ASSESSING THE IMPACT OF CLIMATE CHANGE ON THE GREAT LAKES SHORELINE WETLANDS

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Abstract. Great Lakes shoreline wetlands are adapted to a variable water supply. They require the disturbance of water level fluctuations to maintain their productivity. However, the magnitude and rate of climate change could alter the hydrology of the Great Lakes and affect wetland ecosystems. Wetlands would have to adjust to a new pattern of water level fluctuations; the timing, duration, and range of these fluctuations are critical to the wetland ecosystem response. Two "what if" scenarios: (1) an increased frequency and duration of low water levels and (2) a changed temporal distribution and amplitude of seasonal water levels were developed to assess the sensitivity of shoreline wetlands to climate change. Wetland functions and values such as wildlife, waterfowl and fish habitat, water quality, areal extent, and vegetation diversity are affected by these scenarios. Key wetlands are at risk, particularly those that are impeded from adapting to the new water level conditions by man-made structures or geomorphic conditions. Wetland remediation, protection and enhancement policies and programs must consider climate change as an additional stressor of wetlands.

Keywords: Great Lakes shoreline, wetlands, water level changes, impacts

1. Introduction

Climate change from an enhanced greenhouse effect may add additional stress to wetlands already at risk from the pressures of urbanization, recreational development, conversion to agricultural land, and ecological damage. Wetlands are an interface between the terrestrial and aquatic environments and are particularly sensitive to the indirect changes in regional hydrology that climate change may influence, through changes in air temperature, regional precipitation, surface runoff, snow cover, length of the freezing season, ground water storage, and evapotranspiration. The structure, functioning, productivity, area, and distribution of wetlands are vulnerable to water supply changes that could occur with climate change, as are the ecological, social, and economic values associated with them.

Great Lakes shoreline wetlands were selected to investigate potential sensitivities to climate change under the assumption that water levels would change. Although the Great Lakes shoreline wetlands are adapted to a variable water supply, the projected magnitude and rate of climate change could alter the hydrology of the Great Lakes and wetland ecosystems. Two possible scenarios to assess the impact of climate change on shoreline wetlands were developed: (1) an increased frequency and duration of low water levels; and (2) a changed temporal

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distribution and amplitude of seasonal water levels. The link between climate variability, historical water levels, and wetland functioning is used to provide a preliminary assessment of the potential effect of climate change on these wetlands that could lead to basin-wide, long-term, and possibly irreversible ecological changes.

2. Climate Impact Assessment

Key questions to be addressed in a climate impact assessment are:
- How does current climate affect natural and/or human systems?
- How do climate change scenarios impact on natural and/or human systems?
- What are the climate linkages, sensitivities and vulnerabilities, and thresholds?
- How do natural and human systems adapt to current climate and how will they adapt to climate change?

The process of the assessment is outlined in Figure 1 and follows Carter et al., 1994.

Two phrases, "what if" and "so what," are important components of the assessment (Mortsch, 1996). Questions are posed from an exploratory, not predictive, point of view: "if these conditions were to occur what would be the impact?" The question acknowledges the inherent uncertainty and indeterminacies in issues of resource management and climate impact assessment (Costanza and Cornwell, 1992; Dovers and Handmer, 1992; Wynne, 1992). "So what" suggests that merely identifying impacts is not enough; solutions or responses need to be explored as well. For natural systems such as wetlands, concern is directed toward determining how adaptable the natural system is to climate-driven changes. The impacts of climate change may not be "managed," but knowledge of ecosystem responses assists in determining how robust and adaptable wetland enhancement, remediation, and protection efforts are with respect to climate change.

The use of "scenarios" is another emphasis of this assessment procedure. A climate scenario is defined as "a plausible, future condition without any probability of occurrence attached to it," and it can be developed from climate General Circulation Models (GCMs); spatial transpositions; hypothetical conditions; and historical analogues (Glantz, 1991; Mortsch and Quinn, 1996). "What if" climate scenarios can be designated as "practice climates," since we do not know with certainty that they will occur or evolve exactly in this form (Liverman, pers. comm., 1996). The water level scenarios used in this paper are "hypothetical scenarios" that were developed from a synthesis of hydrologic assessments of climate change in Canada, and GCM and spatial transposition scenarios for the assessment of climate change on the hydrology of the Great Lakes (Cohen, 1986; Croley, 1990; 1993; Croley et al., 1995; Hartmann, 1990; Mortsch and Quinn, 1996).

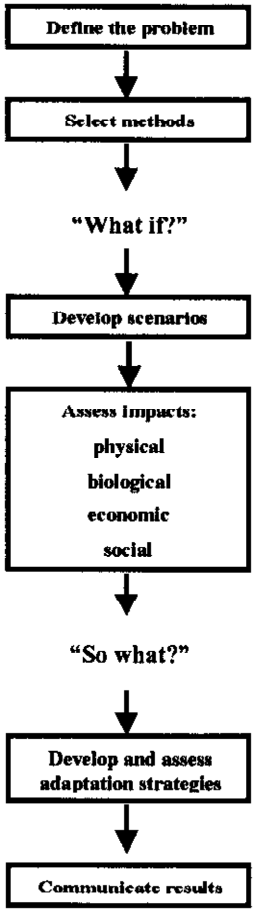

Figure 1. Six steps in a climate impact assessment modified from Carter et al., 1994

3. Climate, Water Levels and Wetlands

Wetlands are areas which are permanently or temporarily submerged or water-permeated to the extent that they are capable of supporting vegetation adapted to saturated soil conditions (Tarnocai, 1980; National Wetlands Working Group, 1988; Bardecki, 1991). The essential components for wetland formation include an excess of precipitation over evapotranspiration, flat-lying terrain or depressions in the landscape, and low permeability of underlying soils or bedrock. Wetlands are often dynamic environments that are transitional between terrestrial and aquatic ecosystems. This makes their location, areal extent, productivity, and diversity particularly reliant on hydrologic conditions. A surplus of water evidenced by a high water table or frequent inundation is required to maintain the wetland ecosystem. The water supply to a wetland from precipitation, surface runoff, ground water inflow, and lake levels is maintained in a dynamic balance.

3.1. CLIMATE LINK

Climate exerts direct and indirect impacts on wetlands. Solar radiation, temperature, precipitation, and other physical factors broadly define ecoclimatic zones and the distribution and composition of wetland regions (National Wetlands Working Groups, 1988; Mortsch, 1990). Air temperature affects the growing season, the types of vegetation present, and wetland primary productivity; water temperature influences the rate of chemical and biological reactions. Indirectly, climatic elements such as solar radiation, temperature, evaporation, precipitation, and wind influence wetlands through long-term change in the water balance.

The development and ecological viability of wetlands depend on water saturation for at least part of the year within the wetland complex, as hydrology affects retention time and water depth, influences the amount and variety of vegetation, and influences wetland distribution and ecological diversity. In the Great Lakes shoreline wetlands, the water table is primarily influenced by lake levels (Cowardin et al., 1979; National Wetlands Working Group, 1988). Although climatic elements such as temperature, precipitation, solar radiation, and wind are important, the strongest climate-wetland link for Great Lakes shoreline marshes and swamps is through water levels.

3.2. GREAT LAKES WATER LEVELS

Lake level fluctuations reflect the variability of the climate system. Three types of water level fluctuations occur on the Great Lakes: there are short-term fluctuations measured in minutes, hours, or days; a regular seasonal cycle; and long-period, inter-annual and inter-decadal variations. Temporary, extreme water level changes, storm surges, and seiches occur locally and are caused by winds or atmospheric pressure changes; they are of short duration since the water levels return to pre-event conditions in a few hours or days. The impact of these short-term fluctuations do not result in significant, long-term, ecological change (Whillans, 1985) and will not be discussed further.

Seasonal and long-term, climatic variations alter the water balance of the Great Lakes and are reflected by changes in water levels. Lake volume is affected seasonally by evaporation/evapotranspiration, precipitation, watershed runoff, and/or ground water flow, elements critical to Great Lakes hydrology and subject to climate change. Wetland hydrology, geomorphology, vegetation communities, water quality, and geochemistry may be affected by climate changes.

Natural climatic influences on water levels still predominate in the Great Lakes, although Lakes Ontario (since 1958) and Superior (since 1921) are regulated. Regulation tries to moderate extremes; it dampens the range of water levels and tries to achieve stable water levels that reflect long-term, mean conditions.

3.2.1. Seasonal Changes

Annually, water levels in the Great Lakes progress through a fairly regular seasonal cycle of minimum levels in winter to maximum levels in summer. Lake levels are at their minimum in winter (Ontario - January; Erie - February; Michigan-Huron - February; Superior - March) because precipitation as snow, storage in the snow pack, and frozen conditions reduce runoff. In the spring, levels rise in response to snowmelt runoff, increased ground water flow, and spring rainfall. The timing of spring melt, amount of snow cover, and rate of melt are important. A rapid snowmelt in the spring when the ground is still frozen results in more runoff going directly into the lakes because of little infiltration; conversely, a slow melt results in less overland flow (Richards, 1965). These factors affect the timing and the amplitude of the water level maximum in summer (Ontario - June; Erie - June; Michigan-Huron - July; Superior - September). Lake Superior attains its maximum level later than any other Great Lake because of the long snowcover season in its northern drainage basin. The cumulative effects of higher air temperatures, increased evaporation and evapotranspiration, and reduced runoff contribute to the decline in water levels through the autumn, leading to their winter minimum during the frozen season.

3.2.2. Interannual Variation

Annual mean water levels in the Great Lakes exhibit the long-term variability inherent in the climatic and hydrologic systems. Superimposed on the long-term fluctuations are seasonal and short-term fluctuations. Interannual variations are not cyclical since the period is not regular, nor are the changes readily predictable. The magnitude of these interannual water level fluctuations can be 3.5 to 6 times greater than the seasonal range (Tovell, 1979) but the range is only 1.8m from minimum to maximum. On most of the Great Lakes, high levels occurred in 1972 and 1986; low water levels occurred in 1934 and 1963-64. The drought of 1987 to 1990 lead to a major decline in water levels that, had the Great Lakes not been at all-time-high antecedent conditions in 1986, significant low water levels would have followed (Magnuson et al., 1997).

Precipitation, temperature, and evaporation are the dominant factors controlling Great Lakes water levels (Croley, 1986; Quinn, 1985). Long-term climatic trends of these elements in the basin affect supplies of water to the lakes (Tovell, 1979; Quinn, 1985). A single dry or wet spell or a short warm or cool period has little effect; *persistence* of the conditions is necessary to have an impact on long-term water supplies and wetland form, functioning, and values. Climate change may fundamentally alter the hydrologic cycle and affect important water balance components and seasonal and interannual water level fluctuations.

3.3. INFLUENCE OF HISTORICAL WATER LEVELS ON FUNCTIONS AND VALUES OF GREAT LAKES WETLANDS

The Great Lakes shoreline wetlands, consisting primarily of marshes and swamps, are affected by the water level fluctuations due to climatic variation over several years (Bedford et al., 1976; Herdendorf et al., 1986; ILERSB, 1981; Jaworski et al., 1981). Many of the wetlands along the shores of the Great Lakes are unlike inland palustrine wetlands in that, depending on their geomorphic form and sediment input, they do not develop into more xeric communities due to a buildup of sediments, soil, and organic material. They are in a continual process of adaptation to the current and historical water level regime. Interannual water level fluctuations act as a "perturbation" on wetland biophysical systems by displacing their development laterally up or down the open-water-to-dry-land continuum. Stable water levels are not beneficial: water level disruptions such as flooding or drying maintain wetlands at more productive, intermediate stages of development. Certain plant species die back and the relative abundance of vegetation communities changes (Herdendorf et al., 1986; Jaworski et al., 1981; Keddy, 1990; Wilcox, 1993). Water level and associated vegetation changes influence wetland areal extent and distribution; wetland-dependent wildlife, waterfowl, and fish; water quality (nutrient and geochemical cycles and sedimentation); and the hydrologic functions of retention time and flood protection (Burton, 1985; Geis, 1979; Weller, 1981).

3.3.1. Vegetation and Seed Bank Changes

The timing, duration, and amplitude of seasonal and long-term water level fluctuations exert an influence on vegetation communities, as these communities exhibit the most distinct response to water level change: they reflect both the current environmental conditions and those of recent years (Busch and Lewis, 1984). With seasonal fluctuations, vegetation responses are possible only for annuals, which complete their life cycle rapidly; perennials must survive the entire range of conditions encountered during seasonal fluctuations (Keddy and Reznicek, 1985). Inter-annual changes in water level can be accompanied by dramatic changes in vegetation: it often takes three to five years to re-establish vegetation communities in a wetland after a significant disturbance (Busch and Lewis, 1984; Quinlan and Mulamoottil, 1987; Whillans, 1985). While water level change may not necessarily eliminate a particular vegetation community, individual species can disappear once their tolerance thresholds have been reached.

Wetland vegetation communities shift lakeward or landward along the water level and soil moisture continuum. Plant community displacement models with a constant topographic gradient can be used to determine vegetation community development in response to inter-annual water level fluctuations (Figure 2) (Harris et al., 1981; Herdendorf et al., 1981; 1986; Keddy and Reznicek, 1985;

Jaworski et al., 1981; Quinlan and Mulamoottil, 1987). Each wetland community has a preferred position along the water depth gradient and shoreline slope relative to other communities, although there may be some overlap. Distribution expands and contracts along this continuum with fluctuating lake levels, and a sequence of changes in abundance of dominant plant species occurs; a total reassortment of species does not occur as it does in pothole wetland drawdowns (Keddy and Reznicek, 1985). During low water levels, communities shift lakeward and displace communities further down the environmental gradient (the lakeward side), and during high water levels the communities shift landward. This shift can only occur if the slope within the wetland is shallow, if there are no confining natural barriers or human development, if there is suitable substrate, and if the rate of water level change is slow enough for vegetation to re-establish itself (Bedford et al., 1976).

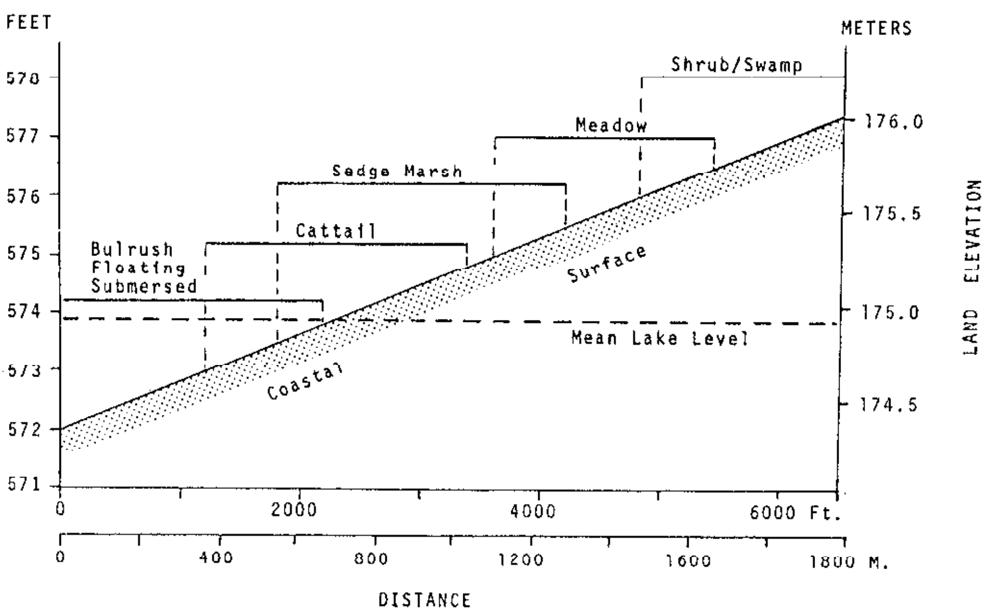

Figure 2. Plant community displacement model (Herdendorf et al., 1981)

During low water years, when landward margins of wetlands are dry and mudflats are exposed, species such as submergents and emergents migrate or die, and they may have to colonize new lakeward areas. They are displaced by plants with drier habitat requirements: sedges, grasses, shrubs, and trees expand into areas where the water depth was once too deep (Hardy, 1982; Herdendorf et al., 1981; 1986; Weller, 1981).

The reverse is true during high water levels: wetlands are inundated, causing trees to die (Hardy, 1982); emergents, grasses, and sedges are flooded and replaced by submergents, floating-leafed plants, and open water (Weller, 1981). There is a general landward movement of vegetation, and vegetation communities along the environmental gradient can become compressed. Where the slope is gradual and the surrounding land is low in elevation and not used by man, lake water can flood beyond the borders of the wetland and emergents can invade (Bedford et al., 1976; ILERSB, 1981; Jaworski et al., 1981; Quinlan, 1985; Quinlan and Mulamoottil, 1987; Weller, 1981). For example, wetland vegetation in Walpole Island and the Lake St. Clair River delta marshes has historically changed from a dominance of emergents, especially cattail, during low and average water level periods to an increase in submergents and areas of open water during high water level periods. Some vegetation communities have made adaptations to reduce the impact of water level fluctuations; they are largely composed of floating vegetation mats which can shift to some extent with rising and falling lake levels (Bedford et al., 1976; Hardy, 1982).

The areal extent of wetland vegetation communities also changes when these communities shift their shoreline location during water level fluctuations. As a wetland becomes more 'wet' or 'dry', plant species and wetland communities which prefer drier or wetter conditions spread (Bedford et al., 1976). During low water levels, the less preferred shrubs and grasses predominate, while emergents and submergent vegetation must colonize new levels are high, open water and submergent vegetation predominate. The changing vegetation patterns have an impact on wetland functioning and values. The effect of water level changes on the areal extent of a wetland is influenced by the geomorphic form of the wetland, the gradient, and human use of the landward slope, and the gradient, bathymetry, substrate, and seed bank of the lakeward slope. When water levels increase in areas where the landward edges of the wetland are steep or have man-made barriers, expansion or migration of wetland vegetation is impeded and wetland area decreases (Whillans, 1985). However, wetland areas increase where the slope is gradual and the surrounding land is undeveloped and relatively low in elevation, since marsh water can inundate the landward side, allowing emergents to invade (Bedford et al., 1976; Quinlan and Mulamoottil, 1987). During low water levels, wetland communities can expand lakeward if the gradient, substrate, and seeds are available (Bedford et al., 1976).

The timing of water level fluctuations is critical. Seasonal Great Lakes water levels that rise in spring to attain their maximum in summer with a subsequent decline in fall and a minimum in winter are opposite to the pattern that occurs in most inland wetlands, where the maximum is often attained in spring after the snowmelt and the minimum occurs in autumn. In some cases, an inland wetland can completely dry out. Higher winter water levels in the Great Lakes have resulted in the elimination of certain plant species such as cattails (ILERSB, 1981; Keddy and Reznicek, 1985; McDonald, 1955). Abnormally high winter water levels can also increase natural habitat disruption through erosion (Geis, 1979). When water levels increase until summer or early autumn from a winter minimum, a well-balanced interspersion of emergents and open water occurs. Cattails and bulrushes require drawdown and exposure of mudflats for reproduction (Markham, 1982); an overwinter drawdown in particular stimulates greater growth of emergent vegetation. When summer levels are low and winter levels are high, wildlife use and productivity generally are limited (Boss, 1976), but with an early summer water level peak, more plants are able to grow from seed banks and the wetlands are more productive (Merendino et al., 1990). Fluctuating water levels in summer result in more wetland plant diversity than stable summer water level conditions (Wilcox and Meeker, 1991).

For long-term water level changes, some vegetation species can survive only as buried seeds, while others exploit the existing conditions (Keddy and Reznicek, 1985). This is reflected by movement up and down the environmental continuum and changes in areal extent and composition of wetlands. A water level rise of at least 30 cm above the mean for a duration of three to five years is required to reduce and/or eliminate dense emergent growth (ILERSB, 1981). These emergents would be temporarily replaced by floating-leafed and submerged species more tolerant of flooding. A drop of at least 30 cm is needed to establish dense emergent growth (ILERSB, 1981).

Seed banks are the amount of viable seed present in the substrate at any given time (van der Valk and Davis, 1976). In a disturbed wetland community, seed banks and links to plant refuges have a major effect on the successional pattern of plants in the community (Francis et al., 1985). During low water periods, species that are not tolerant of drying die out and are replaced by species emerging from reserves of buried seeds. Prolonged low water levels may induce seed dormancy in some stressed species; however, if the right conditions occur, these seeds can germinate many years later. While densities of buried seeds are high in most wetland vegetation types, they appear to increase from prairie marshes to coastal marshes to lakeshore marshes (Keddy and Reznicek, 1985). Seed densities are highest in the littoral zone; perhaps it has the appropriate combination of submersed and emersed periods for seeds to accumulate. The number of seeds declines further offshore in deep water which would retard lakeward colonization by aquatic and emergent plants during prolonged low water levels (Manny, 1984).

3.3.2. Soils

Water level changes affect wetland soils. Soils and nutrients are carried by currents and wave action and deposited in the bottom of littoral areas and deeper water. Generally, shoreline areas have consistently higher turbidity levels than the open lake because of erosion and input from streams and rivers; high water levels often increase erosion and turbidity. Turbidity causes changes in water transparency that adversely affects plant life: this is especially true for submergents which require light penetration. Clay turbidity, in particular, has an adverse influence on productivity (Regier, 1979). When water levels drop, nutrients are lost from the soil due to oxidation and subsequent reflooding. Changes in soil conditions affect the type of wetland plant species present and their distribution and abundance (ILERSB, 1981). Many wetland plants require organically rich sediments that are found in sheltered embayments. They would have difficulty colonizing where the wave-swept substrate is mainly sand, gravel and rock (Manny, 1984). Harris and Marshall (1963) found that vegetation stands on coarse alkaline soils were generally less dense than those on fine organic soils.

3.3.3. Wildlife

Wetlands provide habitat for mammals, birds, fish, reptiles, amphibians and invertebrates. Here animals can rest, feed, breed, and rear their young. Year-to-year water level fluctuations regulate major vegetation growth and thereby influence the behavioural and population responses of wetland wildlife (ILERSB, 1981; Jaworski et al., 1981; Weller, 1978). Wetland vegetation patterns such as cover, interspersion, dominant vegetation communities, and diversity of vegetation species influence the number and species of wildlife a wetland can support.

The value of wetlands to wildlife is variable and depends on the diversity of vegetation, size of the wetland, wetland water quality, geomorphology (e.g. slope), and soil conditions. The greatest diversity and abundance of wetland dependent animal species occurs in hemi-marsh where aquatic and emergent vegetation zones are interspersed with open water. The least species diversity occurs in the drier, more terrestrial sedge/meadow zone (ILERSB, 1981). Higher lake levels are preferred to maintain higher wetland wildlife diversity (Jaworski et al., 1981) while low water levels usually lead to poorer conditions.

3.3.3.1. Waterfowl. The Great Lakes shoreline wetlands provide important spring and fall migration and staging habitat for waterfowl from the Atlantic and Mississippi flyways (ILERSB, 1981; Prince et al., 1992). Waterfowl rely on wetlands for heavy feeding at these times; spring is particularly important as they prepare to breed. The attractiveness of a site to waterfowl is determined by water chemistry, water depth, interspersion, the presence of suitable invertebrate populations, aquatic vegetation for food and cover, and freedom from disturbance (Dennis, 1982; Sather and Smith, 1984). Good waterfowl staging areas have a hemi-marsh condition of 50 percent open water and 50 percent vegetation, with extensive interspersion (Weller and Spatcher, 1965). This provides an ideal ratio of plants for food and cover and areas of open water, although different types of waterfowl prefer different wetland vegetation. Changes in water level can alter this marsh cover-water ratio and the composition of the wetland vegetation (Dennis, 1982; ILERSB, 1981; Weller and Frederickson, 1974).

High water levels are detrimental to migratory waterfowl and marsh birds (Laperle, 1974; Farney and Bookhout, 1982). Loss of emergent vegetation in a wetland disrupts the normal feeding pattern of migratory waterfowl, forcing the birds to seek food in upland fields. The reduction in waterfowl habitat also causes increased competition for space and territoriality (ILERSB, 1981). Nests become concentrated on high ground and dikes, where they are subject to higher rates of predation. Low water levels are not beneficial since wetlands progress to drier wetland communities such as shrubs and wet meadows which do not support feeding waterfowl.

Waterfowl are especially sensitive to seasonal water level fluctuations during breeding periods. Stable water levels are ideal; high nest loss occurs with fluctuating or rising water levels (ILERSB, 1981; McNicholl, 1985). In a three-year study of Readhead ducks, mortality was high when water levels rose during the nesting season and flooded nests. Conversely, when water levels declined, mortality occurred when nesting habitat dried out and birds deserted their nests (Markham, 1982). Timing of seasonal fluctuations seems to be crucial. March and April drawdowns disrupted waterfowl during the egg-laying period, whereas a drop in water levels after nesting was well under way usually was not detrimental (Meeks, 1969). Anderson and Glover (1967) found that a marsh flooded two weeks prior to peak spring migration produced nearly three times the number of ducklings as a similar area flooded two weeks after peak migration. The presence of an adequate quantity of invertebrates during the breeding season is crucial, since they are important to the diets of laying females and young broods (Dennis, 1982). Invertebrate abundance is influenced by the amount, density, and species composition of emergent and submergent vegetation. Waterfowl have adapted to fluctuating water levels through nest alteration, tree nesting, changing nest chronology, renesting, and increasing home range size (Markham, 1982).

3.3.3.2. Mammals. Many mammals are not exclusively dependent upon wetland habitat for survival, since they can occupy multiple habitats. They use wetlands periodically for feeding, cover, breeding, resting, or other purposes. Muskrats, the most economically important furbearer, are almost completely dependent upon wetlands. Relatively stable hemi-marsh conditions are most favourable to them. Muskrat abundance is influenced by three factors: water depth, water quality, and type and abundance of vegetation; emergents, particularly cattails, which are controlled by fluctuating water levels, provide food and habitat and are especially important (Bellrose and Brown, 1941; Bellrose, 1950; ILERSB, 1981; Sather and Smith, 1984).

Muskrat lodge construction and density are dependent upon water levels in a wetland. The optimum depth is 30 to 45 cm.; the minimum is 15 cm. and the maximum is 60 cm. These depths correspond closely with the optimum water levels for growth of the preferred vegetation (Bellrose and Brown, 1941). Low water acts as a dispersion factor by reducing the amount of usable vegetation stands (Proulx, 1982), causing muskrats to abandon their houses and relocate. Prolonged low water levels in the winter lowers muskrat populations due to starvation, disease, and predation. Cattail is the most important cover plant and lodge building material as well as the preferred food. The muskrat does not store large quantities of food; winter food is often restricted to underground plant parts or to what can be reached under the ice. Extremely cold temperatures and low water levels cause the bottom of the feed beds or the approaches to them to freeze, thus curtailing access to food supplies. Muskrats have to tunnel through mud or risk greater predation by feeding on the surface. A water depth of approximately 60 cm. is necessary to prevent winter losses (Patch and Busch, 1984).

The timing of seasonal fluctuations can affect reproductive success. Meeks (1969) conducted drawdowns on marshes in Ohio during different months of the year. March drawdowns reduced the number of young produced to almost zero, while mid-to-late May drawdowns allowed at least two litters to occur uninterrupted.

3.3.4. Fish

Wetlands are essential to maintaining fish stocks. Fish abundance and diversity are relatively high in and adjacent to marshes (Whillans, 1985). The littoral zone provides food, shelter, spawning, and nursery sites for a wide variety of fish.

Water quantity, water quality (chemical and physical), vegetation cover, and interspersion are key climate-sensitive factors that determine the amount and quality of fish habitat in a wetland. Habitat influences the types of species and the biomass of fish that can be produced or supported in a wetland (Taylor, 1985; Jude and Pappas, 1992). Water temperature and dissolved oxygen concentration affect freshwater fish distribution and success. Alkalinity, pH, and turbidity also play a significant role. The water quantity factors that affect fisheries are depth, volume, velocity, and hydroperiod. Cover provided by vegetation is important, since it is used by fish as protection from predators and climatic conditions or as a substrate for feeding or reproduction. Interspersion defines the relationship between open water and vegetation, between various vegetation types and between various types of substrate (Sather and Smith, 1984). Individually and in combination, these factors influence the type of fish that can survive, the suitability of fish habitat and the productivity of the various species. Extended periods of low water levels and abnormal seasonal fluctuations impair these factors.

Low winter water levels reduce the availability of the wetland habitat, increase bottom scouring by ice, increase the amount of aquatic vegetation uprooted by ice movements, decrease oxygen content, and trap fish under the ice in shallow areas (ILERSB, 1981). Low spring water levels may prevent fish from reaching spawning areas. A water level decrease between spawning and hatching of the eggs could lead to exposure of eggs and a decrease in the number of offspring (Hanna and Michalski, 1982; Manny, 1984). Long-term low water levels cause a shift to more terrestrial vegetation in shoreline wetlands; less food would be available with an increase in emergents and decrease in submergents. Lower lake levels could result in a permanent loss or decrease of the nearshore spawning and nursery grounds for a large number of Great Lakes fish species (Manny, 1984).

Meisner et al. (1987) suggested that increases in water levels might be beneficial to the fish population since higher levels would provide more favourable fish habitats. Liston and Chubb (1985) found that the density of submerged vegetation seemed to increase with both seasonal and annual rises in water levels at Pentwater Marsh and that larval fish abundance and density were greatest during this time period. Larger year classes of species such as walleye and pike have been associated with higher than normal water levels for several water bodies (ILERSB, 1981).

3.3.5. Water Quality

The hydrologic regime is an important physical factor governing the water quality of a wetland (Kadlec and Kadlec, 1978) yet wetlands can enhance water quality (Lee et al., 1971; Found et al., 1974; Rubec et al., 1988; Mitsch and Gosselink, 1986; Sather and Smith, 1984). Hydrology affects retention time and water depth and influences vegetation characteristics. Within a wetland, complex hydrological, biological and chemical interactions occur which allow wetlands to function as filters by trapping sediments and removing pollutants such as heavy metals, nutrients and pesticides. Nitrogen and phosphorus are removed from surface waters, at least during the critical period of the growing season (Prentki et al., 1978; Rubec et al., 1988).

During periods of low water levels, sedge and cattail communities become dense and peat can accumulate. Flow velocities through a wetland decrease and longer residence times promote greater sedimentation and plant uptake (Jaworski et al., 1981); however, the water within a wetland may become degraded for wetland vegetation, fish, waterfowl and mammals. The lower flows and greater volumetric load of pollutants and reduced water depths cause greater turbidity, higher concentrations of pollutants, and higher demands on dissolved oxygen. Vegetation is stressed by poorer water quality and higher sediment loads.

4. Climate Change

Climate change could alter the water level conditions under which the Great Lakes shoreline wetlands were formed and are maintained. The direction and magnitude of the water level change, timing of fluctuation(s), duration of the event, and its frequency of occurrence are characteristics that can be used to identify the impact of water level changes on wetland ecosystems. The water level regime in shoreline wetlands would be altered through changes to the mean level, annual range, and seasonal cycle as well as the timing, amplitude and duration of levels. These new water level conditions could prevail and become the new hydrologic environment or "base conditions". Wetlands would have to adjust to a new pattern of water level fluctuations.

4.1. CLIMATE CHANGE HYDROLOGY IMPACTS

Climate change brought on by an enhanced greenhouse effect may alter climatic elements such as temperature, precipitation, snow cover, time of snowmelt, evaporation, and wind, creating a new range of climatic conditions and resulting in a new hydrologic regime for the Great Lakes.

Warmer air temperatures may mean more winter precipitation falling as rain instead of snow. The snow pack and the length of the snow season will be reduced. This has implications for the Great Lakes water level regime. Rain in winter will allow more precipitation to reach the lakes directly through overland flow, as little infiltration will occur in the frozen ground and snow will melt. With less storage of water in the snow pack, higher winter water levels may result. Earlier snowmelt and runoff will contribute to an earlier rise in water levels to their seasonal maximum. Although an earlier peak may be attained, it may not be as high, because there would be greater evaporative losses and less runoff. These are the hypothesized climate changes that were used to develop the "what if" scenario for a change in the seasonal cycle of Great Lakes water levels.

Evaporation from the Great Lakes and evapotranspiration from the land surface would increase with higher air temperatures and higher water temperatures. The percentage of cover and duration of the ice season will also decrease with higher winter temperatures. A longer, open water season will also contribute to more evaporation. Although many areas in the Great Lakes basin receive more precipitation in GCM climate change scenarios, this will be offset by higher evaporative losses. In general there is a decline in moisture availability in the basin which reduces the input of water to the Great Lakes (Mortsch and Quinn, 1996). Table I summarizes the range of Great Lakes water level changes using different climate change scenarios. The GCM and transposition scenarios suggest lower lake levels. These hydrologic impact results provide the basis for the second "what if " scenario of reduced lake levels.

4.2. CLIMATE CHANGE IMPACTS ON WETLAND FUNCTIONS AND VALUES

Wetlands perform numerous functions such as primary productivity, providing wildlife habitat, enhancing water quality, providing recreation opportunities, and supporting commercial activities. They are among the most productive

Table I
Climate change scenarios and changes in Great Lakes mean annual lake levels (m) from base case summarized from Croley, 1990, 1993; Croley et al., 1995; Hartmann, 1990; Mortsch and Quinn, 1996.

Scenario	Lake Superior	Lake Michigan-Huron	Lake Erie	Lake Ontario
GCM				
CCC92	- 0.23	- 1.62	- 1.36	- 1.30
GFDL	-	- 2.48	- 1.91	-
GISS	- 0.46	- 1.31	- 1.16	-
OSU	- 0.47	- 0.99	- 0.79	-
Transposition				
Warm & dry (6°S by 10°W)	- 2.12	- 3.33	- 2.14	- 1.50
Warm & wet(6°S by 0°W)	- 0.75	- 0.23	+ 0.01	- 0.03
Very warm & dry (10°S by 11°W)	-11.30	- 3.49	- 2.28	- 1.52
Very warm & wet (10°S by 5°W)	- 0.97	- 0.23	+ 0.04	+ 0.03

*NOTE: None of these scenarios include the GCM "runs" which have the short-term, regional cooling effect of aerosols. The $2xCO_2$ climate change scenarios containing aerosols may not have as severe impacts on water levels because the warming is not as pronounced.

ecosystems, and their functions have intrinsic, social, and economic value. Identifying wetland functions and establishing wetland values are prerequisites to wetland conservation and protection. Wetland functions and values are not static: environmental and human-induced changes can enhance, degrade, or eliminate certain wetland functions and thereby alter the value of a wetland. Climate change could initiate significant changes.

Two of the most likely, "what if" water level scenarios are a decline in the mean annual water level and a modification of the seasonal cycle. The antecedent climatic conditions that would cause these water level changes were described in Section 4.1 and are summarized in Tables II and III. The shoreline wetland ecosystem responses to these "what if" lake level scenarios are also described. The wetland ecosystem responses are based on an assessment of the historical sensitivity and vulnerability of wetlands to water level changes of these kinds, not on rigorous modelling of the biophysical impacts of the scenarios; these impacts are speculative. While other regions such as the Prairies and the Boreal have had climate impact assessments with wetland modelling, this is an important gap in the Great Lakes climate change research (Poiani and Johnson, 1991; 1993a,b; Woo, 1992).

One of the most important wetland functions is primary productivity. One

Table II

"What if" Scenario of Altered Seasonal Distribution of Water Levels and Potential Wetland Ecosystem Effects

SCENARIO	WETLAND ECOSYSTEM EFFECTS			
CLIMATE CHANGES	VEGETATION	BIRDS (WATERFOWL)	MAMMALS (MUSKRAT)	FISH
• warmer air temperature • more rain or rain on snow events in winter • less snowcover • shorter period of low water in winter • earlier spring melt • earlier rise of water level in spring • more evapo-transpiration • less runoff • earlier onset of water level decline	• timing and degree of fluctuation important • high winter levels: emergent vegetation die-off • summer levels low and winter levels high: wildlife use and productivity limited	• sensitive during breeding season; short period where timing affects breeding success • levels rise: less habitat, increased competition, disease • levels decline: drying of habitat, nest desertion, increased predation	• timing affects reproductive success • water drawdown in March: almost no litters • water drawdown in May: 2 litters • low winter levels: reduced muskrat populations due to starvation, disease and increased predation	• low spring levels: prevent fish from reaching spawning areas • water decline after egg laying: expose eggs • high levels during spawning and nursery period: higher production of young of year and enhanced growth and survivorship • low winter levels: decline in habitat and increased winter kill

Table III

"What if" Scenario of Increased Frequency and Duration of Low Water Levels and Potential Wetland Ecosystem Effects

SCENARIO	WETLAND ECOSYSTEM EFFECTS				
CLIMATE CHANGES	VEGETATION	BIRDS (WATERFOWL)	MAMMALS (MUSKRAT)	FISH	WATER QUALITY
• higher air temperatures • more evapo-transpiration • less runoff • warmer water temperatures • reduced ice cover	• aquatic, submergent and emergent plants die or migrate lakeward • less areas of open water • plants with drier requirements (sedges, grasses, shrubs and trees) expand • mudflats are exposed • seed banks important for reestablishing vegetation if drawdown does not exceed optimum region • wetland area usually decreases: influenced by basin geomorphology, bathymetry and rate of water level decline • diking used to maintain and regulate wetlands	• decline in habitat for waterfowl migration staging, breeding • loss of optimum waterfowl habitat (hemi-marsh: 50% vegetation and 50% open water) • drier conditions, increased abundance and dominance of terrestrial plant species • less emergent and submergent vegetation for food • less habitat; more competition	• habitat quality and availability decreases • reduced amounts of usable vegetation stands (cattail preferred food and building material) • home range extended to compensate for drop in water levels • abandonment of houses and relocation if decline is severe	• loss of submergent vegetation associated with high fish abundance • thermal regime changes, flow and water depth decreases; water quality impaired • decrease in nearshore, spawning and nursery grounds • fish larvae, juvenile and wetland-dependent fish stressed	• water depth and flow decrease • sedimentation high; turbidity increases • higher concentration of pollutants in flow • water temperature increases • anoxic conditions can develop • decline in water quality affects vegetation and wildlife

study calculated that swamps and marshes have a net primary productivity of 2000 g/m^2/year, compared with lakes and streams at 500 g/m^2/year and agricultural land at approximately 650 g/m^2/year (Whittaker, 1970 in Shay, 1981). Warmer air temperatures from climate change would alter the rate of photosynthesis and respiration, lengthen the growing season, and enhance wetland productivity. However, wetland productivity is depressed by prolonged flooding or drying out, while periodic water level changes increase vegetation diversity and productivity. In a five-year period, an 18-fold difference in primary productivity was documented for a prairie marsh as it progressed through phases of drying, regenerating, degenerating, and extreme flooding (van der Valk and Davis, 1978). The "what if" water level scenarios suggest that the duration and intensity of lower water levels will increase, and there will be a negative impact on productivity from lower water levels, the drying out of landward wetland areas, and the uncertain success of colonizing vegetation on exposed mud flats.

In agricultural and urbanized areas of southern Ontario, wetlands provide the only remnants of semi-natural habitat. They act as reservoirs of biological complexity in simplified landscapes (Found et al., 1974). Many rare, endangered, or threatened species of animals and plants survive in unique habitats found only in Great Lakes wetlands. The value of a wetland for wildlife habitat depends on the type of wetland and its size, the structure and diversity of vegetation communities, water chemistry, and surrounding land uses (Sather and Smith, 1984). The greatest diversity and abundance of animal species occurs when aquatic and emergent vegetation zones are interspersed with open water (hemi-marsh); the least diversity occurs in drier terrestrial plant communities (ILERSB, 1981). Drier, less diverse vegetation and wildlife conditions will dominate in the lower water level scenarios.

Wetland response to lower annual water levels depends on the type of wetland and its geomorphology and bathymetry. The geomorphic framework, i.e. exposure to wind, waves, sediments, slopes and land forms, influences the areal extent of a wetland, the structure of the wetland, and the seasonal pattern of flooding. Great Lakes shoreline wetlands display a diversity of land forms normally not seen in other wetland environments, such as the formation of barrier beaches, deltas, and natural levees (Herdendorf et al., 1986). Based on geomorphology, seven marsh types can be used to assess the impact of water level changes (ILERSB, 1981). A pictorial representation of the wetland types is presented in Figure 3.

Due to their geomorphic form and dominant vegetation, certain wetlands are more vulnerable to water level decline. Marshes adapt more readily to lower levels than swamps. Although landward edges of marshes would dry, their main vegetation types, sedges, grasses, reeds and aquatic plants, could colonize suitable exposed sites. Swamps are less resilient since their characteristic vegetation species, trees, cannot regenerate and colonize quickly. Enclosed, inland lake-connected, and barrier beach wetland forms would be more prone to drying out and losing wetland vegetation during low water periods. If dry conditions persisted, the wetland ecosystem would progress to a terrestrial ecosystem. In unrestricted bay, open shoreline, and shallow sloping beach wetlands, vegetation migration is not physically constrained. The areal extent of these wetlands could increase if there were a gentle slope and other suitable conditions such as substrate, seed banks, and wave protection. Precambrian

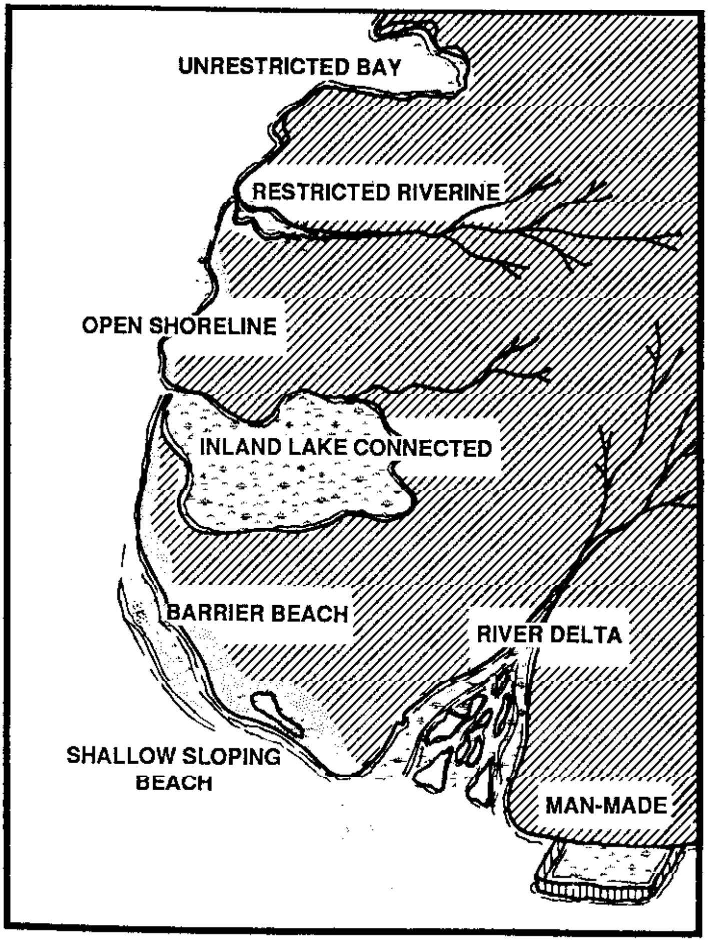

Figure 3. Wetland types based on geomorphic form modified from Liston and Chubb, 1985 and ILERSB, 1981.

Shield shoreline wetlands are located in areas of irregular slope and rocky substrate. These wetlands have fewer sites for successful colonization.

The rate of climatic and hydrologic change is another critical factor affecting wetland ecosystem response. A slow rate of change would allow adaptation and invasion of vegetation and wildlife species. However, a sudden, rapid change could have catastrophic effects as few wetland organisms would be able to adapt.

5. Policy and Management Responses

It has been established that changes to the water regime in the Great Lakes due to climate change could have a significant impact on shoreline wetlands. Whether the water levels rise or fall in different scenarios, the changes will require policy and management adjustments.

Canada is a signatory to the RAMSAR Convention on the Conservation of Wetlands of International Importance. For example, Long Point and St. Clair National Wildlife Areas and Point Pelee National Park are included in the designation. If the viability of these internationally recognized wetlands is threatened, what is the policy response? Will the wetlands be allowed to adapt to the new water regime, perhaps being lost, or will the wetlands be managed? If the wetlands are managed, what uses or functions will be maintained? How much do we know about wetland restoration?

The United States and Canada signed the North American Waterfowl Management Treaty that has significant resources to improve waterfowl habitat, particularly breeding, staging, and overwintering sites throughout North America. The "Lower Great Lakes-St. Lawrence Basin" was identified as a "Priority Habitat Range". How will the plans developed to preserve and enhance wetlands for waterfowl be impacted by climatic change? How can these plans be modified to respond to changes in regional water balances and hydrologic cycles?

The Canadian Federal government has developed a National Wetland Policy where climate change is described as a wetland issue. Wetland functions as they presently are assessed may be altered due to climate change, and the social benefits may be altered as well. The long-term viability of the wetlands that are to be preserved may not exist. How will the policy incorporate the effects of large-scale changes?

In Southern Ontario and elsewhere in Canada, there is conflict between wetland preservation and land use and development. To more effectively manage the remaining wetland resource, the Ontario government developed a planning tool, the Ontario Wetland Evaluation System. Wetland functions are identified and values are quantified so that there is a basis for comparing the uniqueness and importance of wetlands for rational land use decision-making. Climate change may significantly alter the functions of the wetlands and thereby affect the uniqueness ranking of Ontario wetlands. How flexible is the evaluation system? How will the changes to wetland evaluation be incorporated into the land use planning procedure to ensure that wetlands that become more significant are not lost? Many government and private sector management policies for natural areas do not directly consider climate change (Fooks, 1996).

6. Summary

Great Lakes shoreline wetlands are valuable, multi-functional resources which require water level fluctuations in order to remain in an early successional stage; however, the timing, duration, and range of these fluctuations are critical in determining how wetlands react to changes in water level. Climate change will alter the water balance of the Great Lakes. Two "what if" water level scenarios, a change in the seasonal cycle and a decrease in the mean level, illustrate the impact on wetlands. Wetland functions and values such as primary productivity, use for wildlife, waterfowl and fish, water quality, areal extent, and diversity will be affected by these scenarios. Key wetlands are at risk, particularly those that are impeded from adapting to the new water level conditions by man-made structures or geomorphic conditions. Wetland remediation, protection and enhancement policies and programs must consider climate change as an additional stressor of wetlands.

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