8% | -16% | -5% |

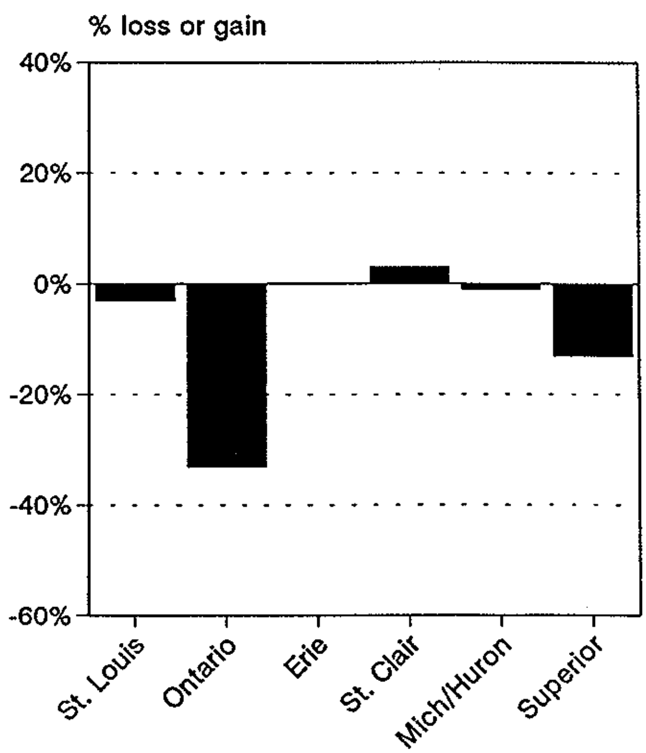
Comparison of Elevation Diff. to BOC (%)

| | St. Louis | Ontario | Erie | St. Clair | Mich/Huron | Superior |
|---|---|---|---|---|---|---|
| Pre-Reg. | 5% | 44% | 0% | -3% | 2% | 36% |
| BOC | 0% | 0% | 0% | 0% | 0% | 0% |
| 77A Mod. | 8% | -2% | -2% | -2% | -3% | 11% |
| 58D-28B | 0% | -8% | NA | NA | NA | NA |
| Wet/Dry | 2% | -3% | 0% | 0% | 0% | 18% |
| 5 Lake Optimized | 2% | -10% | -46% | -40% | -15% | -11% |
| Riparian +/- 1 ft. | 79% | 55% | -26% | -40% | -59% | 0% |
| SEO Combined | 33% | -31% | -49% | -26% | 12% | -7% |
| 77A no C | 0% | 0% | -2% | -2% | 5% | 0% |
| 58D-35P | -3% | 0% | NA | NA | NA | NA |
| 58D-35Z | -6% | 3% | NA | NA | NA | NA |
| Sup-half foot | -3% | 3% | 0% | -3% | 1% | 14% |
| 77A-58D-35P | 0% | -13% | -2% | -2% | 2% | 11% |
| SO Environment | -5% | -3% | NA | NA | NA | NA |
| SEO Extended | 30% | -27% | -34% | -11% | -15% | 29% |

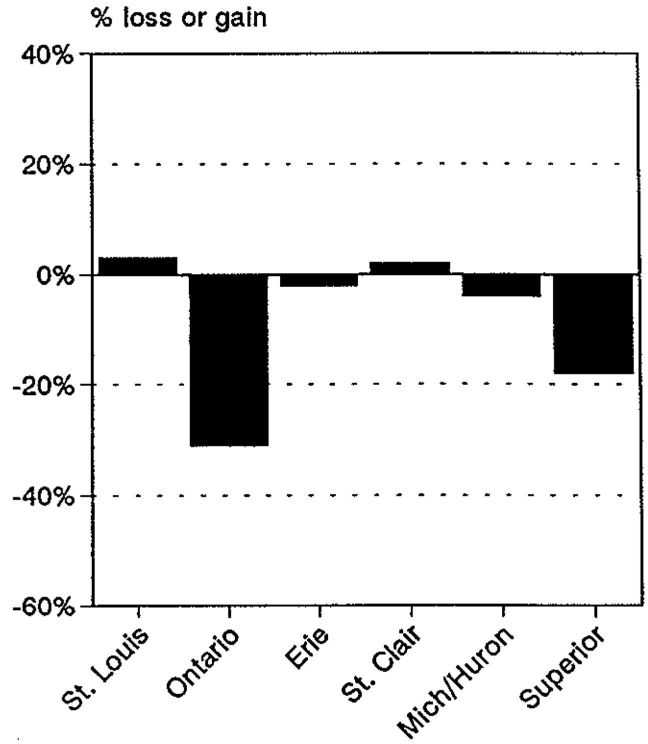
## BOC vs. pre-regulation



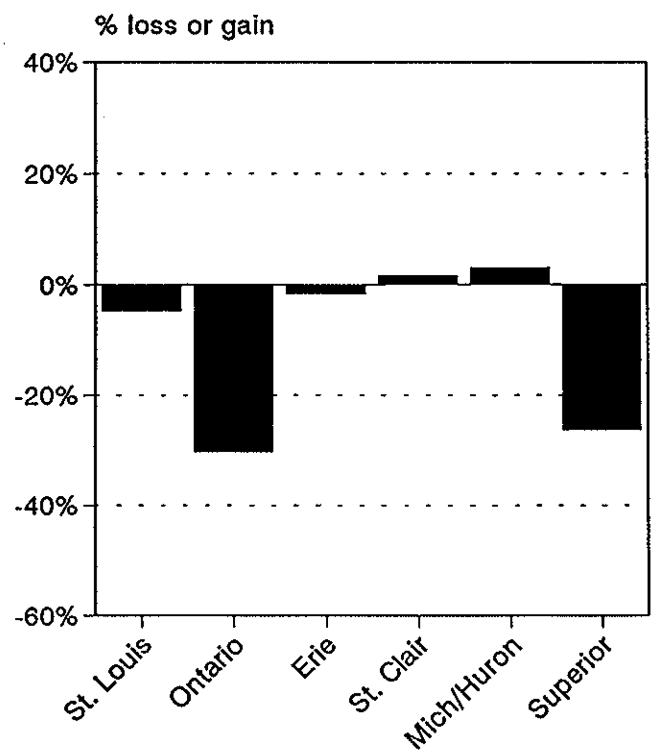

## Wet/Dry vs Pre-regulation



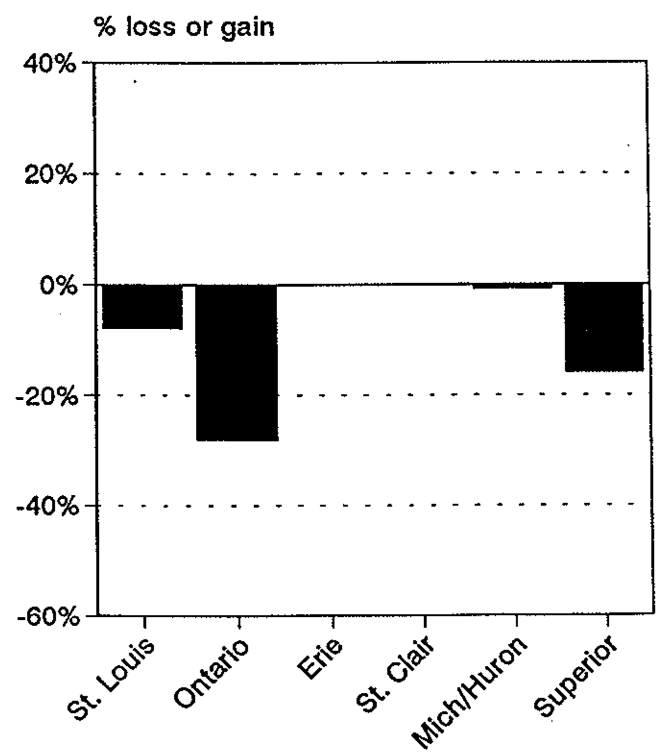
## 77A modified vs pre-regulation



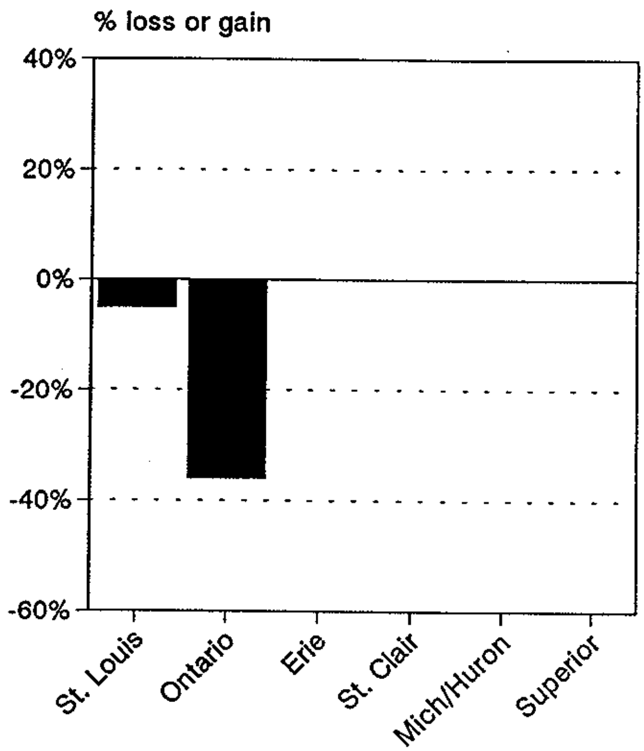

## 77A no C vs. pre-regulation



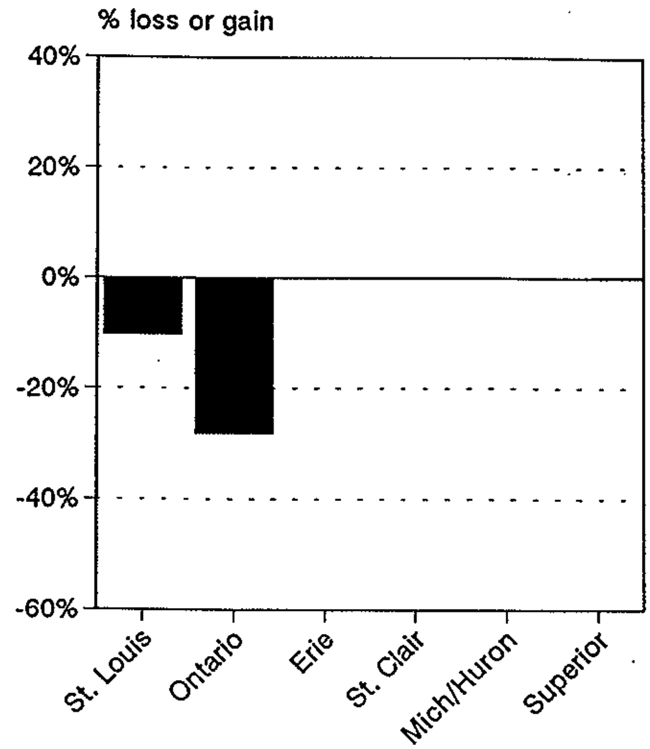

## Superior - one-half vs. pre-regulation



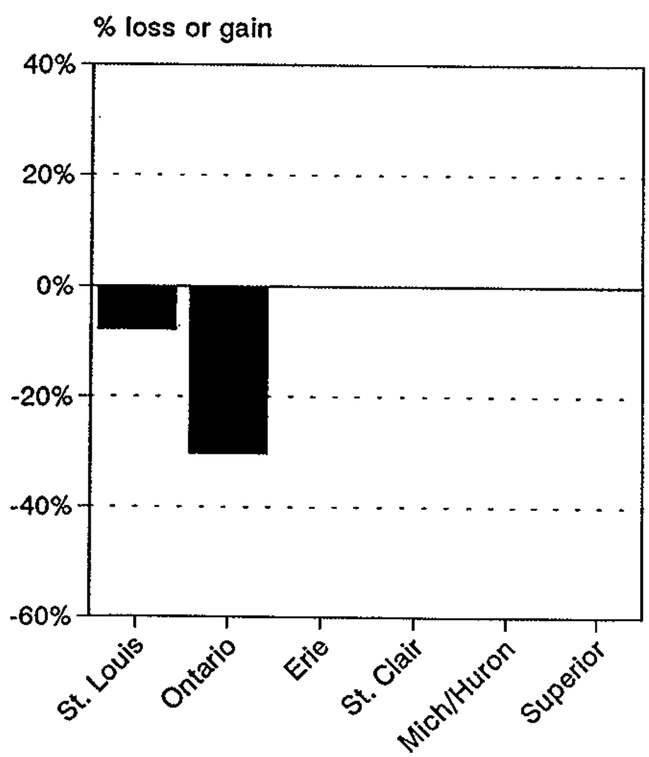
## 58D-28B vs Pre-regulation



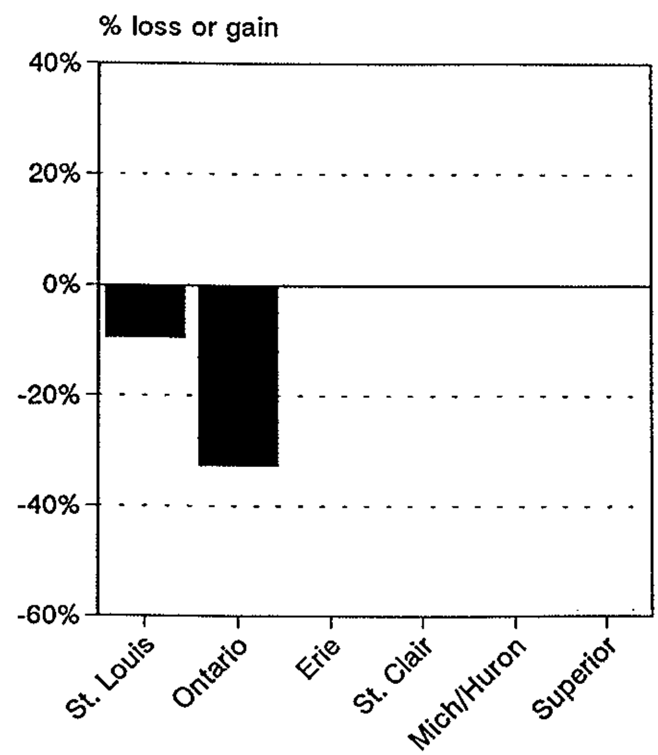

## 58D 35Z vs. pre-regulation



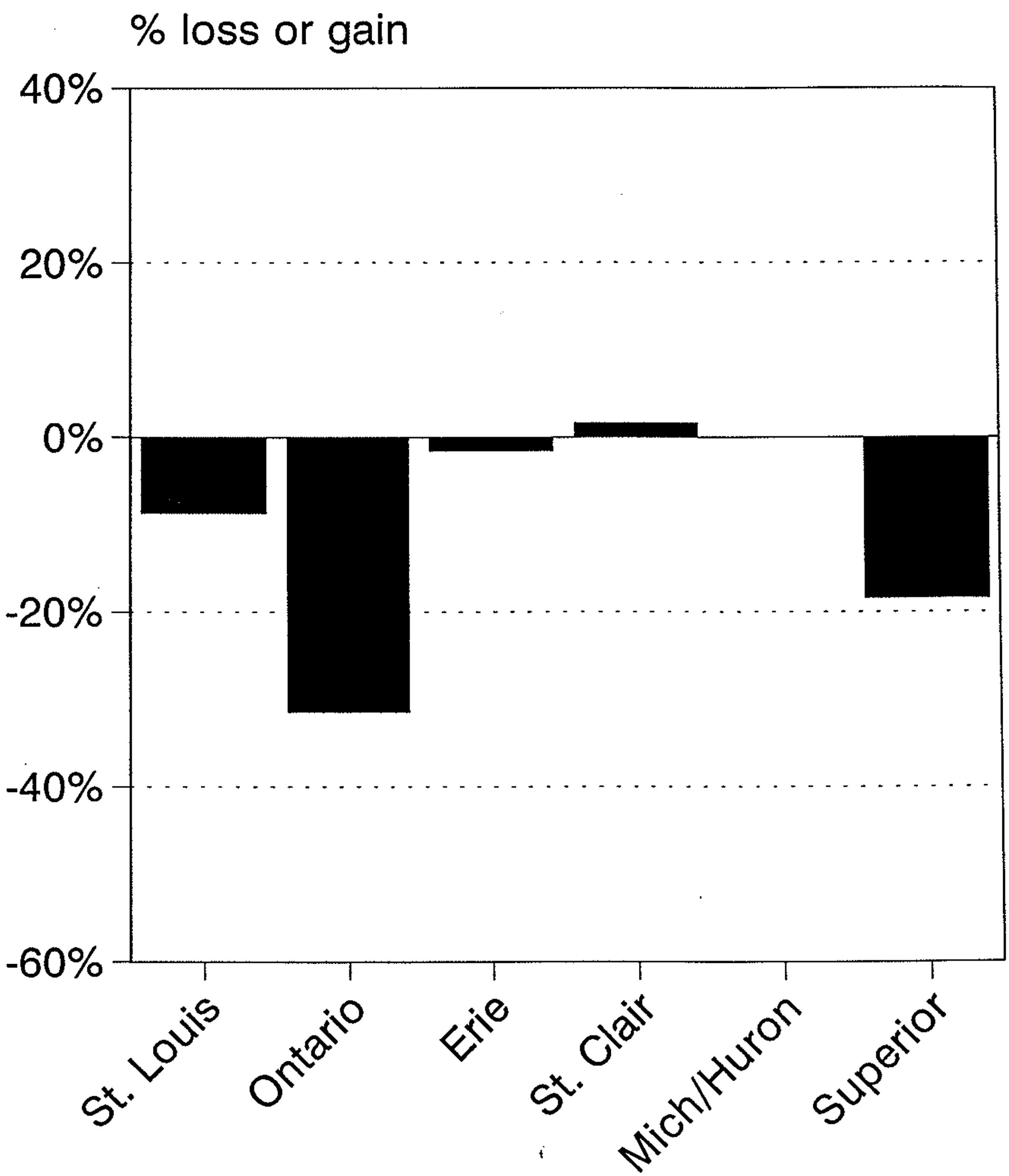

## 58D 35P vs. pre-regulation



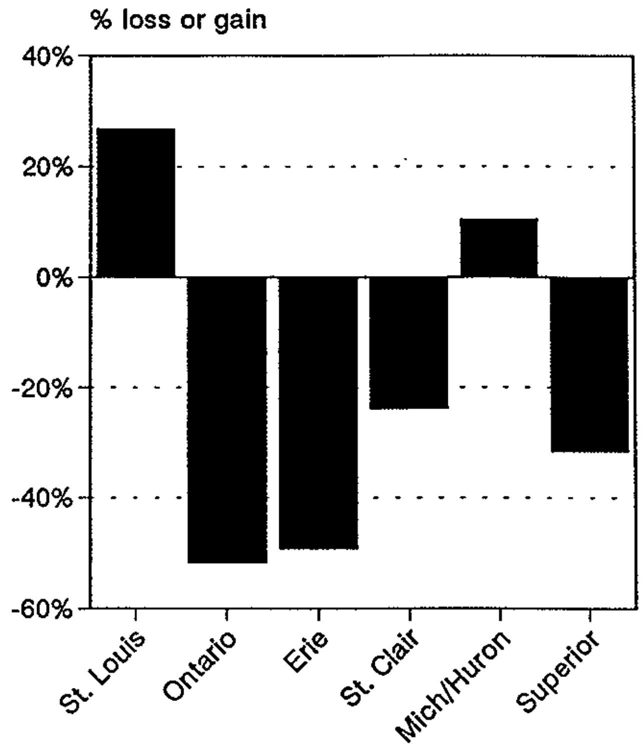

## SO Environment vs Pre-reg.



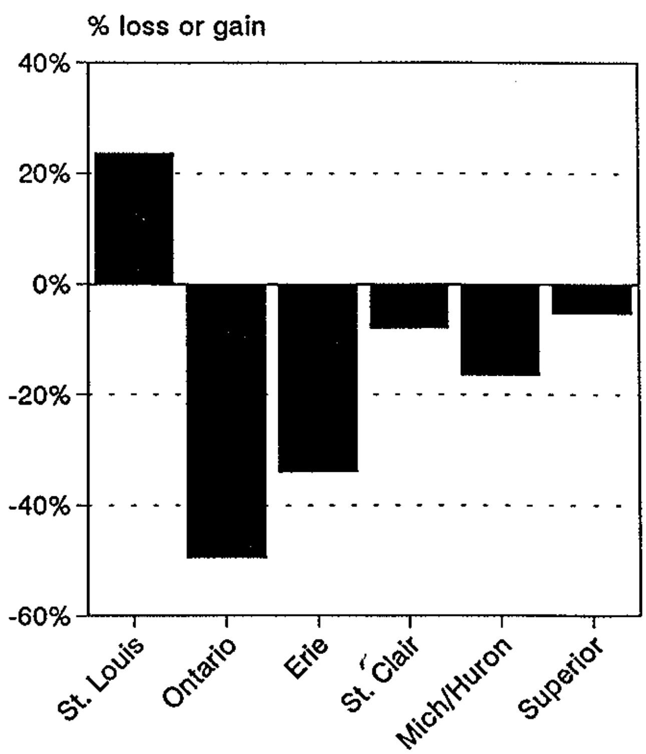
# 77A 58D 35P vs. pre-regulation



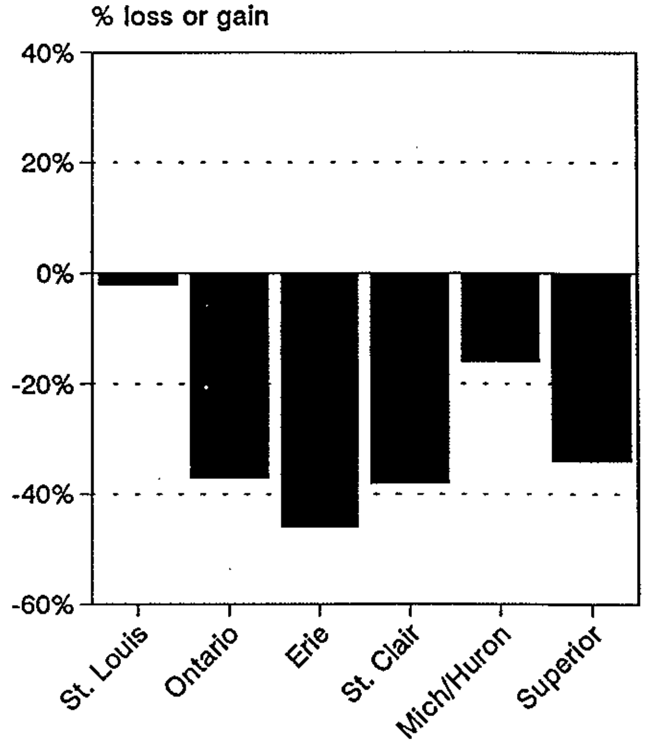
## SEO Combined vs. pre-regulation



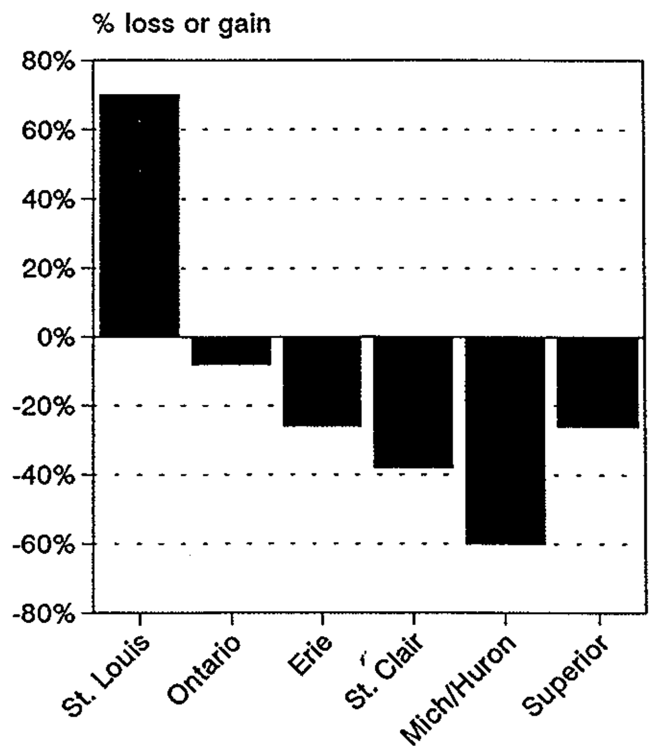

## SEO Extended vs Pre-Reg.



## 5 Lake optimized vs pre-regulation




## Riparian +/- 1 ft. vs pre-regulation



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