Great Lakes, Grand Problem:

The Impacts of Significantly Lowered Lake Levels on the Industries, Ecosystems, and Individuals in the Great Lakes region

A White Paper Produced for the Citizens of Canada and the United States

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Executive Summary

One of the largest freshwater resources in the world, the Great Lakes serve as an integral water source to the more than 40 million residents that use the water in their homes, for recreation, and for the aesthetics of their shores.

Understanding the link between climate change and its impact on the Great Lakes region has been ongoing and has become increasingly important for both Canadian and United States citizens. A warmer and drier climate will likely lower lake levels due to increased evaporation over precipitation. A collaborative group of researchers has produced evidence to show lake levels in the past have dropped tens of meters, probably due to climatic variations, and have reason to believe this scenario could repeat itself. Significant drops in future water levels could be a problem for which many in the Great Lakes basin are unprepared.

The purpose of this paper is to raise awareness and address some of the impacts a drastic drop in lake levels would have on the region. The paper is divided into three parts which are outlined as follows:

- **Part 1** of the paper describes a paleoenvironmental event where lake levels declined, and outlines the events and conditions that could trigger a lake level drop of tens of meters. A shift in air masses due to changes in climate will increase evaporation rates in the region, reducing or ceasing outflow of one or more of the lakes. Once the lakes become “isolated”, they will be more susceptible to evaporation which would result in dramatic drops in lake levels.

- **Part 2** addresses the impacts a significant water drop would have on those industries, ecosystems and individuals that depend on relatively stable lake levels in order to function. The section finds that considerable financial impacts will impede the commercial shipping, manufacturing, and electric power industries in the region. Many of the wetland ecosystems will not survive a dramatic low-stand, and those that do will be permanently altered. Current water diversions into and out of the lakes will magnify low lake levels. Recreational activities such as boating, hunting, fishing, and tourism, as well as drinking water supplies to the region will be affected by decreased water quality and quantity.

- **Part 3** looks at the complexities of decision-making in the Great Lakes region. The Boundary Waters Treaty and the Great Lakes Water Quality Agreement are the main pieces of legislation by which the region is governed. The International Joint Commission as a governing body for lakes issues is restricted to the mandates set forth in this legislation. Questions are raised about the process of international decision-making in the face of rapid change.

It is important to understand the variables that could trigger a dramatic drop in lake levels. By raising questions as to how systems currently in place might be affected by a catastrophic event and how decision-making might function in this case, we can be better prepared to respond should such an event occur.
Part 1: Introduction and Background

A Dangerous Prospect

In just 40 years, the volume of Mono Lake in eastern California shrank to half its original amount, lowering the water level by 13.4 meters (Mono Basin Clearinghouse). It changed so rapidly that more than 900 acres of wetland species surrounding the lake were unable to migrate successfully with the rapidly changing coastline and as a result most have been lost, or significantly degraded. The remaining wetlands have been altered to such an extent that they are uninhabitable for most waterfowl due to water quality declines and wetland species degradation. The water remaining in the lake has experienced an increase in salinity two to three times that of the ocean, or between 70 and 105 ‰, and doubled in alkalinity, which has eliminated all of the freshwater fish populations in the lake (Wetmaap 2006). The remaining survivors are brine shrimp and alkali flies, and even these demonstrate stressed states due to the rapid changes in their environment. Furthermore, the lake bottom sediments that became dried and exposed to air are easily picked up by the wind, creating severe dust storms dangerous for human respiration. As a result, the Mono Basin is currently in violation of Federal Air Quality Standards (Wetmaap 2006).

Mono Lake can serve as a modern analog for another region researchers believe is at risk for sudden and rapid lake level declines—the Great Lakes. While the drivers behind such fluctuations differ—Mono Lake levels declined due to water diversions from the lake, whereas low levels in the Great Lakes might be driven by climate change—the nature of the impacts on the region could be quite similar. Should such a situation occur in the Great Lakes watershed, the impacts would affect industry, ecosystems, and people on a much larger scale, while threatening the source of 90% of the freshwater in North America, or 20% of the freshwater worldwide.

An Area of Concern

One of the largest freshwater resources in the world, the Great Lakes serve as an integral water source to shipping and commercial navigation interests, hydroelectric power, industry, ecosystems, and the more than 40 million residents that use the water in their homes, for recreation, and enjoy the aesthetics of their shores. According to the Great Lakes Commission, water withdrawals from the U.S. and Canada averaged 43 billion gallons (165 billion liters) per day as of 2002, and as the population in the basin continues to grow so too does the dependence on Great Lakes water resources (GLC 2002).

Understanding the link between climate change and its impact on lake levels has become increasingly important for both Canadian and United States citizens. A warmer and drier climate is predicted over the next centuries, and this will likely lower lake levels due to increased evaporation over precipitation (UCS 2003). Just how significant this impact might be on lake levels, and as a result, those who depend on the lakes, is uncertain. Up
to this point various economists, scientists, and modelers have predicted lake level drops of only a few feet (Mortsch and Quinn 1996, Lofgren et al. 2002, GLERL 2004, 2005). Extensive assessments have predicted the impact that might be felt by industries, individuals, and ecosystems should lake levels fall within the two to three meter (six to ten foot) range. But what if the drops in water levels are more substantial than this?

To evaluate this possible scenario, a collaborative group of researchers are currently working on a project to understand the relationship between paleoenvironmental conditions and lake levels. Evidence has shown that about 8,000 years ago, lake levels declined by tens of meters, but the mechanism has not been well understood. The researchers hypothesize that the lake level decline was due to a climatic forcing event which occurred over a period between 9,400-7,700 years ago (cal BP). By studying past factors that have played a role in these significant lake level drops, they are hoping to better understand how modern changes in climate might be more accurately assessed, and just what aspects of the past might play into future predictions. The group has reason to believe that future drops in levels could be in the range of tens of meters: a realistic scenario for which many in the Great Lakes basin are unprepared.

The greater the drop in lake levels, the greater the impact will be on the region as a whole. Therefore, there is a need to extend the impact assessments beyond their current scope. According to DeLoë and Kreutwiser (2000), it is expected that municipalities and other jurisdictions in the Great Lakes basin will have the ability to adapt incrementally and cost-effectively to climate change, anticipating that change will be gradual. However, it is not yet clear that change will be gradual, and it is doubtful that institutional constraints will allow stakeholders in the basin to adapt effectively to rapid changes in lake levels and coastlines (DeLoë and Kreutwiser, 2000).

In the face of a potentially rapid change it is important to look at some of the industries and ecosystems that will be most severely affected by lower water levels. The shipping and hydropower industries, as well as the wetland ecosystems that surround the lakes, are particularly sensitive to lake level fluctuations, and thus would suffer dramatically should water levels drop. By addressing questions as to how these systems might be affected by such a catastrophic event, we can be better prepared to respond should one occur.

*Looking at the Past to Understand the Present*

Lake levels in the Great Lakes Basin are constantly fluctuating. The hot and dry climate which led to the Dust Bowl in the 1930’s caused lake levels to drop by more than a meter in all of the lakes but Superior over a period of three years (Assel et al. 2004). In 1958-1964 levels declined more than a meter on average in four of the five lakes (Assel et al. 2004). Lower than average levels (a drop of a meter or more) from 1999 to the present have followed three decades of unusually high lake levels (GLERL 2006). This time, however, lake level decline will be a trend that hasn’t before been factored in: global climate change.
A collaborative effort funded by the National Science Foundation has brought together researchers that have done extensive work both in and around the Great Lakes Basin. To better understand the sensitivity of the Great Lakes water levels to changes in climate, the researchers are investigating the climatic conditions that occurred 9,400 to 7,700 years ago, creating what is known as a closed lake status.

Closed or terminal lake status occurs when a lake receives water from streams, precipitation, or groundwater, but the water does not flow out of the basin. Instead the lake loses water almost exclusively through evaporation. If inflow and evaporation rates remain constant, then the system establishes equilibrium. A closed basin is more vulnerable to changes in climate, as it can experience fluctuations either in inflow or in evaporation due to atmospheric or temperature changes. Closed basin status is of particular concern in the Great Lakes Basin as the five major lakes are interconnected, and therefore each depends on the outflow from another in order to maintain water levels. The closure of just one lake in the system would affect the levels of all those lakes that follow it in the system as they would no longer gain water from its outflow.

Mono Lake, from the example we began with, is a terminal or closed basin located in California. Lake levels there have fluctuated widely in the last 15,000 years, but since the 1800’s have been relatively stable (Wetmapp 2006). In 1941, however, the Los Angeles Department of Water and Power diverted four of the five major rivers flowing into Mono Lake to serve the water needs of the city of Los Angeles. More than 18,000 acres of former lake bottom were exposed as a result of this action, and it has been devastating to the wildlife and communities in and around the lake. To counter this impact, the California State Water Resources Control Board mandated in 1994 that minimum flows be maintained in all of the diverted streams sufficient to increase the lake level by 5.2 meters (17 feet), but it is expected to take more than 20 years to stabilize the lake at this level (Wetmaap 2006). While this will help the lake ecosystem, it will never be fully restored to its original state.

The Great Lakes run the risk of becoming closed basins not due to diversions, however, but due to a region-wide loss of water through evaporation. To better understand this, one must look at the water balance of the system. The concept of water balance relates precipitation and evaporation. Water balance includes three main components: precipitation or the input to the system; evapotranspiration—a combination of evaporation, which transforms liquid water to a gas which can then be released in the atmosphere, and transpiration, which is the release of water vapor into the atmosphere by plants—or the output from the system; and soil moisture storage, or the storage capacity of the system (Ritter 2006). Although the water volume of the Great Lakes constitutes a huge freshwater resource globally, they are sustained by a relatively small annual positive water balance. This positive water balance is supported by an excess supply of precipitation and runoff over the water loss from evaporation, transpiration, and overflow, and it is this slim positive element of the Great Lakes water balance that is threatened by future global warming (Lewis 2006). If the balance is reduced below present values by increased temperature or decreased precipitation, the result will be lowered water levels in the Great Lakes as shown in figure 1.
It was originally hypothesized that geological indicators of extremely low former water levels between 9,400-7,700 years ago in the Great Lakes, specifically the Michigan, Huron and Georgian Bay basins, were due to low level lakes overflowing isostatically-depressed outlets resulting from loading by the previous ice sheet (Lewis et al. 2006). The Laurentide Ice Sheet, which covered the region 10,000 years ago, was nearly two miles thick, weighing down the continent and depressing the Earth’s crust. When the glacier began to retreat, the land began to return to its original state, or rebound. After deglaciation and before significant rebound had occurred, the Great Lakes basin was depressed differentially, greater in the north where ice was thicker and had lasted longer than in the south. At this time the upper Great Lakes, draining via a depressed outlet to the northeast, were lowered to low levels in their basins. With general knowledge of this condition, it was previously thought that these lake phases were sufficiently low to explain the occurrence of low lake level indicators, such as submerged tree stumps. However, with recent completion of a quantitative empirical model of glacial rebound for the Great Lakes basin, the original elevations of lake level indicators and possible outlets were reconstructed and compared (Lewis et al. 2006). The comparison shows that for several centuries beginning about 9,400 years ago, water level was tens of meters below the lowest possible overflow outlet (Lewis et al. 2006). Closed basin conditions like this normally occur as a result of excessive evaporation in a dry climate. This is a likely cause for the newly discovered closed lake phase, as it coincides with the final diversion of upstream inflowing meltwater away from the Great Lakes watershed. At this point the Great Lakes were supplied only with precipitation and runoff, as at present, and were susceptible to the known dry climate at the time.

Researchers on this project hypothesize that a climate driven shift in air currents (air mass distribution) may have played a significant role in causing lake level fluctuations by increasing evaporation rates (Lewis et al. 2006). Changes in vegetation in the region 8,400 years ago, obtained from pollen data and aquatic microfossil records, indicate shifts in atmospheric circulation. The combined shifts of a dry Arctic air current further southward, and that of a warm dry Pacific air current flowing eastward over the region, would have caused substantial increases in evaporation, as shown in figure 2. Both currents in turn would have transported evaporated water out of the Great Lakes watershed. The combined evaporative effects of these air currents would have been sufficient to lower lake levels tens of meters below their normal status, and maintain closed lake status in lakes Michigan and Huron for 400 years or more as shown in figure 3 (Lewis et al. 2006).

Currently, Earth is undergoing a change in climate so rapid and unprecedented that its impacts are difficult to predict. The more we understand the factors that have altered lake levels in the paleoenvironment, however, the more accurately we might understand fluctuations in the future. Should the results from this research continue to verify these past atmospheric changes, sustained and relatively minor changes in climate can have impacts on lake levels far greater than those predicted.
Part 2: Impacts of Change

Cargo Compensation

Commercial shipping is one of the industries most sensitive to lake level fluctuation. Freighters transport cargo more inexpensively than either rail or air transport in the Great Lakes region. Industries in the region depend on the approximately 200 million tons of bulk commodities (iron ore, coal, grain, limestone, salt, and petroleum products) that pass through the 145 ports and terminals (Sousounis and Bisanz 2000, GLIN 2006). The industry currently supports 60,000 U.S. and Canadian jobs and collects more than $3 billion per year in personal income and business revenue (Sousounis and Bisanz 2000, GLIN 2006). If lake levels remain at their current levels, then jobs and revenue generated from this industry should remain relatively stable. However, small lake level fluctuations can have major impacts on the carrying capacity of these ships and the industry’s overall sustainability. The Lake Carrier’s Association has found that every 1 inch loss in draft reduces a 1,000 foot ship’s (such as those used for intra-Great Lakes transportation) cargo load by 270 tons, and reduces the load of a 740-foot long ship (an ocean-going vessel sized to fit through the St. Lawrence Seaway) by 100 tons (UCS 2003, GLWQB 2003). Draft is the distance between the water line and the vessel’s bottom. For the average sized freighter carrying 70,000 tons, a lake level drop of 1 meter (3.3 feet) would mean approximately a 14% reduction in cargo load, and a drop of 5 meters (16.4 feet) would reduce cargo by as much as 70%. In the shallower lakes, Erie (average depth 19 m) and Huron (average depth 59 m), a lake level drop of tens of meters would make ports inaccessible and make passage through many lake channels difficult, if not impossible. Costs based on milder climate predictions have been estimated to increase between 5 and 40% in response to lake level declines (UCS 2003).

Ironically, a slow lake level decline might benefit the shipping industry for the short term. Warmer temperatures have already been observed to reduce the ice cover on the lakes, meaning the industry would have a longer season in which to operate. Ice cover on the lakes usually closes the shipping season for about two months. This winter (2005-2006) there was very little ice cover on the Great Lakes, an event that will occur more frequently as global temperatures continue to increase (Assel 2006). While the absence of ice increases the amount of water that is evaporated from the lakes annually and in the longer term might actually speed evaporation (ice serves as a cover which prevents lake water from evaporation), it does allow the safe passage of cargo on the lakes year round. If lake levels lower slowly, a longer shipping season might mitigate the impacts of water level declines, at least initially (UCS 2003).

Dredging for Depth

One solution for lake level fluctuations and associated impacts on shipping is dredging. Dredging removes sediment that has accumulated in a basin over time, thereby clearing channels for recreational and commercial shipping traffic. Assuming water levels remain the same, dredging simply removes sediment that accumulates in the channels from erosion on land and displaces water through its accumulation. In 1999 the U.S. Army
Corps of Engineers was removing over 3 million cubic meters of sediment from 35 federal navigation projects in the Great Lakes annually (GLC 1999, GLWQB 2003). If water levels drop, dredging can be used to “deepen” the basin to maintain a constant water level in channels used for shipping.

Although dredging seems to offer a viable solution, inorganic and organic contaminants have long been a problem in the Great Lakes Basin. Industries along the lakes and their waterways have released tons of toxic contaminants directly into the lakes. It is estimated that five tons of polychlorinated biphenyls, or PCBs, currently lie in the sediments of Lake Superior and two additional tons are suspended in the water column (EC and EPA 2005). This practice has been curbed to some degree with the passage of the Great Lakes Water Quality Act in 1972 and its renewal in 1978, which strives to maintain the physical, chemical and biological integrity of the Great Lakes ecosystem. While significant reductions have been made in the amount of contaminants released into the lakes since 1978, many toxic contaminants have not been removed from the lakes but instead have settled on the lake bottoms where they are gradually buried.

The dredging process has the potential to stir up and disturb contaminants that have already settled on the lake bottoms. Dredging can cause contaminants to be resuspended in the water column, posing risks to aquatic life and drinking water. Contaminants such as PCBs are bioaccumulated, or stored in the fatty tissue of fish and mammals as they consume prey that have ingested them. More carnivorous consumers such as birds and fish store these toxins in their fatty tissue, and the toxins are magnified as they move up the food chain. Fish consumption advisories for PCBs, mercury, and other contaminants continue to be in effect for the region, and pregnant women and infants are warned to limit their consumption of many of the predatory fish, such as salmon and lake trout (EC and EPA 2005). Massive dredging projects will exacerbate the amount of toxic material already in the water, and may inhibit efforts to reduce contamination of fish in the Great Lakes.

Furthermore, about half of the sediments currently dredged in the Great Lakes are considered polluted or not suitable for open water disposal, and therefore must be properly disposed of in confined disposal facilities (CDFs). Twenty-six CDFs have been constructed around the Great Lakes since the 1960s in an effort to isolate contaminants in the dredged sediments from the surrounding environment (GLC 1999). This year all but two CDFs are expected to be at full capacity (GLC 1999). Should lake levels fall rapidly and dredging activity increase in magnitude, more CDFs would have to be constructed rapidly.

Dredging is an expensive venture. At the current rates of removal, the U.S. Army Corps of Engineers spends approximately $20 million for maintenance dredging of Great Lakes harbors and channels, removing 4 million cubic yards annually (GLC 1999). Current dredging rates in the U.S. run at a cost an average cost of $8 to $12 on average per cubic yard (GLC 1999). As demand increases, prices will likely rise, and current estimates are that dredging costs could exceed $100 million annually. U.S. estimates for the direct costs of a 4 to 8 foot drop in water level range from $138 million to $312 million, and
those of indirect costs (water supply to docks, docks extensions, and stormwater outfalls to the new water line) an additional $132 million to $228 million (UCS 2003).

Additionally, in some locations standard dredging is no longer practical. The Welland Canal, which connects Lake Erie with Lake Ontario, consists of a base of exposed bedrock as opposed to the soft sediment most easily removed by dredging. Any additional dredging of the canal would therefore require drilling and blasting of the rocky bottom, would take several years, and would increase the cost of dredging substantially (GLC 1999). If lake levels continue to fall, dredging would provide only a temporary and impractical solution.

Manufacturing Impacts

The eight Great Lakes states account for 40% of U.S. industrial water use, and water from the Great Lakes serves more than 75% of the total industrial demand in the basin (USGCRP 2003). The five major U.S. industries in the region dependent on a steady water supply include: steel production, food processing, petroleum refining, the manufacture of chemicals, and paper production. The eight Great Lakes states supply 33% of the U.S. manufacturing output, including 70% of the steel production and 6 out of every 10 cars produced in the U.S (USGCRP 2003). More than 60,000 U.S. and Canadian jobs depend on the transport of cargo through the region’s waterways. Reductions in lake levels would cripple the industries that depend on cargo transported through the lakes and that also depend on fresh water for their operations.

Keeping the Turbines Cool and Turning

Both the nuclear and hydropower industries on the Great Lakes are important energy producers for industries and individuals in the region. With the changing climate, water levels are expected to lower while water temperatures will likely increase, significantly affecting the electric power industry.

Increased water temperatures may require nuclear plants that depend on water to cool their turbines to sink their intake pipes lower into the lake to obtain cooler waters. There are currently 11 nuclear power plants with 18 reactors on the U.S. side, and four nuclear power plant sites with 21 reactors on the Canadian side of the lakes (Alliance for the Great Lakes 2004). As of 2002, 15.14 billion gallons (57.29 billion liters) of water were withdrawn from the Great Lakes per day for nuclear power usage, with all but 0.22 billion gallons (0.83 billion liters) or approximately 1.4% of the total water used being returned to the lakes (GLC 2002). Nuclear power is the second largest water user in the Great Lakes Basin, though this represents a small fraction when compared against the heavy water demands of the hydropower industry.

The hydroelectric industry in the Great Lakes region supplies approximately 25% of the electricity for Ontario, and 10% for New York State, and depends on specific water levels to run their turbines (GLC 2002). Hydropower is not only cheaper (in the U.S. it costs $0.85 per kilowatt hour, which is 50% of the cost of nuclear, 40% of the cost of fossil
fuel, and 25% of the cost of natural gas), it is a renewable resource. It is also cleaner to run than many other forms of energy production such as coal fired power plants, which makes it popular in the face of clean air standards. Approximately half of all the water withdrawn from the Great Lakes daily is put toward hydropower generation, though nearly most if not all of this water is returned to the lakes once it has passed through the plant (GLC 2002).

Significant problems arise with lower lake levels. A stipulation in the Boundary Waters Treaty of 1909 is that sufficient water be supplied to the hydroelectric industry in order to run their turbines and generators. Many diversions have been constructed along the Great Lakes to ensure a steady flow of water through the hydropower facilities in the region. There are currently five major diversions which transfer water either into or out of the Great Lakes drainage basin: the Ogoki, Long Lac, Chicago, Welland Canal, and the New York State Barge Canal (Indiana DNR 1996). The Welland Canal Diversion diverts water from Lake Erie to Lake Ontario bypassing the Niagara River and Falls, providing water for navigation, hydropower, and industrial and municipal water supplies. The increase in outflow from Lake Erie has reduced water levels by about 5.3 inches (13.5 cm), and has reduced levels in Lakes Michigan and Huron by 2.2 inches (5.6 cm), and in Lake Superior by 0.7 inches (1.8 cm) (Indiana DNR 1996).

Intra-basin diversions transport water to areas in the basin where it is heavily utilized. The Niagara Power Project diverts up to 375,000 gallons (1,425,000 liters) per second from the Niagara River to the Robert Moses Niagara Power Plant through conduits that run beneath the city of Niagara Falls (NYPA 2006). Approximately 5,660 cubic meters (200,000 cubic feet) per second of water flow from Lake Erie to the Niagara River. But The Niagara River Treaty signed between the U.S. and Canada in 1950 requires that a minimum of 2,830 cubic meters per second (100,000 cubic feet per second) spill over the falls during the daytime, which limits the ability of utilities to adapt to low flow conditions. If the water volume passing through the region declines, the treaty will either have to be renegotiated, affecting the tourist industry and the more than 14 million tourists the Falls attract, or the plant will have to run on less water. Conservative estimates based on milder climate conditions suggest that hydropower production could decrease by 15% by 2050 (Union of Concerned Scientists 2003). How long a plant can produce less power and still be considered economically viable is an important question to consider.

The St. Lawrence-Franklin D. Roosevelt Power Project maintained by New York State is not sustained by a diversion, but instead depends on the outflow of all five lakes to spin its turbines. Should outflow from one or more lakes be significantly reduced or cease altogether, the plant would no longer have a ready source of power generation. A five foot drop in lake levels would lead to a 20-40% reduction in river outflow through the St. Lawrence River (USGCRP 2003).

*The Chicago Diversion*
Although most of the diversions on the Great Lakes have been designed to promote shipping and hydroelectric interests, the Chicago Diversion serves a different purpose. For decades in the second half of the 1800’s, the Chicago Diversion served to transport wastewater and sewage from the city directly into Lake Michigan. Although the current was usually strong enough to carry the raw sewage offshore and away from the city, the contaminated contents of the river posed threats to the city’s drinking water supply and beaches during periods of heavy rain (IN DNR 1996). In the early 1920’s the flow of the river was reversed to remove the threats the contaminated water posed to the lake and the region.

The water that is now diverted via the Chicago Diversion no longer returns to the Great Lakes. Instead it is carried through a series of tunnels and canals into the Illinois River system (IN DNR). More than 2.4 billion gallons of water (9.1 billion liters) of freshwater are drawn daily by Chicagoans from Lake Michigan through the Chicago Diversion. A warmer, drier climate will increase demand for water both inside and outside the basin, increasing the demand for diverted water. A further complication is that the Chicago Diversion, which was an existing diversion exempted by the Boundary Waters Treaty, is under the jurisdiction of a U.S. Supreme Court decree which has resulted in many national and international disputes, and continues to be problematic in the decision-making processes for the Great Lakes (IN DNR 1996).

As long as there is a steady amount of inflow and outflow from the basin, water diversions have minimal impact on the Great Lakes water levels over time. However, should the water balance decline and evaporation rates increase dramatically, water diversions could exacerbate the effects of lower lake levels. The industries and individuals in the Great Lakes Basin will have to evaluate carefully the impact both inter and intra-basin diversions might have on the lakes and decide whether the electric power industries that depend heavily on diversions should or could continue to operate.

Deep Lake Water Cooling

A new energy industry operating out of Toronto has been using the cooler (4°C) lake bottom water to cool city office buildings. Intake pipes sit at a depth of 83 meters, 5 km offshore in Lake Ontario, and pump the cold lake water into the John Street Pumping Station in Toronto. The pumped deep lake water at the pumping station transfers the cool energy with the aid of heat exchangers to a chilled water supply loop that passes through city office buildings. Deep lake water cooling is not only a clean source of energy, (meaning it reduces greenhouse gases and air pollution directly through its supply and indirectly through its ability to reduce dependence on less clean energy sources such as coal and nuclear power plants), it is also renewable—the cool water drawn from the lake is then distributed through the city’s potable water system where it will eventually return to the lake (Boyce et al. 1993).

Increasing lake temperatures and lower lake levels will affect deep water cooling technologies. The thermocline in the lake, which develops during the warmer summer season and separates the upper surface mixed layer of water from the underlying year-
round 4°C deeper water, will shift further downward as lake temperatures in the region increase (Boyce et al. 1993). As a result intake pipes may have to be increasingly lowered to supply cool deep lake water to the city. Furthermore, increased temperatures in the region are also expected to increase the duration of summer stratification of the lake, which can lead to anoxic conditions in lake bottoms (UCS 2003). Anoxic conditions are a result of stratification, as the oxygen that is consumed by the bottom sediments in the deep cool lake water cannot be replenished by oxygen from the warmer surface waters. Because deep lake water cooling uses the water pumped from the deep lake as a potable water supply for the city, anoxic events which can result in foul-smelling and musty-tasting drinking water, and that might occur with more frequency due to future climate change, are occurrences with which deep lake water cooling technologies and city water supply will increasingly have to contend.

Diversity Diminishes

Though at one time viewed as unproductive wastelands that were often filled or drained, wetlands have gained recognition for their critical ecological contributions. Not only do they mitigate flood effects, recharge groundwater, and help maintain river flow during dry periods through the storage and slow release of water, these highly productive areas engage hunters, anglers, and bird watchers alike. Among their most important functions is their ability to absorb and store contaminants such as heavy metals and sulphur from acid rain. Excess nutrients such as nitrate can be stored and transformed in wetlands reducing their impact on water quality. Wetlands are also proving to be important stores of organic carbon. Canadian wetlands contain about 150 billion tons of carbon in the form of peat, which is 25 times the amount of fossil fuel carbon released each year by the entire world (Lemmen and Warren 2004). As long as wetlands remain saturated they have the ability to store and retain carbon, mitigating the release of carbon dioxide, a greenhouse gas, to the atmosphere.

Human intervention and alteration has reduced the area of wetlands in the Great Lakes region by approximately two-thirds within the Great Lakes states and Ontario. What remains amounts to about 1500 coastal wetlands, that encompasses approximately 1730 square kilometers, the majority of which surround Lakes Michigan and Superior (Canadian Wildlife Service 2002, GLWQB 2003). Wetlands are highly dependent on temporary, seasonal, and multiyear water level fluctuations to maintain diversity and overall health. Just as land in a floodplain depends on flood events to restore sediment and soil nutrients to the area surrounding the river, wetlands depend on the periodic rise and fall of water levels from the water bodies they surround (Van der Kamp and Marsh 2005). Periods of lower water levels expose bottom sediments which allow seeds within these sediments to germinate, whereas high levels saturate the ground and replenish nutrients and sediments making it suitable for the plants to continue to grow. Lake levels in Lake Ontario have remained stable since the creation of the St. Lawrence Seaway in 1960, and outflows have been carefully regulated for hydropower and shipping interests. While more stable water levels aid industry, they also may result in a reduction in wetland diversity and a loss of wetland functions (Canadian Wildlife Service 2002).
An enormous amount of research has gone into assessing the value of wetlands (Canadian Wildlife Service 2002). While wetlands produce some goods that have market value, such as peat and cranberries, they are largely difficult to assess because their worth comes more in the form of their societal or public value as enhancers of water quality and quantity. The difficulty in assessing wetlands for this value means that often wetlands are destroyed before their value is realized. However some useful questions can be asked, such as what it would cost to replace the filtering capacity of a Great Lakes coastal wetland in the region? The answer is likely millions of dollars. With the degradation of water quality that is expected with lower water levels, the filtration the wetland can offer the region becomes that much more important. The cost of wetland creation ranges from $20,000 to $40,000 per acre, yet this is more to replace wetlands that have been destroyed due to physical alterations such as draining or filling, and would be futile in the face of falling water levels. In addition, created wetlands frequently fall short of their natural counterparts in terms of habitat and water quality and quantity functions.

Wetlands can migrate or “chase” the changing shoreline when water levels fluctuate. The ability of wetlands to migrate and adapt to water level fluctuations, however, is determined by several factors. The first is the geomorphology or physical barriers that might impede migration. Wetlands that exist on gentle slopes with suitable substrate migrate relatively easily, whereas wetlands that exist on steep slopes with rocky substrate or that might encounter natural barriers or human alterations to an area such as levees, buffers, or pavement are unable to migrate (Mortsch 1998, Mayer et al. 2004). As much as 75% of Great Lakes shorelines have been “hardened” through the construction of breakwalls, groins, and retaining walls to make them resistant to erosion and flooding. While this provides shoreline stability, it changes sediment supply and availability to wetlands, while impeding migration.

Wetland migration is also dependent on the rate at which the water level changes, which must be slow enough for vegetation to reestablish itself. A rapid water level decline would require migration at a rate too high for most vegetation to successfully reestablish itself (Mortsch 1998). Wetlands routinely respond to water rises and falls within the range of a few feet over a few seasons or even a year, but falls not accompanied by a residual rise would leave exposed habitat to dry out (Mayer et al. 2004).

Knowing which of the coastal Great Lakes wetlands have a gentle enough slope and suitable substrate on which to migrate would be helpful in predicting the likelihood of wetland survival. If the water level decline is slow enough, many wetlands on gentle slopes with sufficient sediment supply to sustain them might successfully migrate. Furthermore, there is the possibility that if lake levels lower beyond natural or human barriers, new habitat might be available for wetland species colonization.

Wetland migration further depends on the overall health of the wetland (Mortsch 1998). Wetlands that have been fragmented or otherwise altered due to agricultural and urban development, may already be functioning at a marginal level, and the biota will likely not survive the change in water levels and a subsequent forced migration.
Wetlands experience high rates of evapotranspiration, a term that refers to both evaporation and plant transpiration. Wetlands require precipitation or replenishment by groundwater to keep water moving through the system, and to continue to perform water quality services such as reducing turbidity and lowering the pollutant load. If precipitation in the basin is decreased by hot, dry air masses carrying water out of the basin, and if wetlands lose their connection to the groundwater because of falling water tables, their overall health and likelihood of survival will further decline.

Wetlands that have dried out present other risks to the region. Contaminants that have accumulated in wetlands such as metals (cadmium, copper, lead, and zinc) may be released by acid rain, and there may be a reduction in the ability of wetlands to transform nitrate, the most mobile form of nitrogen (UCS 2003). Carbon stored in wetlands when they are saturated can be released when they are dried to the atmosphere through fires or decomposition, which only adds to an atmosphere already experiencing increasingly high levels of carbon dioxide. On the positive side, however, drier wetlands may aid in the retention of mercury through an increase in oxygen which can bind to the metal and immobilize it (UCS 2003).

A reduction in the number of wetlands surrounding the Great Lakes will affect the diversity in the region, and certainly the lakes as a whole. The wetlands that have survived around Mono Lake have been revived somewhat by the increase in lake levels, though the quality and functions of vegetation and open water has been altered, and they will likely never attract the numbers or diversity of waterfowl they once did.

**Individual Interests**

Individuals living in and around the Great Lakes Basin will certainly feel the effects of considerably lowered lake levels. Drinking water supplies will be affected by changes in water quality and quantity. Shorefront properties may diminish in value, though new shorefront property for development may be opened. Larger beaches may prove to attract more tourists to the area, but decreases in water quality and quantity may drive them away. Registered recreational boaters in the U.S., 34% of whom have their boats registered in the Lakes states as of 1992, may risk hull damage as a result of more shallow lake levels (USGCRP 2003). Marinas may have to invest in costly private dredging and may need to extend docks to stay in business. Impacts will undoubtedly affect wildlife which would in turn be felt by hunters, anglers, and outdoor enthusiasts alike. Industries that experience cost increases due to increased shipping and/or electricity costs may be forced to make reductions in workforce, productivity, and may pass along increased costs to the consumer.
Part 3: Decision-making and the Future

The International Joint Commission

The international ownership of the Great Lakes adds a further degree of complexity to the low water scenario. The difficulty of making decisions in the face of rapidly lowering lake levels is confounded by two countries with different leaders, decision making processes, and priorities. Depending on the rate of lake level decline this is an added crucial variable that may affect successful overall lake management.

In the past this complexity has been addressed by the International Joint Commission (IJC). The IJC was established in 1909 with the Boundary Waters Treaty “to help prevent and resolve disputes relating to the use and quality of boundary waters and to advise Canada and the United States on related questions.” The Boundary Waters Treaty empowers the International Joint Commission, an independent, binational organization, to regulate works on either side of the Canadian-U.S. border which would adversely impact interests on the other side. The priority interests in the Treaty which the IJC must protect include: 1) domestic and sanitary purposes, 2) navigation, 3) hydropower and 4) irrigation purposes. The IJC also promotes the priorities put forth in the Great Lakes Water Quality Agreement to protect the biological, chemical and physical health of the lakes.

The IJC may establish individual committees to make recommendations, though it is bound by the priorities in the Boundary Waters Treaty in their decision making. Any ruling made by the IJC encompasses projects that may affect boundary or transboundary waters and their regulation, or that may resolve any disputes over water resources. Once the IJC makes recommendations, it is up to the individual governments to decide how to respond and what policies to implement.

De Loe and Kreutzwiser (2000) question the institutional constraints the region might have to adaptation. They cite a 1993 report by the Levels Reference Study Board that developed a set of guiding principles to be used by the IJC to “enhance management of future water levels issues.” One of these principles was a “full recognition of the potential for reduced water supplies due to climate change.” The Commission did not include this principle in its report to the federal governments stating that some of the principles differed in “some fundamental respects from those found in existing international agreements such as the Boundary Waters Treaty” (IJC 1993).

The Science Advisory Board issued reports in 1989, 1991, and 1993 to the IJC projecting the impacts climate change would have on the Great Lakes system and the region in the form of socio-economic impacts. In 1997 the IJC released a document entitled “The IJC and the 21st Century” in response to a request by both Canadian and U.S. governments “to provide proposals on how it might best assist the parties to meet the environmental challenges of the 21st century” (IJC 1997). Climate change was found to be one of the
key issues that may affect transboundary relations in the future. As the impending impacts of climate change have become more accepted, the IJC requested that the Great Lakes Water Quality Board produce a report with advice as to how to manage the implications and impacts of climate change on Great Lakes water quality (IJC 2003). The document has been published and is available to the public. While the priorities set forth by the IJC are clear, and the Commission is working to recommend and incorporate new priorities this century, the design, modification, and enforcement of regulations still remains the responsibility of each country’s respective government, and relies on agreement between them for implementation.

Conclusions

It is clear that industries, ecosystems, and individuals will be impacted by significantly lower water levels. Reductions in limits on cargo for shipping transport would affect the shipping industry and manufacturing industries that rely on the more inexpensive and environmentally friendly means of transporting large volumes of material as compared with railroad or truck transport. The electric industry would have to adapt to lower flow regimes and may have to dig deeper to find water to run its turbines and to cool its nuclear reactors. Diversions in and out of the basin would have to be carefully monitored and adjusted for increasing rates of water loss. Wetlands would suffer increased habitat loss and decreased diversity, and would be compromised in their ability to filter and protect the lakes from toxins. Wetlands would further experience a loss of appeal to wildlife and those who enjoy them for recreation. Individuals would face an array of damaging socio-economic impacts. International decision-making processes would have to be expedited, possibly against the interests of the individual nations.

There are signs of positive collaboration. In December the governors of the eight states surrounding the Great Lakes signed a joint agreement that prohibits the direct export of water out of the basin for commercial or other interests. This action sets a precedent, now and in the future, that lake water in the basin will be kept in the basin and not exported to increasingly thirsty cities nationwide as the climate continues to warm. Cooperation and collaboration will be critical in the future as water shortage issues arise.

While the prospect of significantly lowered water levels in the Great Lakes may never be fully realized, to deny this possibility could be equally as damaging. The more prepared North America is for climate change and all of its scenarios, the more likely it is that successful strategies will be available to address developing impacts on citizens, industry, and the environment.
Works Cited


Great Lakes Environmental Research Laboratory (GLERL), 2004. Lake Level Modeling under Climate Change, Fact Sheet.


Figure 1. Diagrams illustrating water balance. The top shows conditions where precipitation occurs over evaporation, yielding an open, overflowing lake. The middle diagram shows a situation where evaporation starts to exceed precipitation, causing the water body to reach a closed lake threshold. In the bottom diagram, conditions are such that evaporation exceeds precipitation, establishing a closed lake where evaporative impacts are magnified. From Lewis 2006.
Figure 2. Reconstruction of the paleogeography of the Huron, Erie, and Ontario basins at 7600 14C BP showing posited shoreline of the closed lowlands (yellow) relative to potential open lake shorelines (red) and present shorelines (white). Paleotopography and paleobathymetry were digitally reconstructed from a digital elevation model of the modern Great Lakes by removing the effects of a post-7600 BP glacial rebound using geographic information system data processing. From Lewis et al. 2006.
Figure 3. Diagram illustrating the shifting of air masses due to climate change in the past. The dry arctic incursions traveled further south between 7900-7000 14C BP, while dry Pacific incursions pushed further east until 7000 14C BP. These incursions would have resulted in increased evaporation rates in the Great Lakes region during this time period. Similar shifts in air masses to these could occur in the future due to increasing temperatures as a result of climate change. From Bryson and Hare, 1974.