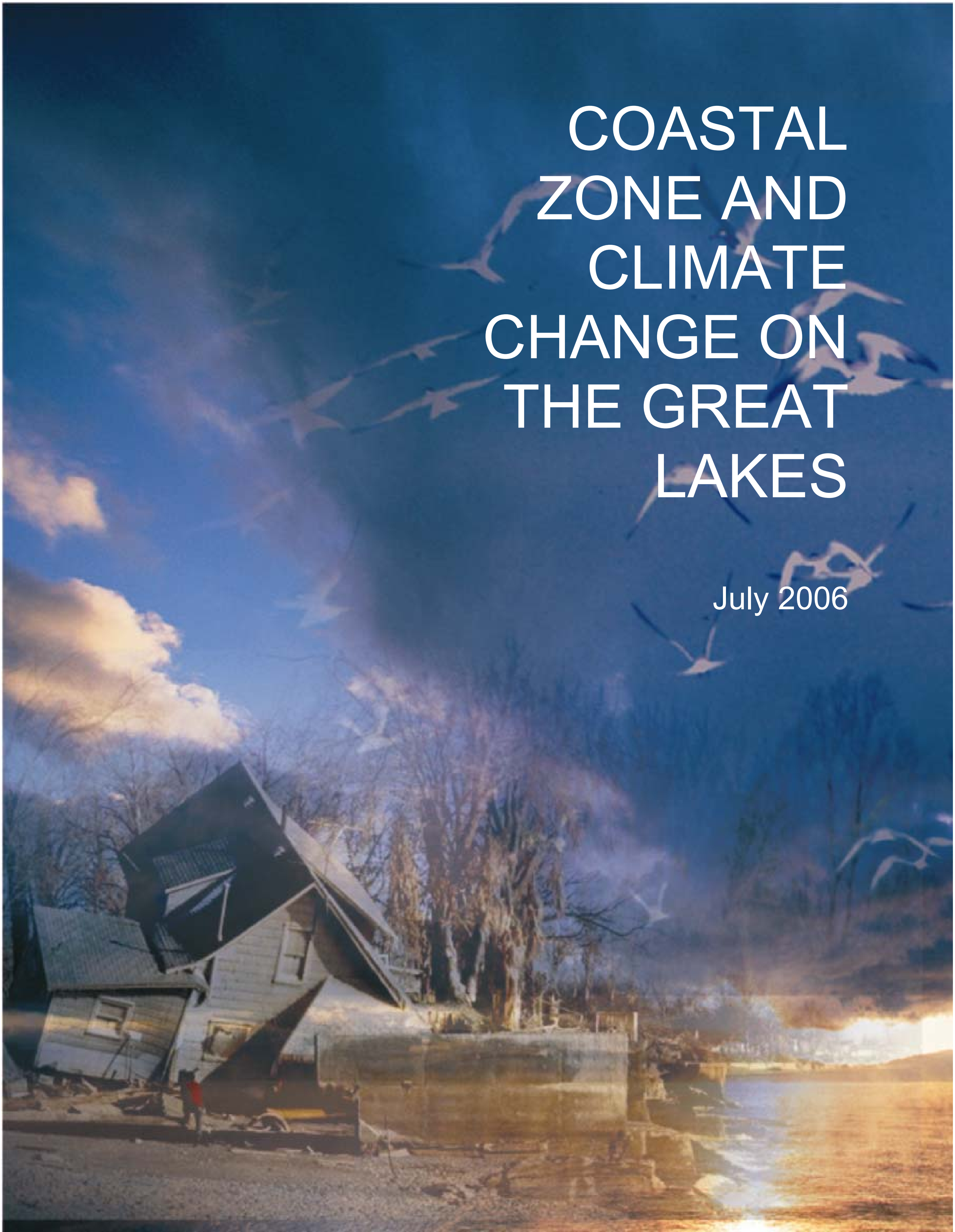
COASTAL ZONE AND CLIMATE CHANGE ON THE GREAT LAKES

July 2006



COASTAL ZONE AND CLIMATE CHANGE ON THE GREAT LAKES

FINAL REPORT

Submitted to:

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EXECUTIVE SUMMARY

Climate change is a feature of the planet Earth and has been going on since the planet was formed. Within the recent past (Pleistocene 1,8 million to 8,000 years BP and Holocene 8,000 to present), there have been warm and cool periods, and the Great Lakes region has experienced periods in which the land was covered in ice. Since the last ice age approximately 10,000 years BP, the land has risen, lake drainages have changed and the climate has gone through periods of warming and cooling. In the past hundred years, as a result of human activities, greenhouse gases in the atmosphere have increased to levels that scientists have concluded are changing our climate. The rate of change is faster than that which occurred in the Pleistocene, and our coastal communities are vulnerable to the impacts of these changes.

Prior to European settlement in the Great Lakes basin, First Nations people utilized the resources found in coastal locations and evidence of their presence can be found in many locations from the rivers draining into Lake Ontario to the rocky shores of Lake Superior in Pukaskwa National Park. Their impact on the coastal area was minor and there was no impediment to the movement of fish or wildlife. Much has changed since European settlement and the Great Lakes basin now is home to approximately 31% of Canadians. Major cities such as Toronto, Hamilton, Sarnia, Windsor and Thunder Bay are located on the shores of the Great Lakes and are very dependent on the lakes for their fresh water supply, for marine transport and for recreation.

This project set out to examine the impacts of climate change on coastal communities. We have researched the literature, organized workshops with expert speakers and have sought input from community representatives. We wished to determine what impacts may occur in the foreseeable future (100 years) and what we can do to adapt to them. We examined the historical climate records for the Lake Ontario, Erie, Huron and Superior regions and examined information for eleven coastal sites: Presqu'ile Provincial Park, Toronto, Hamilton, Long Point, Point Pelee, Walpole Island, Goderich, Sturgeon Bay, Sault Ste. Marie, Pukaskwa, and Thunder Bay. Workshops were held in Belleville, Toronto, Port Rowan, Parry Sound and Sault Ste. Marie and a total of 41 presentations concerning the Great Lakes were given and are available on CDs available with this report.

The climate changes that can be expected to occur with a doubling of CO_2 levels during the 21st century are warmer temperatures (annual increase of 2-5^{0}C) and increased precipitation (up to 15% more annually and 25% in some seasons) with more falling as rain than occurred in the 20th century. It is expected that as a result of a shorter winter with warmer temperatures, and a warmer climate overall, there will be increased evaporation resulting in a general lowering of water levels (up to 1 m) of the Great Lakes. The warmer air temperatures will result in warmer water temperatures, particularly in shallow coastal waters and this will affect the timing of the seasonal mixing of water that occurs in the spring and fall and keeps the deeper waters oxygenated.

The adaptation options that are available to coastal communities vary considerably depending on their size, location and other pressures that may influence their vulnerability. For instance, heavily urbanized areas will now be vulnerable to severe rain events and this should be reviewed in light of recent high intensity storms such as the August 2005 rain event in north Toronto that resulted in considerable loss and damage to roads, sewers and buildings. Likewise the January 1998 ice storm in eastern Ontario and Quebec had a major impact on hydro transmission facilities and water control devices on dams. Adaptation options are available to reduce the impacts of future ice storms.

Adaptation opportunities can improve the situation for some coastal communities. Warmer winters will reduce heating costs and allow for a reduction in salt use on roads, improving water run-off quality. Lower snowfall and more rain during winter months should serve to cleanse urban areas and reduce the spring run-off toxic surge that has been a phenomenon of urban areas for many decades. Longer summers will allow coastal resorts to have longer seasons with the associated economic benefits, though lower water levels may result in marinas having to dredge harbours or relocate their operations. Both commercial and recreational fisheries may be able to expand their operations with increased productivity of coastal waters, provided that pollution levels are reduced, wetlands protected and new fish stocks such as warm water species (like Smallmouth Bass) are utilized. The presence of invasive non-native species (Grass Carp and Zebra Mussel) is an increasing threat that is likely to change the lake ecology significantly, while impacts to other ecosystem components are unpredictable.

To properly address the threats and opportunities to coastal communities will require the full cooperation and financial commitment of federal, provincial and local governments. Local communities can assist in providing direction. They have the knowledge of local systems though often not the resources and expertise available to upper tier governments. The most significant impact of climate change is likely to be on water levels. These will continue to fluctuate seasonally and inter annually and will at times drop below historic lows. Low water levels will affect riparian properties and waterfronts and there must be a major effort to introduce legislation regarding ownership of newly exposed lake beds. An adaptation option may require the regulation of water levels in Lake Huron with control devices near its outfall at Sarnia. However, regulating water levels will impact and put at risk the natural processes of coastal wetlands.

The increased frequency and size of extreme weather events is likely to have major impacts on coastal communities and preparing for such events should be a priority. Actions include updating and revising (as required) design criteria, codes and standards for structures and facilities such as culverts, bridges, and water treatment plants as well as community disaster management planning. Prevention is more cost effective than rebuilding or restoration, so all new coastal initiatives should be designed with the effects of a changing climate in mind. Many changes have been made to coastal communities in the past two decades as a result of the implementation of remedial action plans. Improvements to water quality and wetlands have been made, but the ecosystems are dynamic and continue to change. Therefore it is imperative that monitoring programs be in place to measure the adaptation actions and the environmental responses to ensure that we continue to learn how best to adapt to a changing environment.

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1.0 INTRODUCTION

Most Canadians and millions of Americans live in coastal towns and cities in the Great Lakes basin. Climate change will impact every ecosystem and there are significant ecological, cultural, social, and economic implications to people living in towns like Parry Sound and Trenton and in cities like Toronto, Sault Ste. Marie and Thunder Bay. In addition to climate change, it is important to remember that continued urbanization and associated industrialization resulting in pollution, land and water modification and loss, invasive species, and over-harvesting of some species will add to the suite of eco-physiological impacts caused by climate change.

Climate change is a complex phenomenon which occurs as a result of both internal variability within the earth's climate system and natural (i.e., changes in solar output, volcanic activity), as well as anthropogenic factors. The human induced contribution to climate change and warming of the atmosphere is of particular concern, as the scientific consensus in the Third Assessment Report of the Intergovernmental Panel on Climate Change (Houghton et al., 2001) is that most of the warming observed over the past 50 years is attributable to human activities. In particular, increased emissions of greenhouse gases to the earth's atmosphere (e.g., carbon dioxide, methane, and nitrous oxide) generated by burning fossil fuels and a smaller contribution from land use change (e.g., the conversion of forest land to urban areas) are primary contributors to climate change and global warming. A number of models (e.g., Folland et al., 2001; Houghton et al., 2001) indicate that natural and human-caused global warming is increasing at an unprecedented rate, elevating temperature, altering precipitation amounts and intensity, and increasing the frequency and intensity of severe events such as extreme precipitation, heat waves and drought. In Ontario, for example, the mean annual temperature has increased by approximately 0.6^{o}C since the start of the 20th century and Global Climate Models (GCMs) project an additional warming of 2 to 5^{o}C for Ontario by the latter part of the 21st century with increasing emissions of greenhouse gases (Smith and Lavender, 1998). Annual precipitation has also increased in some areas of Ontario by as much as 25% since the start of the 20th century (Zhang et al., 2000; Vincent and Mekis, 2006). Similarly, increases in heavier precipitation are being detected in some areas of Ontario, although many of these changes are not statistically significant (Vincent and Mekis, 2006; Stone et al., 2000).

1.1 The Project

The purpose of the Coastal Zone Climate Change and Adaptation Project is to identify coastal features and processes on the Great Lakes, which are likely to be affected by climate change and to determine sustainable management practices that will reduce the vulnerability of these features and processes. The project will provide an assessment of knowledge on adaptive management plans and activities that can be used in coastal areas such as provincial and national parks, marinas, wildlife areas, important bird areas, significant spawning and nursery areas for fisheries, and areas of concern on the Great Lakes. Common names are used throughout the text but scientific are provided in Appendix A. The project is limited to the coastal areas of Ontario within Lakes Ontario, Erie, Huron, and Superior.

The potential adaptive management actions employed to sustain coastal zones in the Great Lakes Basin are expected to be different between the four Canadian Great Lakes. Therefore it is important to investigate sites within each drainage area, which reflect multi-regional interests, and the differences that can be expected to occur in coastal zones given different regional climates. The following are the chosen areas:

- Lake Ontario – Toronto Area of Concern, Hamilton Area of Concern, Presqu'ile Provincial Park;

- Lake Erie – Long Point Important Bird Area/Provincial Park, Point Pelee National Park, St. Clair Marshes Important Bird Area;

- Lake Huron – Goderich Harbour, Sturgeon Bay; and,

- Lake Superior – Thunder Bay Area of Concern, Pukaswa National Park and Sault Ste. Marie (Figure 1).

A number of direct climatic factors are likely to drive changes in the coastal zone such as: (a) air temperature, precipitation and wind, and (b) indirect factors such as (c) water height, range, seiche effects, currents, water temperature, range, seasonality, thermoclines and wave height and the frequency of extreme events There are changes in the timing of freeze up and the length of time there is ice cover and this has a major impact on storm damage and turn over of the epilimnion and will be discussed. There are a number of other important parameters that are not directly climatic, but are in part indirectly driven by climatic factors, such as changing land use, agricultural and urban activities. These include such factors as: sediments, riverine flow, coastal movement, siltation, nutrients, and bacteria. There are also other factors such as the presence of introduced non-native species that are able to succeed in the Great Lakes basin more easily because of changed climatic conditions. These may affect human health, aquatic and terrestrial ecosystems (Auld et al.; Doka and Minns; MacIssac; Petrie [Table 1])

To assist Canadians in their efforts to identify and address the important questions about climate change, a number of agencies and organizations partnered in 2002 to help Great Lakes coastal communities develop climate change adaptation options. The primary objective of this project is to evaluate potential changes that could occur as a result of changing climate various climate change scenarios and create a list of potential adaptation options that can be used by land owners and managers in coastal zones of the Canadian Great Lakes. The project involves:

- Development of site-specific case studies describing recent historical climate variability, trends and climate change in the 21st century;

- Identification and description of potential and known impacts based on the conditions described in each of the case studies;

- Completion of adaptation workshops in communities around the Great Lakes to identify and discuss impacts and adaptation options; and,

- Development of information extension and transfer tools.

The potential impacts of climate change in the Great Lakes region are extensive, and have been reviewed, with varying degrees of thoroughness in a number of studies (i.e., Beveridge et al. 2004, Galley 2004, Kling et al, 2003, Lemmen and Warren 2004, Mortsch et al. 2003, Scott and Suffling 2000, Smith and Lavender 1998, Sousounis and Bisanz, 2000). This project deals largely with impacts that are biological in nature and for which there may exist feasible and practical management options.

1.2 Workshops

The purpose of the project study workshops was to bring together speakers and local representatives to discuss and identify issues that might be caused by a changing climate and adaptation options that might be relevant to each location. The local representatives were invited based on their expertise, business area, and on what were thought to be issues of importance to each site. Land managers were among those invited, as well as academics, industry personnel, Ontario Conservation Authorities, community based environmental organizations, and government employees from all levels of government. An effort was made to try and make each workshop distinct in terms of the content of presentations (Table 1) and a list of speakers at the workshops is presented in the table. The intent was to provide a “bottom-up” multi-stakeholder approach to examining climate changes in coastal areas of the Great Lakes. The presentations at each workshop are provided in the CDs accompanying this report, and are referenced by author and Table 1 in the text. In all, about 250 people attended the workshops and their names and affiliations are provided in the accompanying CD.

The five workshops held during the course of the project were as follows:

- Belleville, Quinte Conservation. March 4, 2003;
- Parry Sound, Township of the Archipelago, August 27, 2004;
- Long Point, Long Point Region Conservation Authority, March 30, 2005;
- Sault Ste. Marie, Holiday Inn. September 9, 2005; and,
- Toronto, Toronto and Region Conservation Authority November 22, 2005.

Human activities are often compartmentalized into different business areas such as forestry, agriculture, fisheries or government. Changes in climate affect different businesses in different ways and the potential to adapt to these changes differs across the country. Adaptation can be reactive or anticipatory (Smit et al. 2000) and while humans can make adjustments in either mode, organisms in general only respond reactively. We have attempted to identify the impacts that climate change will have on different business areas and the options that may be available to adapt to these changes. These are summarized in Tables 2 to 9 and many of the issues, impacts, and adaptation options were discussed in the workshops. The references to particular workshop presentations are made in the tables. The cross-referencing is not exhaustive but provides a key to looking up particular presentations on the CDs provided with this report. The intent is to provide a "bottom-up" multi-stakeholder approach to examining climate changes in coastal areas of the Great Lakes (Burton 1998). Mitigation or reduction of greenhouse gas emissions from human activities is an important and necessary complement to adaptation actions that are required to reduce and slow the rate of climate change. This study focuses only on the adaptation strategies that will need to be considered in the Great Lakes coastal zone.

1.3 Web Site

An informational study web site was developed during the project. It can be reached at http://www.public-participation.ca/Climate_Change_001.htm. The summaries of our workshops are available on the site together with ongoing updates regarding activities of the group, publications etc. It is proposed that information generated during this project will also be made available on an Ontario Ministry of Natural Resources website. The site has been visited by an average of 15 visitors per month since it was started and the number of pages viewed and the country of origin of visitors is provided in Appendix B.

2.0 CLIMATE CHANGE AND THE COASTAL ZONE

2.1 Recent Changes in Climate within the Great Lakes Basin

The Great Lakes climate is essential in shaping the social, cultural and economic development of the region, and in sustaining its natural ecosystems. Plants and animals respond to the conditions in which they live and climate is one of the drivers that organisms respond to. These drivers include changes in temperature and precipitation patterns and their variability, extreme weather events and indirect effects of changes in weather including water levels and water temperature. Other factors such as soils, the landscape, and other species are other factors that influence the distribution and abundance of organisms (including man). Human activities are often compartmentalized into different business areas such as forestry, agriculture, fisheries or government. Changes in climate affect different businesses in different ways and the potential to adapt to these changes differs across the country.

Over the past century, there has been mounting scientific evidence that the climate is changing at the global and regional scales, and notable changes to the regional Ontario climate are also being detected. Since 1900, mean annual air temperatures have increased in the Great Lakes Basin by approximately 0.7°C with most of the warming observed in winter and spring, and the least in fall. Increases in minimum temperatures have generally been greater than those in the mean and maximum temperatures. The frost-free period has lengthened. Increases in total annual precipitation of 5 to 25% have been recorded over the region in the past century, but the ratio of snow to total annual precipitation has decreased while rainfall the number of days with rainfall and total precipitation have both shown significant increases in most parts of Ontario (Vincent and Mekis, 2006). Snow cover – depth, areal coverage, and duration, has been reduced, while ice coverage on regional lakes has declined with later dates of freezing of lakes and earlier ice-off dates. Low water levels in Great Lakes were experienced from 1999 to 2001, as a result of very dry and abnormally warm conditions (record warmth in 1998 and near record low water levels in 2000). The warming winter temperatures have also led to an earlier onset of the spring melt/freshet (Smith and Lavender, 1998; Sousounis and Bisanz, 2000; Mortsch et al., 2003; Mortsch et al., 2005; Kling et al., 2003)

However, as will be shown in the four Great Lakes' regional discussions within this report, the 20th century changes in temperature and precipitation have not been uniform across Ontario and also cannot be expected to be uniform in the future changing climate. Although extreme precipitation has been determined to be increasing in the U.S. (Groisman et al., 2001 and 2005; Kunkel et al., 1999; Kunkel, 2003; Kling et al., 2003), no consistent trends in extreme precipitation have been detected in Canada or the Great Lakes basin. Although increases in heavier precipitation are being detected in some areas of Ontario, many of these changes are not statistically significant (Vincent and Mekis, 2006; Adamowski and Bougadis, 2003; Stone et al., 2000; Zhang et al., 2001).

2.2 Climate Change Scenarios for the Great Lakes Basin

Many of the climatic conditions and extreme events that have occurred in the climate records of the past century act as analogues for what could be experienced with increased frequency and intensity in the region during the 21st century. Determining how the climate system will respond to increasing atmospheric concentrations of greenhouse gases requires the development of future climate change scenarios. These scenarios are best described as plausible, coherent, internally consistent descriptions of a possible future state of the world, and are used to assess potential impacts and adaptation responses and acknowledge this uncertainty (Mortsch et al., 2005). A number of scientific techniques can be used to develop these future climate scenarios. These include spatial and temporal analogues, application of systematic changes to observed climate data with guidance from Global Climate Models (GCMs), statistical downscaling techniques applied to coarser resolution GCM output and dynamical downscaling methodologies including Regional Climate Models (RCMs). However, the most common climate change projections used in climate impact assessments are developed from complex Global Climate Model (or GCM) output. The spatial resolution of GCMs is relatively coarse (generally on the order of several hundred kilometres) and hence GCMs are only able to capture the large-scale features of the climate system. Higher resolution Regional Climate Models (RCMs) are better able to simulate local climate and forcing features and processes, but computational demands are greater with their use and their output may not always be available for use in the climate impact assessment.

Climate change scenarios derived from GCMs were used in a five year (2000-2005) study commissioned by the International Joint Commission to assess and evaluate the current criteria used for regulating water levels and flows on Lake Ontario and in the St. Lawrence River. Twenty eight candidate scenarios from six GCM international modelling centres were considered in the scenario selection for the Lake Ontario-St. Lawrence (LOSLR) study. The Great Lakes-St. Lawrence Basin area-averaged changes in annual and seasonal temperature and precipitation were plotted in scatter plots (Figures 1a to 1e) to guide in the selection process. Four coupled atmosphere-ocean GCM experiments were chosen to best represent the bounds of climate change uncertainty within the basin. The four experiments represented two different emission scenarios from the third generation United Kingdom Hadley Centre (HadCM3) and Canadian Centre for Climate Modelling and Analysis (CCCma) model runs. The four different annual "extreme" temperature and precipitation scenarios averaged over the basin for the 2050's represented the following range of future climate conditions:

1. Warm and Wet — the greatest warming and wettest conditions
   GCM and SRES emission scenario: HadCM3 A1FI

2. Warm and Dry — the greatest warming and driest conditions
   GCM and SRES emission scenario: CGCM2 A21

3. Not as Warm and Wet — the least warming and wettest conditions
   GCM and SRES emission scenario: HadCM3 B22

4. Not as Warm and Dry — the least warming and driest conditions
   GCM and SRES emission scenario: CGCM2 B23

For further information on SRES Greenhouse Gas Emission Scenarios (SRES) used in climate models, please refer to Mortsch et al. (2005).

The area-averaged annual and seasonal temperature and precipitation changes over the Great Lakes-St. Lawrence Basin for the four selected scenarios are summarized in Table 10. All scenarios project annual and seasonal warming in the region with three of the four scenarios indicating the greatest warming will occur in the winter. The warm and wet HadCM3 A1FI scenario projects the largest temperature increases will be during the summer rather than the winter. Similarly, annual and seasonal precipitation is projected to increase with each model scenario, except during summer with the warm and dry scenario.

The gridded GCM temperature and precipitation “change” fields for the 2050's, where changes are relative to the 1961 to 1990 baseline model climate, were made available from the LOSLR study for use in this Great Lakes coastal zone climate change study. They were subsequently used to provide plausible future climate scenarios for each of the Great Lakes study regions in the 2050's.

These scenarios, as well as other available GCM climate change projections, indicate warming of annual average temperatures by 2 to 4°C and increases in total annual precipitation by approximately 2 to 13% over the region by the middle of the 21st century. Rainfall is expected to increase, while snowfall decreases. The frequency of heavy lake-effect snow in some of the traditional Great Lake snow belts will be significantly reduced by the 2080's, and could be accompanied by an increase in winter lake-effect rain events, which are now most frequent in the autumn (Kunkel et al., 2000). Scientists project that these regional and global changes in the “average” climate will also be accompanied by an increased frequency and severity of extreme weather events such as heat waves, drought and extreme precipitation leading to flooding. However, even with increased precipitation, warmer temperatures will likely lead to increased evaporation loss, contributing to significant reductions in Great Lakes, river and stream water levels. By late in the 21st century, water levels on Lake Superior could be reduced by almost ½ m, close to 1 m on Lakes Ontario and Erie, and almost 1.5 m on Lakes Michigan-Huron (Mortsch et al., 2003). A decline in duration and extent of ice cover and reductions in snow cover extent are also expected. Changes in intensities and tracks of storms, diminishing ice cover in the Gulf and increases in freeze-thaw events will contribute to the erosion of coastlines. Although the total number of winter storms is expected to decrease in the future climate, an increase in the number of intense events is projected (Lambert. 2004). Higher wind speeds with intense winter storms and possibly with other types of more frequent and intense extreme events could also lead to an increased risk in infrastructure damage or failure of our built infrastructure.

3.0 CLIMATE CHANGE IMPACTS, AND ADAPTATION WITHIN THE GREAT LAKES BASIN

Climate change, coupled with increased urbanization and population growth, is expected to have a dramatic impact on human and natural systems health, the quality and quantity of our water resources, the regional economy and our built infrastructure in the Great Lakes Basin. The discussions in this report and case studies that are presented focus on the Ontario Great Lakes coastal zone's vulnerability to current climate variability, projected changes in climate and its impacts on the region, and adaptation strategies to address these changes.

In particular, we have attempted to identify the impacts that climate change will have on different business areas and the options that may be available to adapt to these changes. These are summarized in Tables 2 to 9 and many of the issues, impacts, and adaptation options were discussed in the workshops. These are brought out in discussions relating to the different case studies in this report. The references to particular workshop presentations are made in the tables. The cross referencing is not exhaustive but provides a key to looking up particular presentations on the CDs provided with this report.

3.1 Air Temperature

The changes in air temperature are not expected to be consistent through the year, with most scenarios projecting winter warming to be greater than increases in summer temperatures. Increases in night time temperatures will be greater than in daily maximum temperatures. This will result in longer growing seasons and increased biological productivity providing that other factors are not limiting. This will have impacts on agricultural activities in the coastal zone such as the greenhouse operations on the coast of Lake Erie, the various wineries and other soft fruit operations and a shift northwards of many warm weather crops such as tomatoes, peppers, melons, aubergines and peanuts. There is likely to be a northward shift of many non-agricultural species with those weedy species and annuals moving more rapidly than long-lived tree species (Malcolm et al. 2002). Plants will start growing earlier in the spring with earlier germination, leaf out and flowering times. If drought conditions occur in mid to late summer there may be a decline in productivity and some species may not be able to adjust to the new climate. Milder winters will certainly have an effect on over-wintering insect pests, allowing many species to proliferate and have a major impact on agricultural and forestry production.

Warm weather will affect the proportion of precipitation that falls as snow, and more winter rain will result in a reduced snow pack and less likelihood of large spring run-offs. This may result in water shortages later in the summer. Where winter access to remote communities depends on the use of lake ice to transport goods, this is less likely to be a safe option. Warmer summers will result in more photo-chemical smog and increased pollution presenting health problems to the vulnerable (the young and elderly in particular). The warm summers are already resulting in a greater demand for electrically driven air conditioning such that peak demand now occurs in the summer rather than the winter. This will have obvious implications to the updating of the electrical energy system in Ontario.

Increased summer temperatures will see an ever increasing need for coastal parks and ensuring water is clean and swimmable. The ever increasing population in the Golden Horseshoe at the western part of Lake Ontario and demand for recreational outlets is currently putting the present park system under considerable pressure, and the expansion of facilities within close proximity to the major population centres should be a major concern for decision makers.

3.2 Precipitation

Climate change scenarios for projected changes in precipitation are more variable than temperature scenarios, although climate models project an overall increase in precipitation, there are likely to be major differences in impacts depending on the location around the Great Lakes. If there is an overall increase in precipitation over evaporation and evapotranspiration, then there will be an increased flow between the Great Lakes that may result in increased scouring through places such as Lake St. Clair. River and stream outflows to the Great Lakes may be affected by increased flows that will cause physical changes to the watercourses and result in increased sediment loads to deltas. This has implications to all manner of coastal facilities.

If drought conditions in mid to late summer occur, there will be major implications for municipalities and farmers around the Great Lakes. Water conservation measures are already used regularly by some coastal and inland communities, but water quality as well as water quantity is relevant. Contamination of ground water through poor waste management practices and the effect of warmer temperatures on the growth of blue green algae in coastal waters is necessitating the upgrading of water treatment facilities. Increasing extreme events is also stressing drainage systems and municipal infrastructure, and the costs of insurance claims of flooded basements and buildings continue to increase dramatically. With an increased risk of extreme weather events and changing/more variable precipitation patterns in a future climate, there is an increased risk of failure of our built infrastructure. New infrastructure will need to be designed for a changing climate, and older infrastructure may need to be upgraded or replaced to reduce these risks of failure under a changing climate (Auld [Table 1], Auld and MacIver, 2006; Auld et al., 2006a and 2006 b).

Increased precipitation will also affect the amount of pollutants such as selenium washed from the atmosphere (Petrie [Table 1]). If snow accumulates during the winter, it holds quantities of pollutants and this is often the cause of a serious toxic flush associated with spring melt and break-up. This affects fish and other aquatic organisms. This may change as more winter precipitation occurs as rain, resulting in a less severe toxic flush in the spring and ameliorating the impacts of pollutants on aquatic ecosystems.

Changes in precipitation patterns will have impacts on the various agricultural activities around the Great Lakes. Farmers will adapt to such changes by using different varieties of crops and changing irrigation and drainage practices (Oliver [Table 1]). Natural systems may be slower to adapt to such changes. Weedy species are adapted to colonize extreme environments while species characteristic of stable climax plant communities will be much slower adapting to new conditions. One can expect to see the northward progression of Carolinian species in the longer time periods (many decades) providing that their other requirements such as soils are met.

3.3 Wind

Although the total number of winter storms is expected to decrease in the future climate, the number of intense storms is projected to increase. With changing wind patterns, storm tracks projected to move northward and the possibility of increased winds with other types of extreme wind events, average, as well as maximum, wind speeds could increase in the future climate. Increases in winds, if sufficiently large, will have major impacts on the coastal environment; both directly through blow downs of trees and structures and indirectly through increased wave height and seiche effects. This is likely to have direct effects on dune systems and the movements of sediments in the littoral zone. Studies have shown that small increases in wind speed can result in a disproportionately large increase in building damages. A 25% increase in peak wind speed can generate a 650% increase in building damages (Coleman, 2002).

Another impact of increased winter storms is that the near shore areas may have deeper and more frequent disturbances, which could resuspend toxins buried in surface sediments. These various types of impacts may be managed and controlled to an extent with changes in design parameters for coastal infrastructure. Other changes may have to be behavioural in the sense that coastal shipping warnings and navigation aids and controls may be modified as an adaptation option.

Wind farms may or may not be able to generate more power locally, depending on the changes that occur in winds in the future climate. An increased frequency of high winds beyond the “cutoff” turbine threshold and/or an increase in very light winds could result in a reduction in available wind energy potential. If there is an increase in the frequency of winds within favourable operating turbine thresholds, this could result in an increase in available wind for wind power production and energy that can be generated in coastal wind farms.

With an increased number of intense winter storms, accompanied by strong winds, and with a possible increase in wind speeds with other extreme events, there is an increased risk of failure of our built infrastructure. New infrastructure will need to be designed for a changing climate, and older infrastructure may need to be upgraded or replaced to reduce these risks of failure under a changing climate (Auld and MacIver, 2005; Auld et al., 2006a and 2006 b).

3.4 Water Temperature

Water temperatures will have a number of potential impacts on aquatic ecosystems. The cumulative impacts of climate change are difficult to determine, for example, the projected increase in productivity due to increased temperatures may be offset by the fact that increased temperatures will increase the length and depth of summer stratification causing an increase in oxygen depletion and the formation of “dead zones”, thereby decreasing productivity (Lehman, 2002). There are not many management options available to limit the impacts of increased water temperatures on aquatic ecosystems which will affect the length and depth of summer stratification, bottom dwelling invertebrates and fish exposed to low oxygen levels, and changes in water chemistry (Scheifer [Table 1]). Increases in water temperature will facilitate the invasion of species adapted to warmer waters (e.g., from the Mississippi) (Mandrak 1989) or to exotic species from Europe or Asia (MacIssac et al. 2002, MacIssac [Table 1]). Coastal water temperatures will affect the cooling efficiencies of generating stations so that higher flow through of cooling water may be required. The benefit of warmer temperatures will make beach use and swimming at the various Great Lakes resorts a more popular activity and so there is likely to be a net benefit for recreation providing that water quality is acceptable.

The increase in water temperature will result in a decrease in ice cover and this combined with an expected increase in the intensity of winter storms will leave coastal areas more vulnerable to the effects of winter storms and flooding though allow oxygenation of shallow bays that are no longer ice covered (Fang and Stefan 2000). Management options exist that can reduce the vulnerability of coastal areas to such storms.

3.5 Water Levels

Water management structures have been built to deal with variability of water levels in the present climate (Clamen; Krantzberg [Table 1]), though whether they are sufficient to adequately deal with future climates is not known (Lofgren et al. 2002). Levees have been built to withstand flood events and dams and reservoirs have also been built to manage water flow in streams and rivers. One adaptive response that has been proposed to deal with projected lower lake levels is to regulate water levels with control structures and diversions. Lakes Superior and Ontario have had control structures in place for hydropower and navigation purposes since 1921 and 1960 respectively. Whether additional hydrologic interventions of this magnitude will be environmentally damaging or even necessary and effective is still a rather contentious issue.

It appears that while dams, dykes and impoundments of various sorts may be useful for protecting wetlands, they generally exclude fish and so what is good for some wildlife is not good for other components of the ecosystem (Doka and Minns; Mortsch and Hebb [Table 1]). It is also probable that navigation, marinas and harbours may be significantly affected by climate change and in some cases it may be feasible to maintain harbours by dredging, in other cases it may be prohibitively expensive and relocation may be the better form of adaptation (DeLoe and Kreutzwiser 2000; Scheifer [Table 1]).

Low water levels that were experienced in the Great Lakes during 1999 to 2001 are projected to occur more frequently in the future climate, and have significant impacts on commercial navigation and shipping. During 2000, lake cargo carriers reduced their loads by 5 to 8% (e.g., a standard commercial carrier will load approximately 35 metric tons less for each centimetre of draft lost due to low water levels) (International Lake Ontario-St. Lawrence River Study, http://www.losl.org/twg/navigation-e.html). Navigation in the Great Lakes area slowed in 2001, causing an $11.25 million decrease in business volume, a portion of which could be attributed to low water levels (Wheaton et al., 2005).

For shipping at simulated water levels 0.5 to 1.5 m lower than base levels, dredging costs would be incurred or ships would have to reduce their loads. If lighter loads are carried, then it has been estimated that the costs per ton transported in a future climate (2 X CO_2) scenario will increase from 1.6 to 33% depending on the harbour (Duluth/Superior, Two Harbours, and Whitefish Bay on Lake Superior, and Toledo, Cleveland, and Buffalo on Lake Erie) and the climate model scenario selected. Cargoes would have to be reduced by 1.6 to 2.7% in order for ships to navigate into the harbours without additional dredging being required (Magnuson et al., 1997).

Extensive dredging may be required to deepen channels and harbours and keep connecting rivers navigable for commercial shipping. However, the economic costs associated with dredging are high, as are the environmental and human health concerns. Changon et al. (1989) estimated that dredging costs can be as high as $31 million per harbour on the U.S. Great Lakes, not including the costs associated with shipping related facilities. For the 101 km Illinois shoreline of Lake Michigan including Chicago, the study estimated that $138 million to $312 million would be needed over a 50-year period for dredging harbours to compensate for a 1.25 to 2.5 m decline in lake level. When additional factors are considered, the total shipping costs to compensate for the drop in lake level was estimated at $251 to $515 million over the 50-year period (Changon et al., 1989). Schwartz (2001) estimated dredging costs as high as $6.84 million for Goderich harbour on Lake Huron if water levels were to drop 1 m from February 2001 levels. Under climate change and lower water levels, annual transportation costs could increase by 13 to 29%, based on current prices (Millard, 2005).

A shorter duration of the ice season could increase the length of the shipping season, and possibly help to offset some of the losses resulting from climate change. Adaptation strategies for this sector could include a complete review of the commercial transportation strategy in the northeastern portion of the continent, including fleet adaptations and Great Lakes-St. Lawrence navigation channel and seaway infrastructure modifications though this is beyond the scope of this study.

3.6 Water Flow – Coastal Riverine

Changes in precipitation are likely to result in changes in the timing and intensity of major flow events in the coastal sections of rivers and streams. Lake levels influence the coastal riverine section of a river and so a lowering of lake levels will result in a change in the region at which water flow rate changes with the resultant precipitation of sediments. This is likely to impact the structure of riverine wetlands such as at the mouth of the Humber, Don and Rouge Rivers in Toronto and because there are facilities built around the mouths of most major rivers, this may result in significant modifications to harbour and wetland functions. Depending on the location of the river, the presence of control structures to regulate water flows, the water flows from rivers to the lakes may be increased or decreased.

3.7 Water Flow – Coastal Lacustrine

A change in water flow in rivers will result in changes to coastal water flow and the movement of sediments in the near shore environment (littoral drift). Deposition of sediments in the mouths of rivers currently cause problems to navigation and where significant, requires regular dredging. The supply of sediments also affects the littoral drift of sediments, impacting coastal morphology and processes. A hardening of the shoreline with sea walls and groynes has affected the erosion and accretion of shorelines and the rates of these processes may be affected by climate change.

4.0 LAKE ONTARIO

Great Lakes Case Studies - Introduction

A number of previous studies have examined possible adaptation options to climate change. These studies have however tended to be general in nature and of little use to local land managers who are in need of more specific guidance with regards to how they can prepare for climate change. Since the impacts of climate change and their associated management options are likely to differ from one lake to the next, and even from one shoreline area to the next, this project will target specific sites on each of the Great Lakes in order to reflect these regional and local differences. It is important to realize that we do not intend on extrapolating one site to all sites around each lake. The selected sites (Figure 1) will serve as case studies, with specific and feasible management options.

The climate of each of the four Great Lakes' study areas is described and historical trends in air temperature and precipitation are discussed. Significant changes are already being observed in the climate in these areas, changes which are generally consistent with what scientists are projecting under climate change. Although it is generally accepted that the climate will continue to change during the 21st century, there is still scientific uncertainty on the exact rate and magnitude of change that will occur. The intent of this project is to examine potential adaptation options that can be used when the impacts of climate change are felt, recognizing that the rate of change, as well as the number and severity of extreme weather events, will ultimately affect our ability to effectively cope with climate change.

4.1 Climate

4.1.1 Temperature

The coastal Lake Ontario climate is highly influenced by the proximity of this large body of water which serves to moderate temperatures and influence precipitation patterns. The range of temperature annually is therefore smaller in the near-shore environment of Lake Ontario versus just a short distance inland. Another important factor in the observed temperature pattern is the influence of large urban centres of the Golden Horseshoe, where the buildings, concrete, asphalt, and the human and industrial activity of urban areas results in large urban centres being warmer than surrounding rural areas (the "urban heat island" effect). Overall, this continental climate modified by Lake Ontario experiences hot and hazy summer conditions, with a relatively short winter season of three to five months (Phillips, 1990).

The mean annual temperature in the Lake Ontario region for the 30-year climate normals period (1971 to 2000) averages between 7° and 9°C, with the highest temperatures experienced over the Niagara Peninsula and within the large urban heat island influenced centres of, for example, Toronto (Figure 2).

The normal mean temperature for July ranges between 20° and 22°C, with higher temperatures found in the urbanized areas (Figure 3). During the spring and summer, lake breezes can develop during the day, bringing cool lake air inland and during the summer, providing the nearshore lake environment with welcome relief from the heat. These lake breezes form when regional surface winds are light and there is a strong temperature contrast between air over the cold lake and that over the warm land. Lake breezes can moderate the air temperature as far as 20 km inland, but the greatest cooling is experienced generally less than 5 km inland) (Brown et al., 1980; Auld et al., 1990). Similarly, off-land breezes can occur at night. As a result, maximum daytime and minimum night-time temperatures are generally cooler and warmer, respectively, in the nearshore environment during the spring and early summer.

The extreme maximum temperatures in the near-lake environment range from 34.0° to 40.0°C, over the various climate stations' periods of record. The average number of days per year with temperatures greater than 30°C is higher at the western end of the lake (maximum of 18 days), than the northeastern shore (1 day per year), likely due in part to urbanization effects (Environment Canada, 2004). The influence of Lake Ontario on the near shore air temperatures is evident in the pattern of fewer days exceeding 30°C along the northern lakeshore compared to locations further inland (i.e., 5 at Toronto Island compared to 13 at Toronto Pearson Airport).

January is normally the coldest month of the year in the region (Sanderson, 2004). Mean temperatures during this representative winter month are warmer at the western end of the Lake Ontario region (-4°C), with colder temperatures found to the north and east end of the lake in the Kingston area (-8°C) (Figure 4). Similar to the extreme maximum temperature pattern, the lowest recorded minimum temperatures are found in the northeast portion of the region (-39°C), with higher extreme minimums found at the western end of the lake (-25°C). The average number of days per year with minimum temperatures less than -20°C is highest in the northeastern part of the study area (i.e., 10 to 11 days in the Kingston area, versus only one day at the western portion of the Golden Horseshoe) (Environment Canada, 2004a).

4.1.2 Historical Temperature Trends

The trends in annual mean, maximum and minimum temperatures at five selected climate stations within the basin are shown in Figure 5. All trends in temperature, precipitation and wind that were analysed by Environment Canada for this study and are discussed in Sections 4-7 are based on best-fit linear regression, where the statistical significance has been tested by the Student's t-test at the 0.05 level. There are no decreasing trends of temperature in the historical records presented. In general, maximum and mean temperatures have been increasing or showing little change during the 20th century, while minimum temperatures have shown the greatest warming. The largest increases are observed at the urban centres of St. Catharines and Toronto, where mean/maximum/minimum temperatures have increased significantly by approximately 1°C / 1°C / 2°C and 3°C / 1°C / 4°C over the past 100 and 128 years of record, respectively. In contrast, maximum temperatures at Vineland Rittenhouse have shown no change in the past 80 years, while small upwards trends in mean and minimum temperatures are both non-significant. The trend analysis for Toronto is based on historical monthly temperature data from Environment Canada's National Climate Data Archive. For the remaining four stations, data was retrieved from Environment Canada's special database of "adjusted" temperatures (Mekis and Hogg, 1999; Environment Canada, 2006; Vincent and Mekis 2006). This homogenized temperature dataset incorporates a number of statistical adjustments to

Environment Canada's National Climate Archive monthly temperature data to identify and adjust any "inhomogeneities" in the historical data that may have been caused by station relocation and/or changes in instrumentation and observing practices. The dataset is used for climate research, including the detection of climatic trends.

4.1.3 Precipitation

Precipitation through the year is fairly uniform within the basin (Phillips, 1990). Annual mean precipitation near the lake ranges from 800 to 970 mm over the 1971 to 2000 period. Lake breeze convergence zones can form inland during the summer, resulting in a "rain shadow" effect near the lake and the inland development of thunderstorms, sometimes severe. The most significant effect of the Great Lakes is the generation of lake-effect snow to the downwind shoreline areas when cold air flows over the ice-free/open lake water during th e late fall and winter. Southwest winds can generate heavy lake-effect snowfall over Prince Edward County and the Kingston area, while northeast and east winds over the western end of Lake Ontario can result in snow squalls or enhanced storm snowfall in these areas. Lake-effect snows generated off Lake Huron and Georgian Bay rarely reach the northwestern shores of Lake Ontario (Figure 6). Of note is a topographically induced drier area west of Toronto and east of the Niagara escarpment.

The distribution of rainfall versus snowfall over the region (Figure 7) indicates that the majority of annual precipitation falls as rain (approximately 85%, decreasing to 75% further eastward as the contribution of snow/lake-effect snow to total precipitation increases). The extreme daily rainfall amount over the various station period of records ranges from 67 to 145 mm with no discernable overall pattern (Environment Canada, 2004b), while the maximum one-day snowfall recorded in the region is 64 cm (Belleville in 1900) (Environment Canada, 2004c).

4.1.4 Historical Precipitation Trends

Trends in historical precipitation over the Lake Ontario region are mixed. There is no general/ consistent directional trend in precipitation, rain or snow over the stations' period of record (greater than 30 years), with some stations showing increasing trends, and others recording decreases (Figure 8). Large statistically significant increases in annual precipitation and rainfall are observed at Kingston and Hamilton RBG (approximately 200 mm and 135 mm / 100 years, respectively at Kingston; 145 mm and 160 mm / 60 years, respectively at Hamilton), with an additional significant increase in snowfall (75 mm / 100 years) at Kingston. Non-significant decreasing trends in precipitation and snowfall occur at Oshawa WPCP, while snowfall has decreased significantly at the downtown Toronto station since 1900 (approximately 30 cm over 100 years), with urbanization, as well as a warming climate likely contributing to this decrease. The trend analysis for Oshawa WPCP is based on historical monthly precipitation data from Environment Canada's National Climate Data Archive. The precipitation trend analyses for the remaining three stations used data from a special database of "adjusted" monthly rain, snow and total precipitation amounts for 495 stations across Canada (Mekis and Hogg 1999; Environment Canada, 2006; Vincent and Mekis, 2006), based upon Environment Canada's National Climate Archive historical station rain and snow amounts. Separate adjustments were applied to rain and snow to correct for gauge specific recording errors, “trace” amounts and snowfall density. As noted previously in Section 4.1.2, this database is used in climate research, including climatic trend analysis.

4.1.5 Wind

Wind speed and direction measured in the Lake Ontario Basin are influenced by the overlying synoptic flow, smaller scale weather phenomena (i.e., thunderstorms), local effects of topography, obstructions and lake/land induced breezes. For these reasons, wind is a highly variable parameter over short distances, although it is generally stronger near the lake. On a seasonal basis, winds are strongest in the winter with frequent storm passages and lighter in the summer with generally less frequent and weaker storm systems. However, during the spring and summer because of the contrast between land and water surface temperatures, mesoscale lake breezes (on-shore flow) can form during the day, extending several kilometres inland. The distance inland that the lake breeze penetrates to is dependent on the temperature contrast between the land air temperature and that over the lake. Typically, this distance is between 15 and 25 km, and in rare cases it reaches a maximum of about 40 km (although in lake breeze case studies conducted by Environment Canada, the Lake Huron breeze has been found to penetrate as far as 100 km inland). Conversely, at night, this flow can reverse and a land breeze will develop blowing from inland towards the lake. These breezes are especially likely to develop on days and nights when there is a lack of a strong synoptic flow with its associated windfields that would tend to “overpower” the lake/land flow.

The Canadian Wind Energy Atlas (2004) was developed and released by Environment Canada in 2004, and is available online at:
http://collaboration.cmc.ec.gc.ca/science/rpn/eole/eole/index_en.html.

The Atlas contains modelled wind speed and wind energy contoured maps and model data, at a 5 km horizontal resolution, with its primary use intended for wind energy resource analysis. The modelled “average” wind climatology for Canada is produced from multiple historical model runs of synoptic conditions from the period 1958 to 2000. A comparison of modelled to observed winds is also provided in tabular format in the atlas (where 50 m modelled winds are reduced to 10 m observation height by assuming a specific wind profile). A sample modelled mean annual wind speed map from the atlas is shown in Figure 9 for the Lake Ontario region for the lowest height available from the atlas –30 m. Wind speeds at this level will normally be greater than those at the standard wind instrument level of 10 m, but the contours provide some general information on wind patterns. Wind speeds are strongest over the open lake (7 m/s or 25 km/h) as might be expected, with the influence of local topography also evident on this map. The near-shore wind speed is generally found to average about 5 m/s (18 km/h) on an annual basis. The pattern of wind speeds being seasonally higher in the winter and weaker in the summer is evident from monthly maps that are available from the atlas.

4.1.6 Historical Wind Trends

In 2005, under research funded by the federal Program of Energy Research and Development (PERD), Environment Canada-Ontario analysed historical wind observations for various Ontario airport locations, investigating recent historical trends in average and maximum wind speeds, percent frequency of occurrence of calm winds, winds exceeding 60 km/h and winds less than 15 km/h at 10 m observation level. The results from three stations in the Lake Ontario region indicate that from 1974 to 2004, average and maximum winds, as well as wind speeds in excess of 60 km/h have generally decreased, calms are unchanged, and the occurrence of winds less than 15 km/h has increased (Figure 10).

4.2 Lake Ontario - Presqu'ile Provincial Park

4.2.1 Introduction

Presqu'ile Provincial Park encompasses 974 ha at the eastern end of Lake Ontario on a peninsula south of the town of Brighton (Figure 11). It is classified as a Natural Environment Park containing four types of zones (OMNR 1979, 2000). About 80% of the park is comprised of five Nature Reserve Zones, including the park's panne, back dune and marsh ecosystems, part of the fore dune system, Owen Point, most of the foot of the peninsula, and Gull and High Islands (Figure 12). A Historical Zone encompasses about 0.2% of the park and includes Presqu'ile Point and the lighthouse, while a Natural Environment Zone encompasses about 11% of the park, and includes the managed beach and the fore dunes behind it, the Calf Pasture Cove day use area, and the park's south shore. Park infrastructure located in the Development Zone (9% of the park area) includes campgrounds, the south shore day use area, the park store, roads, and administration and maintenance buildings.

4.2.2 Physical Description

The most significant park landform is the peninsula or tombolo created from the deposition of sand between the mainland and an old limestone island (outcrop). Currently, the tombolo is characterized by a sand beach facing Popham Bay with sand dunes and the panne behind. A flat, thinly layered limestone outcrop also provides the core of the Gull and High Bluff Islands located near the southern end of the peninsula. These islands provide nesting habitat for a variety of colonial waterbird species. The north side of the park includes an extensive wetland that encloses small areas of open water.

4.2.3 Biological Description

Presqu'ile is located near the southern boundary of the Great Lakes-St. Lawrence Forest Region. The park's vegetation is interesting because it shows affinities for both more southerly deciduous forests and more northerly coniferous forests. Important tree species include Sugar Maple, Beech, Basswood, Black Berry, Red Ash, Black Ash, White Birch, Yellow Birch, Jack Pine, and Eastern White Cedar. Additional ecosystems include the panne, coniferous plantations (that will be replaced with indigenous species under the direction of the park's management plan), sand and cobble beaches, dunes, and wetlands. A number of "Committee on the Status of Endangered Wildlife in Canada" (COSEWIC) and "Committee on the Status of Species at Risk in Ontario" (COSSARO) species inhabit the park. For example, the park provides habitat to 6 nationally, 2 provincially, and 28 regionally rare plant species.

The panne is a seasonally wet meadow vegetated with grasses and sedges, and is the best example of its kind along the Lake Ontario coastline. The major wetland areas occur to the north of the peninsula and are mostly vegetated with Cattail stands, though reed beds occur further out into Presqu'ile Bay. Submergent species such as Yellow Water Lily grow in pools within the cattail stands. Presqu'ile Bay Marsh is a Provincially Significant Wetland that serves as a major staging area for waterfowl in spring, fall, and winter.

The vegetation in Presqu'ile is diverse and comprised of a number of significant species (Tyerman [Table 1]). For example, several rare species of grasses and sedges grow on the panne, including Panic Grass and Nut Rush. In beach habitats grow rare sedges (e.g., *Cyperus engelmanni* and *Scirpus heterochaetus*).

While many species of insects and other invertebrates live in the park, Presqu'ile is best known as an important staging habitat for Monarch Butterflies, which gather each autumn en route to winter habitat in Mexico.

Presqu'ile provides habitat for four species of salamanders (e.g., Yellow-spotted Salamander), six toads and frogs (e.g., Spring Peeper and American Toad), four turtles (e.g., Common Snapping Turtle and Blanding's Turtle), and five snakes (e.g., eastern Garter Snake and Brown Snake). Characteristic fish species inhabiting surrounding waters include Northern Pike, Walleye, Smallmouth Bass, Yellow Perch, White Perch, Bullheads, and Sunfish.

The park is a haven for migratory birds. At least 321 species have been sighted en route to South America, the Arctic, Europe and Asia, and about 126 species nest here. Presqu'ile is a globally significant "Important Bird Area" (IBA) because it supports more than 1% of the global or national populations of seven species: Double-crested Cormorant, Ring-billed Gull, Caspian Tern, Brant Goose, Greater Scaup, Dunlin, and Whimbrel.

Resident mammals include: Chipmunk, Mink, Beaver, Muskrat, Red Fox, Coyote, and Raccoon. Snowshoe Hare and River Otter are at the southern limit of their ranges. A resident herd of White-tailed Deer has significantly impacted understory vegetation in the park and is harvested from time to time.

4.2.4 Recreation

Presqu'ile provides recreational opportunities for campers and day users. There are about 400 campsites and 1,250 day parking areas. From 1985-2005, an average of 104,345 day users and 121,508 campers (camper nights) used the park each year. Interpretive programs are regularly scheduled to view waterfowl and migrating shorebirds in the spring and monarch butterfly banding in the fall.

4.2.5 Land Use Planning and Management

The Presqu’ile Park Management Plan (OMNR 2000), prepared in consultation with the public and stakeholders, addresses a number of features and processes that may be affected by climate, though no direct reference to climate change is made in the document.

4.2.6 The Changing Climate: Projections for the 21st Century

Over the past century, the climate in the Belleville and Kingston area has seen significant changes in annual temperatures, as well as changes in annual precipitation amounts. The largest changes in temperature have been in the annual minima with Belleville recording an increase of 2.1^{o}C since the early 1920's. Total annual precipitation, rainfall and snowfall have all increased at Kingston since the start of the 20th century: 207 mm, 135 mm and 73 cm, respectively.

Using GCM output from the four climate change scenarios described in Section 2.2, the projected annual warming in the Presqu’ile area by 2050 is in the range of 2 to 4^{o}C by the middle of the 21st century. Total annual precipitation is projected to increase by 2 to 13% by the 2050's. In addition to the changes in the annual average temperature and precipitation, extreme precipitation is likely to be more frequent and intense while there is also an increased risk of drought and an increased number of hot days. By 2050, lake water levels could decline by about 0.5 m and up to 1 m by the end of this century. Although snowfall is projected to decrease during the 21st century, as winters warm and more precipitation falls as rain rather than snow, there is also the possibility that in the near future with lakes remaining ice-free for a longer period during the year, snow squall activity could actually increase. As noted above, snowfall at Kingston has increased over the past 100 years, which is consistent with the results of a study that has shown a significant increase in Great Lakes U.S. lake-effect snowfall during the 20th century (Burnett. et al., 2003, Ellis and Johnson, 2004). However, as temperatures continue to warm during the 21st century, this trend would not be expected to persist and the frequency of lake-effect snow events would likely decrease during this century with winter lake-effect rain events becoming more likely (Kunkel et al. 2000).

4.2.7 Threats and Opportunities Resulting from Climate Change: Adaptation Options

Air Temperature

Opportunity: Longer shoulder seasons in spring and fall will increase the length of the warm weather operating season, which may result in increased day use and opportunities for a longer camping season. Increased operating periods likely will require changes to budgeting and staffing in the park. In addition, management strategies that address potential impacts from increased human activities on the park’s ecosystems may be required.

Threat: Opportunities for traditional winter activities may completely disappear. For example, park staff no longer maintains cross-country ski trails because of the unpredictable nature of snow conditions in past decade. Ontario Parks likely will need to reassess winter activity opportunities.

Threat: Increased frequency of hot days. There are likely to be more heat waves in summer and the park will be under greater pressure to provide access to the increased population from the Golden Horseshoe area.

Threat: Increased temperature and altered precipitation patterns may affect the success of trees planted during restoration projects. Given that Ontario Parks is replacing the coniferous plantations, tree species (and individual trees) likely will need to be selected on the basis of their ability to thrive in a warmer climate that is exposed to summer drought. Accordingly, tree species that are better adapted to the new, emerging climate (e.g., Carolinian species) may provide appropriate stock.

Precipitation Changes

Threat: Increased fire hazard. A warmer climate with possibly more frequent and serious drought could generate more frequent and longer periods of severe fire hazard. Ontario Parks may need to regulate the use of fire pits during high fire hazard periods.

Threat: Increased frequency and severity of extreme events that include rain storms (Haley [Table 1]). Ice storms may damage forested ecosystems and require increased clean-up and/or repairs or replacement to park infrastructure.

Wind Changes

Opportunity: Emerging wind patterns may improve sailboat and beach sailing.

Opportunity: Emerging wind patterns could result in an active dune system (Davidson-Arnott [Table 1]). On the other hand, with lowered water levels the dune system will migrate lakeward and the walks from the parking lots to the beach will be longer. This may require the extension of boardwalks through the dunes.

Threat: Emerging wind patterns may create more hazardous conditions for boaters. Ontario Parks may need to develop a wind advisory system for park users.

Threat: Emerging wind patterns may damage wind sensitive trees along shorelines and in wooded areas, including some of the willows and Manitoba Maple near the lighthouse and Presqu'ile Point. Ontario Parks may need to manage for wind resistant vegetation along the shoreline.

Threat: Emerging wind patterns may create a more active dune system that could require more aggressive sand management regimes (e.g., increased sand removal from parking lots).

Water Temperature Changes

Opportunity: Longer swimming season as a result of warmer water will lead to increased park usage with increased revenues (Gray and Mulrooney [Table 1]).

Threat/Opportunity: Loss of some species from and the addition of new species to the sport fishery. Changes in fish community structure and function may require changes to recreational fishing regulations (Stanley [Table 1]).

Threat: Water quality degradation caused by increased distribution and abundance of algae and increased beach cleaning costs. In addition, there maybe an increase in the presence of noxious blue-green algae, this could impact swimming areas. This may be exacerbated by the large colonial waterbird colony on the islands and the excrement droppings of the birds into the water surrounding the islands and beach.

Water Level Changes (Decline in Levels)

Opportunity: Increased beach area. The increased area will provide more beach area for recreational activities.

Threat/Opportunity: The marsh ecosystem boundaries will shift. The marsh boardwalk may require relocation in response to the outward reformation of the marsh.

Threat/Opportunity: A change in the park boundary as defined by water depth. A major potential impact of climate change will be on the terrestrial boundaries of the park, which will increase as a result of a lowering of Lake Ontario water levels. Currently, the park boundary is measured as the distance from the shore (200 m), and given that much of the littoral zone of the park is very gently shelving, a small drop in lake water levels will result in a significant increase in the size of the park. For example, a 1 m drop in water levels would increase the size of the park by many hectares.

Threat: Loss of panne vegetation. The panne may dry out if the water table drops enough. This moisture loss drop will encourage successional plants to colonize the area.

Threat: Loss of wildlife habitat. Lower water levels will impact a number of wildlife habitats. For example, the colonial waterbirds inhabiting the islands, the shorebirds that stage on the beaches in the spring and fall, and the waterfowl that use Presqu’ile as a staging area in the spring, fall and winter may lose habitat. For example, with a 1 m drawdown, the islands may be connected to the peninsula, which would provide a bridge for predators to access colonial bird nests (Figure 12). One strategy would involve dredging the channel between the mainland and the islands to ensure that they remain separate.

Water Movement - Lacustrine Changes

Threat: Interference with dune establishment. There may be changes to water flow along Popham Bay that affects sediment transport, which may affect dune build up and dynamics.

Threat: Interference with water circulation in the wetlands. There may be changes to the water circulation in Presqu'ile Bay that affects nutrients and water quality. This could also impact water quality for domestic use in the Town of Brighton.

4.3 Lake Ontario – Toronto

4.3.1 Introduction

Canada's largest city is located on the north shore of the western part of Lake Ontario. The Toronto and Region Area of Concern (AOC) extends from the Rouge River in the east to the Etobicoke Creek in the west and includes six watersheds: Etobicoke Creek, Mimico Creek, Humber River, Don River, Highland Creek and Rouge River (Figure 13). More than 3 million people live in this 2,000 km^2 area. The waterfront encompasses the Toronto Islands that enclose Toronto Harbour and various land-fill projects along the shoreline such as Tommy Thompson Park (aka Leslie Street Spit), Bluffers Park, and Marie Curtis Park.

4.3.2 Physical Description

Most of the shoreline has been altered by human activities that include construction of harbour facilities, walls, groynes, and breakwaters. The rivers that flow into Lake Ontario run through the most urbanized area in Canada, and some of the creeks run entirely within urban areas. There are several Environmentally Significant Areas along the waterfront, including the Scarborough Bluffs, the Toronto Islands with some remnant dune systems, and the marshes in the lower parts of the Rouge and Humber Rivers.

Most industrial facilities along the waterfront that defined the shoreline of the 19th century and the first half of the 20th century have been replaced with marinas, parks and residential/ institutional facilities.

Through lake infilling the location of the original waterfront in downtown Toronto is now several hundred metres inland and Fort York once strategically located near the shoreline is now isolated between roads, rail lines and large residential developments. In addition, some of the original creeks like Taddle and Garrison Creeks are buried and the extensive marshes in the Ashbridge's Bay area at the mouth of the Don River have been filled in and used as industrial land for more than a century. The course of the lower Don River was straightened and confined between armoured banks, and urban activity in the watershed has caused significant siltation of the river and Inner Harbour.

4.3.3 Biological Description

Toronto is located at the junction of the Great Lakes-St. Lawrence Forest Region and the Eastern Deciduous Forest Region. Although there is little left of the original coastal vegetation, the Black Oak savannah of High Park and the remnant patches of dune system and shoreline on the Toronto Islands exemplify remnant parts of these once extensive ecosystems. Typical tree species in the area include Sugar Maple, Red, White, Black and Bur Oak, Beech, Basswood, Eastern White Pine, Eastern Hemlock and Eastern White Cedar.

The riverine marshes are composed largely of cattails and depending on the amount of scouring, some submergent species like Water Smartwort may grow as well. Remaining wetland areas in protected waters such as around the Toronto Islands and Tommy Thompson Park include aquatic species such as Waterweed, Water Celery and Water Milfoil.

In addition, there are some small remnant beaches and dune systems near the mouth of the Rouge River and on the Toronto Islands where Sea Holly, Dune Grass and other relict species grow. Surviving remnants of coastal successional forest dominated by poplars and willows continue to provide important migratory bird habitat.

Of the many species of insects inhabiting the Toronto area, the Monarch Butterfly is best known and its migration can be observed from Tommy Thomson Park, where they gather each autumn en route to winter habitat in Mexico.

Toronto’s wetlands provide habitat for several species of toads and frogs (e.g., Spring Peeper and American Toad), turtles (e.g., Midland Painted Turtle, Common Snapping Turtle, Map Turtle, Spiny Softshell and Blanding’s Turtle), and snakes (e.g., Eastern Garter Snake and Brown Snake). Characteristic fish species inhabiting surrounding waters include Northern Pike, Smallmouth Bass, Yellow Perch, White Perch, Bullheads, and Sunfish (Toninger [Table 1]) that are monitored on a regular basis.

The Toronto Bird Observatory was the first urban-based bird banding observatory established in North America and is run as a charitable organization by volunteers (Joos 2006). The volunteers have banded birds on the Toronto Islands and Tommy Thompson Park for many years (Toninger [Table 1]) and have recently moved their banding activity to High Park. Some 81 species were banded in 2005; as many as 100 species have been observed in the Toronto area in one day. These areas provide important stop-over habitat for migratory species crossing Lake Ontario. There are also major colonies of Ring-billed Gulls, Herring Gulls, Double-crested Cormorants, Caspian Terns, Common Terns and Black-crowned Night-herons at Tommy Thompson Park, and numerous Canada Geese nest on the islands. Mute Swans are an introduced species that now breed along the coast. Shorebirds such as Spotted Sandpiper, Killdeer, Dunlin, and Dowitchers may be found along some of the enclosed beaches.

Resident mammals in Toronto include Chipmunk, Grey Squirrel, Red Squirrel, Beaver, Muskrat, Red Fox, Coyote, Eastern Cottontail and Raccoon. White-tailed Deer are relatively common and move through the river valleys and reach the waterfront parks. Carolinian mammals such as the Virginia Opossum have also colonized the Toronto area.

4.3.4 Recreation

Many parks and natural areas have been created along the Toronto waterfront. The Toronto Islands provide many attractions and are used by hundreds of thousands of visitors. More than 2 million people visit Toronto's High Park every year and areas like the Toronto Beaches area, the Western Beaches, and Bluffers Park are major attraction as well. Waterfront marinas provide facilities for sail boats and power boats, and many people sailboard from beaches located across the Greater Toronto Area. There are also several rowing clubs (e.g., Argonauts, Hanlans, Bayside). Toronto received accreditation for four beaches (Cherry, Hanlan, Ward's Island and Woodbine) in 2005 under the international Blue Flag program.

4.3.5 Land Use Planning and Management

Several agencies are responsible for planning in the Toronto area. The City of Toronto has major planning roles that affect the coastal area and work with the Toronto and Region Conservation Authority (TRCA) on many issues. The TRCA undertakes the lead role in many projects and has been responsible for initiating numerous waterfront protection and restoration projects and has a major planning role in protecting the physical and biological aspects of the coastal environment. The Toronto Harbour Commission is a federally regulated body responsible for shipping in the harbour, as well as the Toronto Island Airport. The Department of Fisheries and Oceans (DFO) is responsible for activities under the Fisheries Act and works with the Ontario Ministry of Natural Resources (OMNR) which has jurisdiction over fisheries, wildlife and provincial Areas of Natural and Scientific Interest (ANSIs) such as the High Park Black Oak savannah.

4.3.6 The Changing Climate: Projections for the 21st Century

Since the late 19th century, temperatures at the downtown Toronto climate station have warmed considerably, with statistically significant increases in the annual maximum, mean and minimum temperatures of 2.3^{o}C, 3.4^{o}C, and 4.5^{o}C, respectively. The heat island effect has been a significant contributor to the warming, particularly in the minimum temperatures but climate change has also likely added to the increases. Over the past century, total annual precipitation and rainfall have shown small non-significant increases: 21 and 50 mm, respectively, while annual snowfall has decreased non-significantly by 29 cm over the same period.

The warming that has been observed in the past 100+ years is expected to continue under climate change in the 21st century, with GCM output from the four climate change scenarios described in Section 2.2, projecting additional annual warming in the Toronto area by 2050 in the range of 2.5^{o} to 4^{o}C. By the middle of this century, total annual precipitation is expected to increase by 2 to 13% with more precipitation arriving as rain than snow. Increases in extreme weather events such as intense rainfall, severe drought and heat waves are also likely. Lake

Ontario mean annual water levels could decrease by about 0.5 m and 1 m by the middle and end of this century, respectively.

4.3.7 Threats and Opportunities Resulting from Climate Change: Adaptation Options

Air Temperature

Opportunity: The waterfront parks are popular locations for residents, and warmer temperatures will likely increase the length of the picnic, beach and boating season.

Opportunity: Increased revenue generated from an increased demand for use of waterfront parks and marina facilities could be used to raise awareness of the importance of the coastal area.

Opportunity/Threat: Shorter winters and longer summers will decrease the need for heating in the winter but increase the need for cooling in the summer.

Threat: Increased frequency of hot days (Klaassen [Table 1]). Higher air temperatures and release of smog-forming chemicals and particulates (i.e., formation of ground level ozone from pollutants emitted by cars and trucks) will likely result in an ever increasing number of poor air quality days in the city and heat-related health problems, particularly in the vulnerable (i.e., elderly, very young, those suffering from cardio-respiratory problems). This will lead to an increased the burden on clinics, hospitals and health facilities.

Threat: Increased temperature and altered, more variable precipitation patterns (Klaassen [Table 1]) will affect tree health and survival in city parks. Tree species (e.g., Carolinian species) will need to be selected on the basis of their ability to thrive in warmer climates with an increased frequency and intensity of drought conditions.

Precipitation Changes

Threat: Drought in the summer is likely to put increased pressure on water supplies and the capacity to deliver water to homes and businesses.

Threat: Increased frequency and severity of extreme precipitation events (Klaassen [Table 1]). It is anticipated that an increased intensity of rain storms will have significant impacts on the infrastructure in the city. A recent example of the type of damages that can be incurred by extreme rain events is the August 2005 rain storm which resulted in severe flooding in the Black Creek and the Highland Creek areas damaging roads, sewers and other facilities worth many millions of dollars (Figure 14, Haley [Table 1]). New infrastructure will need to be designed for a changing climate, and older infrastructure may need to be upgraded or replaced to reduce the risks of failure under a changing climate (Haley [Table 1]).

Threat: Severe rainstorm events cause higher flow rates and volumes in rivers and creeks leading to increased erosion of river banks and increased sediment loads in river mouth areas

(Haley [Table 1]). The costs of protecting channels, weirs, dams and other facilities and dredging costs at river mouths will continue to escalate if not managed.

Wind Changes

Opportunity: Emerging wind patterns may improve sailboat and beach sailing.

Opportunity/Threat: Emerging wind patterns could provide additional wind energy potential along the waterfront. Alternatively, optimal conditions for development of wind energy could also decrease.

Opportunity: Some of the active dune system may increase in size under emerging wind patterns and with lowered water levels may migrate lakeward.

Threat: Emerging wind patterns may create more hazardous conditions for boaters. An improved wind advisory system is an adaptation option.

Threat: Emerging wind patterns may damage wind sensitive trees along shorelines and in wooded areas, including some of the willows and Manitoba Maple near the Toronto Island lighthouse. Toronto Parks may need to plant and/or manage for wind resistant vegetation along the waterfront parks.

Threat: Various waterfront parks may require to be redesigned to allow for severe wind events that may pose a risk to pedestrians, boaters and others. Closure of parks may be necessary under severe storm conditions.

Threat: The few remaining dune systems such as in the Hanlan's Point beach area may be altered depending on sediment supply.

Water Temperature Changes

Opportunity: Longer swimming season as a result of warmer water will lead to increased waterfront, beach and park usage.

Threat/Opportunity: Fish community populations may change; warm-water species may become more abundant. The potential impact of non-native warm-water species may disrupt the local fish communities. Changes in fish community structure and function may require changes to recreational fishing regulations.

Threat: Water quality degradation caused by increased distribution and abundance of algae and increased beach cleaning costs. In addition, there maybe an increase in the presence of noxious blue-green algae which may be exacerbated by the excrement droppings of birds from the large colonial waterbird colony at Tommy Thompson Park. This can impact water quality in swimming areas and would result in more beach closures.

Threat: Increased costs for water filtration and treatment can be expected.

Water Level Changes (Decline in Levels)

Opportunity: Increased beach area. The increased area will provide more beach for recreational activities.

Threat/Opportunity: Riverine marsh ecosystem boundaries will change where space allows and one can expect to see the structure of the lower reaches of the Rouge, Humber and Don Rivers change.

Threat/Opportunity: A change in the water level may well affect the footings of shoreline and submerged structures such as water intake and outflow pipes, piers, revetments, and groynes. If these are then exposed to greater storm activity during periods of low water (e.g., during the autumn months) they may eventually fail (Haley [Table 1]).

Threat: Lower water levels will jeopardize access to a number of marinas in the Toronto area. Significant increases in dredging costs are likely to occur. Some marinas may no longer be viable.

Threat: Lower water levels will impact a number of wildlife habitats. For example, with a 1 m drawdown, the channels between many of the Toronto islands would dry up and impact bird, fish, amphibian, reptile and other wildlife habitats.

Water Movement - Lacustrine Changes

Threat: Water level changes and associated water movement may affect sediment deposition in Ashbridge's Bay, the Toronto Inner Harbour and other areas. Seiche effects that serve to flush water around the Toronto Islands may be reduced and cause increased stagnation affecting the people living on Ward's Island.

4.4 Lake Ontario - Hamilton Harbour

4.4.1 Introduction

Hamilton is an industrial city located at the western end of Lake Ontario (Figure 15, Hall [Table 1]). A sandbar separates Hamilton Harbour from Lake Ontario. The harbour is connected to Lake Ontario by the Burlington Ship Canal, constructed in 1823, that allows the passage of sea going freighters. The Hamilton Harbour Area of Concern (AOC) includes Cootes Paradise at the western end of the harbour, as well as the major body of water (2,150 ha) bordered by the City of Hamilton (500,000 people) on the south side and the City of Burlington on the north side and Dundas (25,000 people) on the west side.

4.4.2 Physical Description

The drainage area for Hamilton Harbour is 49,400 ha. Water drains into the harbour via a number of streams including Redhill, Spencer, and Grindstone Creeks (Figure 15). Between 1862 and 1926 the extensive marshes on the south side of the harbour were filled in to create a land base for Stelco and Dofasco steel companies and Windermere basin was created (Hamilton Harbour Remedial Action Plan 1992). The north shore of the harbour has been armoured for most of its length and residential housing, a golf course and La Salle Park and marina created. The shoreline of Cootes Paradise is relatively natural, though a man made channel, the Desjardins Canal, was made in 1853. This canal was blocked to navigation in 1997 by the construction of a carp barrier. Cootes Paradise shoreline is owned by the Royal Botanical Gardens, and McMaster University.

The creeks that provide water to the harbour originate on the Niagara Escarpment and run through residential and industrial areas. There are several Environmentally Significant Areas such as Grindstone Creek, Bridgeview Valley and Sassafras Woods in Burlington, and Cootes Paradise in Hamilton. Cootes Paradise is a Class 1 wetland.

Hamilton is one of the busiest of Canadian ports on the Great Lakes and handles a wide variety of goods particularly those associated with the steel industry. The industrial operations of Stelco and Dofasco remain a significant component of the shoreline of the harbour and make significant contributions to the local economy. However many changes have occurred during the past 30 years and significant remediation efforts have resulted in improved water quality, sediment and shoreline protection. Much of the industrial infrastructure that characterized the shoreline in the latter part of the 19^{th} century and the first half of the 20^{th} century have been replaced with marinas, parks, and residential and institutional developments.

4.4.3 Biological Description

Hamilton is located at the junction of the Great Lakes-St Lawrence Mixed Forest and the Eastern Deciduous Forest Region and is influenced by the Niagara Escarpment that encircles the harbour and creates some interesting microclimates within the area. There is little left of the extensive marshes that originally occurred in Cootes Paradise and along the south shore of the harbour, though with the construction of the Carp barrier in Desjardins Canal and major replanting efforts, marsh and wetland vegetation is returning to Cootes Paradise.

The marshes are composed largely of cattails and reeds, but as time passes since the exclusion of Carp in 1997, improved water clarity enables many more areas of submerged macrophytes such as pondweed to recolonize the shallows in many areas (Lundholm and Simser 1999). Other shallow areas around the north shore of Hamilton Harbour such as those in the vicinity of La Salle Park now support increased macrophyte beds as a result of some of the breakwaters and habitat modifications that were implemented as part of the RAP process.

A few remnant beach areas in the harbour have been restored, particularly in the area of La Salle Park and along the northeast shore (Hall [Table 1]). The coastal woodlands in Cootes

Paradise are dominated by poplars and willows and provide important habitats for Wood Duck, Screech Owl and other woodland species. Much of the woodland within the Royal Botanical Gardens contain typical deciduous forest species such as Oaks, Beech, Hickory, Ash with understory species like Sassafras and Witchhazel.

The Royal Botanical Gardens and the Hamilton Field Naturalists have completed bird banding in the Cootes Paradise area since 1935 where more than 30,000 birds (over 100 species) have been banded. Cootes Paradise is one of the largest and most important wetland areas for waterfowl staging on the lower Great Lakes (Heagy 1993).

These are also major colonies of Ring-billed Gulls, Herring Gulls, Double-crested Cormorants, Caspian Terns, Common Terns and Black-crowned Night-herons in Hamilton Harbour that have been re-established on artificial islands (Figures 16 and 16a). Local populations of Canada Geese, Double-crested Cormorant and Mute Swan have expanded greatly in the past two decades and require ongoing management (Theysmeyer et al. 1998).

The Hamilton Harbour wetlands provide habitat for many amphibian and reptile species (Lamond 1994). Toads and frogs (e.g., Spring Peeper and American Toad), turtles (e.g., Midland Painted Turtle, Common Snapping Turtle, Map Turtle, Spiny Softshell and Blanding's Turtle), and snakes (e.g., eastern Garter Snake and Brown Snake) are common and characteristic fish species inhabiting surrounding waters include Northern Pike, Smallmouth Bass, Yellow Perch, White Perch, Bullheads, and Sunfish (Theysmeyer 2001).

Resident mammals in and around Hamilton Harbour include Chipmunk, Grey Squirrel, Red Squirrel, Beaver, Muskrat, Red Fox, Coyote, Eastern Cottontail and Raccoon. White-tailed Deer are common and present a major problem for some of the restoration activities.

4.4.4 Recreation

Several parks (e.g., Princes, La Salle, and Royal Botanical Gardens) and natural areas around Hamilton Harbour provide recreational opportunities for people. There are several marinas around the harbour including the Burlington Sailing and Boating Club, La Salle Marina, the Hamilton Royal Yacht Club, Leander Rowing Club and the Macassa Bay Yacht Club.

4.4.5 Land Use Planning and Management

Several agencies are responsible for planning and management of resources around Hamilton Harbour for example, the Cities of Hamilton and Burlington have major planning roles that affect the coastal area and they work with the Hamilton Region Conservation Authority and Halton Region Conservation Authority. The Hamilton Harbour Commission was established in 1912 by the Government of Canada and is responsible for managing issues related to shipping and recreation. The Department of Fisheries and Oceans (DFO) is housed at the Canadian Centre for Inland Waters (CCIW) at the eastern end of the harbour and has a major interest in fisheries management, including monitoring programs in the harbour.

4.4.6 The Changing Climate: Projections for the 21st Century

Since 1960, Hamilton's climate has warmed significantly and precipitation has increased. Statistically significant increases in annual maximum and mean temperatures of 0.9°C, and 0.8 °C, respectively, and a non-significant increase in annual minimum temperature of 0.6°C have been observed at Hamilton Airport from 1960 through 2004 (this station is not shown on Figure 5, the temperature trend graphic). Annual precipitation and rainfall have also increased significantly at Hamilton RBG from 1939 to 1996: 145 and 137 mm, respectively. Annual snowfall during this 58 year period has shown little change, a non-significant increase of 10 cm.

By 2050, the four GCM scenarios described in Section 2 indicate that mean annual temperatures can be expected to increase by 2.5° to 4°C while total annual precipitation could show little change to an increase of 14% by the middle of this century. As noted in the other case studies, Lake Ontario water levels are projected to decline while extreme weather events could increase in severity and frequency.

4.4.7 Threats and Opportunities Resulting from Climate Change: Adaptation Options

Major shoreline improvements undertaken as part of the Remedial Action Plan have resulted in improved habitats on the North-east Shore, LaSalle Park, Cootes Paradise, Grindstone Creek and Windermere Basin. However, during these remediation efforts, the potential for climate change to impact the outcomes of the restoration was not considered.

Air Temperature

Opportunity: The waterfront parks are popular locations for residents, and a longer summer will likely increase the length of the boating season.

Opportunity: The longer open water season may lengthen the commercial shipping season.

Opportunity: Increased revenue generated from an increased demand for use of waterfront parks and marina facilities could be used to raise awareness of the importance of the coastal area.

Opportunity/Threat: Shorter winters and longer summers will decrease the need for heating in the winter but increase the need for cooling and energy use in the summer.

Threat: Warmer air temperatures and release of smog-forming chemicals and particulates from human activities will likely result in an ever increasing number of poor air quality days in the city. This will particularly impact the young and old and increase the burden on hospitals, clinics, and health facilities (HAQI 1997).

Threat: Increased temperature and altered precipitation patterns will affect tree health and survival planted at the Royal Botanical Gardens and in city parks. Tree species will need to be selected on the basis of their ability to thrive in a warmer climate.

Precipitation Changes

Threat: Summer drought periods are projected to become more common providing an additional stress on the existing water supply infrastructure.

Threat: It is anticipated that with more intense and extreme weather events, there will be an increased risk of infrastructure failure. For example, more frequent and intense extreme rain storms will have a significant impact on Hamilton's municipal infrastructure (Auld and MacIver, 2006). The older parts of the city have combined sewage and stormwater runoff in single sewers. Several major stormwater storage facilities such as the one at Bayfront Park enable contaminated water to be held during major rain events and it is subsequently treated. The sizing of these storage tanks may not be sufficient to hold water from an increased number and size of storm events in a changed climate, which may result in more sewage discharges to the harbour. New infrastructure will need to be designed for a changing climate, and older infrastructure may need to be upgraded or replaced to reduce the risks of failure under a changing climate (Auld et al. 2006a, Auld et al. 2006b, Auld et al. 2006c).

Threat: With an increased frequency and size of rainstorm events, increased flow rates and volumes in rivers and creeks may increase river banks erosion and sediment loads being deposited in river mouth areas. The costs of protecting channels, weirs, dams, other facilities and dredging the harbour will continue to escalate if not managed.

Wind Changes

Opportunity: Emerging wind patterns may improve sail boating and beach sailing in the harbour.

Threat: Emerging wind patterns may create more hazardous conditions for boaters. Improved wind advisory systems may be warranted.

Threat: Emerging wind patterns may damage wind sensitive trees along shorelines and in wooded areas, including some of the willows and Manitoba Maple. Local management agencies may need to plant and/or manage for wind resistant vegetation.

Threat: Waterfront parks may require modification to allow for potentially more frequent and intense severe wind events that may pose a risk to pedestrians, boaters and others.

Water Temperature Changes

Threat/Opportunity: Fish community populations may change; warm water species may become more abundant. The impact of more non-native warm water species may also disrupt the local fish communities.

Threat: Water quality degradation caused by increased distribution and abundance of algae and increased beach cleaning costs. At the moment there are no swimming beaches in the harbour itself, although Burlington Beach on the Lake Ontario shore does receive an algal build up that is removed by the City of Burlington.

Water Level Changes

Threat/Opportunity: The Cootes Paradise marsh ecosystem boundaries will move out into the Bay with declining lake levels. The marshes near the mouths of Redhill, Grindstone, and Spencer Creeks will move further out.

Threat/Opportunity: A change in the water level may well affect the footings of shoreline and submerged structures such as water intake and outflow pipes, piers, revetments, and groynes. If these are then exposed to greater storm activity during periods of low water, they may eventually fail.

Threat: There may be a significant expansion of the meadow community in Cootes Paradise given the very shallow nature of much of the wetland.

Threat: Lower water levels will jeopardize access to a number of marinas in the Hamilton area and commercial shipping ports. It is likely that there will be significant increased dredging costs. Some marinas may no longer be viable.

Threat: Lower water levels will impact a number of wildlife habitats. For example, with a 1 m drawdown, the channels between the islands created on the North-east shore would be shallow, though the design is such that they should still be safe for colonial waterbird breeding islands in the foreseeable future (Figures 16a and 16b).

Water Movement - Lacustrine Changes

Threat: Water level changes and associated water movement changes may affect circulation around La Salle Park and the North East shore islands. There may be some change to areas of sediment deposition.

5.0 LAKE ERIE

5.1 Climate

5.1.1 Temperature

Lake Erie and its basin are the warmest in the Great Lakes region on an annual basis. The annual mean temperature ranges from 8°C to 10°C, with the warmest of these temperatures in extreme southwestern Ontario, near Windsor, and near Niagara Falls (Figure 17). The climate is characterized as modified continental with hot and hazy summer conditions, and a relatively short winter season of three to five months (Phillips, 1990). In comparison to the other Great Lakes, the relative shallowness and smaller volume of Lake Erie lessens its modifying effects on the shoreline environments. In the spring and summer, the lake warms quickly and more than surrounding Great Lakes, whereas in the winter, the lake cools more rapidly and frequently freezes over (Phillips, 1990). Nevertheless, lake breezes can still provide some relief to the summer heat at areas such as Long Point where in summer the air temperature is usually very close to the Lake Erie water temperature in the low to mid 20°C range.

The variations in July mean temperatures (Figure 18) show a similar pattern to the annual contours. The temperatures range from 21°C to 23°C, with the warmest temperatures at the western end of the lake. The extreme maximum temperatures recorded in the basin range from a high of almost 41°C at Harrow, to 33.5°C at Port Colborne. The average number of days per year with a temperature greater than 30°C in the near shore environment is 12 at the western end of the lake, lowering to 2 on the central and eastern shores of the lake (Environment Canada, 2004). These values reflect the cooling influence of the lake during the early summer as inland, on average, the number of days exceeding 30 ranges from 7 central inland to near 21 in the southwest at Windsor.

The January mean temperatures vary from -4°C to -6°C across the region (Figure 19). The extreme minimum temperatures recorded in the Erie coastal zone range from -26°C at Port Colborne to -29°C in the southwest and near Harrow to -33°C in the central and eastern portions of the lake basin. Based on 1971 to 2000 data, in an average year, this area does not experience any days with temperatures less than -30°C (Environment Canada, 2004a).

5.1.2 Historical Temperature Trends

The historical trends in annual mean, maximum and minimum temperatures at four selected stations in the region are provided in Figure 20. The temperatures show little change to a small increase since the early to mid 1900's. Small, but statistically significant, increases are observed in annual minimum temperatures at three of the four stations, and in mean temperatures at two of the stations, with no significant trends in annual maxima. The largest significant temperature increase has occurred in the annual minimum temperature at Welland (approximately 1°C/100 years). All temperature data used in the analysis was obtained from Environment Canada's Homogenized Temperature Dataset, described in Section 4.1.2 (Mekis and Hogg, 1999; Environment Canada, 2006; Vincent and Mekis, 2006).

5.1.3 Precipitation

Precipitation in the Lake Erie basin is quite evenly distributed over the entire year and predominantly in the form of rain (Brown et al. 1980). Annual mean precipitation varies on average from 920 mm to 1000 mm over the region, with the lowest amounts at the west end of the lake, and the highest values in the central/Long Point and northeastern areas (Figures 21 and 22). During the summer, lake breezes flowing off the north shore of Lake Erie can converge inland with the Lake Huron lake breeze frontal zone, resulting in the development of thunderstorms in this northeast-southwest oriented convergence zone. During the late fall and early winter, southwesterly winds blowing colder air over an ice-free Lake Erie can result in significant lake-effect snowfalls on the northeastern end of the Lake and over Long Point. However, as the Lake normally freezes rapidly during the winter, lake-effect snowfalls off Erie are normally limited to the early winter months.

In this region, rainfall is the predominant contributor to total annual precipitation, with snowfall comprising generally 11 to 16% of the total with a minimum of 9% to the total at Pelee Island. Annual rainfall is lowest in the southwest (Harrow and Windsor) with the highest values on average recorded at Pelee Island and central region climate stations. The maximum snowfall amounts are observed in the eastern end of the Lake and near Long Point, while Pelee Island records an annual average of only 80 cm of snow. The extreme daily rainfall amounts recorded in the area range from 182 mm near Harrow to a low of 84 mm near Port Stanley between Ridgetown and Tillsonburg (Environment Canada, 2004b). Daily snowfall extremes range from a maximum of 60 cm near Port Colborne, to a low of 20 cm near Ridgetown (Environment Canada, 2004c).

5.1.4 Historical Precipitation Trends

Total precipitation and rainfall are increasing in the Lake Erie region, with statistically significant upward trends in each of these variables at three of the five selected stations (Figure 23). Precipitation has increased by approximately 120 to 160 mm/ 100 years, except for Harrow which has shown a larger increase of approximately 370 mm over 75 years. Similarly rainfall increases of 100 to 260 mm/100 years have been observed, with the largest increase at Harrow, 350 mm over 75 years. Both upward and downward trends in annual snowfall are observed at the selected locations, but only one significant increase of approximately 40 cm over 100 years is detected at Windsor. Historical monthly precipitation data from Environment Canada's National Climate Data Archive was used in the analysis of the Pelee Island precipitation data. The precipitation trend analyses at the remaining stations used data from Environment Canada's Adjusted Precipitation Dataset, described in Section 4.1.2 (Mekis and Hogg 1999; Environment Canada, 2006; Vincent and Mekis, 2006).

5.1.5 Wind

Wind speed and direction are influenced by the overlying synoptic flow, smaller scale weather phenomena (i.e., thunderstorms), local effects of topography, obstructions and lake/land induced breezes. Wind is therefore a highly variable parameter over short distances. As in most areas of Ontario, wind speeds are generally higher in the winter months than summer. Lake/land breezes are also common during the spring and summer months.

As described in Section 4.1.5, mean annual wind speeds at a 30 m elevation have been computed and mapped by Environment Canada for the Canadian Wind Energy Atlas (2004). The wind speeds are modelled at a 5 km horizontal resolution, and the speeds at 30 m can generally expected to be higher than those at a standard wind instrument height of 10 m. A sample map for the Lake Erie region is shown in Figure 24.

The highest wind speeds are found over the lake where surface roughness is reduced with speeds annually approaching an average of 8 m/s (29 km/h). In the near-shore environment, annual mean speeds of 5 to 6 m/s (18 to 22 km/h) are more typical. As in most areas of Ontario, wind speeds are generally higher in the winter months than summer.

5.1.6 Historical Wind Trends

As described in Section 4.1.6, Environment Canada-Ontario has investigated trends in historical wind observations across Ontario. Decreasing annual mean wind speed trends are found at two airport locations in the area, London and Windsor (Figure 25). It should be noted that London Airport is not in a near-shore environment, but allows for a longer-term record for this investigation. At both sites, average wind speeds have decreased annually and seasonally, with increases in the number of calm and less than 15 km/h wind occurrences (some of these trends are statistically significant). Wind speeds in excess of 60 km/h and peak wind speeds have generally shown either no change or a slight decrease annually and seasonally, but these trends were all non-significant. Wind has a major impact on storm surge flooding on Lake Erie (Gabriel et al. 1997) and the seiche effects have a significant impact on shipping movements through Lake St. Clair.

5.2 Lake Erie - Long Point Biosphere Reserve

5.2.1 Introduction

The Long Point Biosphere Reserve encompasses 27,000 ha and includes federal lands managed by the Canadian Wildlife Service, Long Point Provincial Park managed by Ontario parks, the Long Point Company and private landowners. This site was designated as a Ramsar wetland in 1986 and a Biosphere Reserve in 1986. Long Point is the largest sand spit and dune formation in the Great Lakes and extends approximately 34 km into Lake Erie. The Reserve includes the surrounding waters of Lake Erie to a depth of 10 m. In addition, the Big Creek National Wildlife Area and Turkey Point Provincial Park are located in the area (Robinson [Table 1]) (Figure 26). The sheltered Inner Bay has extensive submerged wetland vegetation and is a major staging and breeding area for waterfowl (Cheskey 1994, McCracken et al. 1981. Wilcox and Knapton 1994; Robinson [Table 1])

5.2.2 Physical Description

Long Point has formed from sediments carried by currents that originate from as far away as Rondeau (100 km). The point builds constantly to the south east at a rate of about 7 m/year. The Inner Bay is relatively shallow (1.6 to 12.3 m deep). Big Creek National Wildlife Area includes two artificial dyked impoundments created in 1984 that encompasses about 80 ha.

Periodic storms have had major impacts on the structure of the spit, occasionally breaching the spit and flooding into the Bay. Westerly winds create the relatively harsh wave and ice action on the south side of the spit, while the marsh on the north side is sheltered from the worst effects of waves and ice. In addition, the shores of the Inner and Outer Bay are subject to the short- and long-term fluctuating water levels,

Because of the dynamic nature of Long Point, the plant communities are generally successional and are able to adapt to the changing climate and lake conditions. The rate of erosion and deposition varies with the height of water in Lake Erie. The ice that has traditionally covered the Bay and parts of the Point has been much reduced in recent years resulting in greater erosion of the spit during winter storms. Ice in the Inner Bay was often responsible for freezing aquatic macrophytes and marsh plants and during spring break up, tearing large wads of vegetation loose, leaving exposed substrate and causing repeated successional plant growth in the nearshore aquatic environment.

5.2.3 Biological Description

Long Point has a variety of habitats including beaches, dunes, meadows, deciduous and coniferous woodlands and savannas, tamarack sloughs, marshes and ponds (McCracken et al. 1981). The plant communities contain distinct deciduous Carolinian forest and about 700 species of vascular plants have been recorded in the Long Point ecosystem of which 90 are rare in Ontario and four are found nowhere else in Canada. Some of the rare species include Cucumber Magnolia, American Sweet Chestnut, Tulip Tree, Hop Tree, and Hackberry (Robinson [Table 1]).

The marshlands and nearshore waters of Long Point, Big Creek and Turkey Point provide staging areas for a large proportion (approximately 50%) of the eastern Tundra Swan population (Figure 27), as well as 11% of the total population of redhead and 14% of canvasbacks (Ramsar database 2004). Tundra Swans feed on the agricultural fields around Long Point. Submerged macrophytes are an important food source for waterfowl (Knapton and Petrie, 1999; Pauls and Knapton, 1993), as well as providing nursery conditions for fisheries (Doka and Minns [Table 1]). A major increase in the number of Mute Swan on the lower Great Lakes is having a major impact on wetlands and associated waterfowl because of their aggressive nature and also because they feed solely on aquatic vegetation (Petrie [Table 1]) (Figure 27b). Rare breeding birds of Long Point include Prothonotary Warbler and Bald Eagle.

Invertebrates have not been extensively studied but include large numbers of migrating Monarch butterflies in autumn. Ontario's rarest crayfish, the Meadow Crayfish, occurs here.

Zebra and quagga mussels have colonized Long Point Bay and have become an important component of the diets of several species of waterfowl (Petrie and Knapton 1999). Many of Canada's reptile and amphibian species live in the Long Point ecosystem including the Snapping Turtle, Soft-shelled Turtle and Fowler's Toad (Robinson [Table 1]).

The Inner Bay provides habitat for most species of Lake Erie fish and Long Point ecosystems provide important spawning and nursery areas for Largemouth Bass, Smallmouth Bass, Yellow Perch and Northern Pike (Doka and Minns [Table 1]). Commercial fishing is largely restricted to areas outside the Inner Bay and Rainbow Smelt and Yellow Perch are the two most important species harvested. Several rare species of fish are to be found at Long Point including Spotted Gar, Warmouth, Lake Chubsucker, Pugnose Shiner and Yellow Bullhead.

5.2.4 Recreation

There are 256 campsites in the provincial park and a number of lodges in the immediate vicinity. The Long Point Company, established in 1886 as a private hunt club, has managed much of the marsh as an exclusive reserve for waterfowl hunting. Considerable recreational development has been completed around the Inner Bay. For example, in 1940 there were 50 dwellings and by 1990 there were 900. There are about 2,800 boat slips in 13 marinas in the area; the Inner Bay is an important recreational fishing area (Elder [Table 1]).

5.2.5 Land Use Planning and Management

The Long Point area is under the administrative control of four levels of government: national, provincial, regional, and local (Elder [Table 1]). In addition to the Long Point Company, there are many private land owners and farmers around Long Point Inner Bay that have an impact on the general area and the coastal ecosystems in particular (Francis et al. 1985, Wilcox and Knapton 1994).

The Norfolk County Official Plan (2005) recognizes the north shore of Lake Erie as one of the County's greatest physical assets and has proposed special zoning for this coastal zone. The Plan also recognises the Long Point-Turkey Point complex as the Long Point Biosphere Reserve and has developed policies to ensure protection of the natural features found here. The Plan also recognizes that coastal areas may be subject to severe storm events and those vulnerable communities at Long Point and Turkey Point should employ an emergency response plan.

5.2.6 The Changing Climate: Projections for the 21st Century

Long-term climate records from Ridgetown were analysed to give a general approximation of changes in temperature and precipitation during the 20th century that are occurring in the area west of Long Point. Since the early 1900's, temperatures at Ridgetown have shown little change to a small increase in annual minimum and mean temperatures and a 0.4°C non-significant increase in temperature. There has been a significant increase in annual rainfall of 130 mm since the early 1900's but little change in snowfall, resulting in a non-significant increase in total precipitation (about 115 mm) over the period (MacIver et al. [Table 1]).

Using the four GCM climate change scenarios described in Section 2.2, warming in the Long Point area is projected to be approximately 3 to 4°C by 2050. Total annual precipitation is expected to increase by approximately 1 to 14% by the same period. In addition to the changes in the annual average temperature and precipitation, extreme precipitation is likely to become more frequent and intense while there is also an increased risk of drought and more hot days. Mean annual Lake Erie water levels could decrease by as much as 0.8 m by 2050 and to just over 1 m by 2100. Ice cover on Lake Erie will decrease significantly during the 21st century. During the winter, the change in Lake Erie water temperature by 2100 is expected to be similar to the warming in air temperature, and subsequently a reduction in heavy lake-effect snow could be accompanied by an increase in winter lake-effect rain events (Kunkel et al., 2000).

5.2.7 Threats and Opportunities Resulting from Climate Change: Adaptation Options

Air Temperature

Opportunity: Longer shoulder seasons in spring and fall will increase the length of the warm-weather operating season, which may result in increased day use during periods of the park and adjacent recreational facilities. Increased operating periods will require changes to budgeting and staffing in the park. In addition, management strategies that address potential impacts from increased human activities on the Point's ecosystems may be required.

Opportunity: Increased temperatures may result in the expansion of Carolinian species in southern Ontario.

Threat: Warmer temperatures may result in the spread of Lyme disease beyond its present distribution that includes Long Point, Turkey Point and Rondeau and a number of other places in Ontario.

Opportunity/Threat: Earlier spring weather may precipitate earlier movement of Tundra Swans and other migrant waterfowl. Tundra Swans graze on local agricultural fields. A longer growing season will allow different crops to be grown and these may not be suitable for Tundra Swans, in which case special management activities may be required.

Threat: Introduced Mute Swans are non-migratory and are increasing rapidly in the lower Great Lakes. They feed more or less exclusively from the water and are fiercely territorial, preventing native waterfowl from breeding (Petrie [Table 1]). Their northward spread to the middle Great Lakes is of concern and they may have a significant impact on waterfowl that breed in the marshes.

Threat: The warmer winter temperatures are currently impacting ice cover and the dynamic shoreline is more susceptible to equinoctial gales and storm events.

Threat: Increased temperature and altered precipitation patterns will affect the sensitivity to fire which may become an issue in late summer with higher temperatures, and in extended periods of dry weather and lower water levels.

Threat: Increased number of hot days could result in conditions conducive to a higher incidence of poor air quality days. Long Point records some of the highest number of poor air quality days annually in Ontario, with long-range transboundary flow from the U.S. a major contributor to the air pollution (MacIver et al. [Table 1]). Under climate change, this number could increase further.

Precipitation Changes

Opportunity: Drier summer weather may result in increased numbers of park visitors seeking access to the beaches.

Threat: Extended dry periods during the summer or more frequent/intense drought may reduce water available for irrigation. Expanded water conservation measures will be needed.

Threat: Increased fire hazard. A warmer climate with increased frequency and severity of drought could increase the duration and significance of severe fire hazards.

Threat: Increased numbers of severe rainfall events will have major impacts on streams and drainage canals in the hinterland (Elder [Table 1]). Continued programs by the Conservation Authority to naturalize stream channels and educate landowners on the benefits of properly vegetated streams and headwaters should ameliorate this vulnerability (Oliver [Table 1]).

Wind Changes

Opportunity: Emerging wind patterns may improve sailboat and beach sailing.

Threat: The spit is susceptible to severe storms and may be significantly eroded. There may be damage to trails and public and private facilities. It is probable that winter storms will result in changes in dune dynamics and an increase in drifting sand in parking lots and around facilities. The spit may rebuild in time.

Threat: Emerging wind patterns may damage wind sensitive trees along the spit and surrounding shorelines. Management agencies and private land owners may need to plant and/or manage for wind resistant vegetation along the shoreline and spend more on maintenance.

Threat: An increase in the number of severe storms will have an impact on coastal areas. In spite of potentially lower water levels, these severe storms may occur during high water periods and significantly alter coastal ecosystems. Planning by Norfolk County recognizes the vulnerability of the coastal zone and is developing special zoning for this area.

Water Temperature Changes

Opportunity: Longer swimming season as a result of warmer water will lead to increased park usage in the summer months.

Opportunity/Threat: A longer ice free period will permit waterfowl to remain in the area, increasing viewing opportunities. Any increase in the length of time waterfowl use the area will increase the pressure on aquatic vegetation and associated invertebrate food items.

Threat/Opportunity: Loss of some species from and the addition of new species to the sport fishery. Changes in fish community structure and function may require changes to recreational fishing regulations.

Threat: Water quality degradation caused by increased distribution and abundance of algae and impacts from pollution such as selenium and pesticides. A longer growing season for aquatic algae will increase algal problems and Inner Bay water quality issues. Also it could lead to an increase in noxious blue-green algae.

Threat: Bio-magnification of pollutants. Zebra mussels growing in the lake are accumulating high levels of selenium and other pollutants that are passed on to diving ducks such as Lesser Scaup (Petrie [Table 1]). Therefore the longer a species spends at Long Point the greater the increase in their body burden prior to continuing to their breeding grounds.

Threat: Warmer water is likely to permit more rapid colonization by non-native species such as Common Reed that is already expanding along Long Point (Petrie [Table 1]).

Threat: Invasive species such as many Ponto-Caspian species will have the opportunity to expand their populations with warmer waters (MacIssac; Petrie [Table 1]).

Water Level Changes

Opportunity: Increased beach area with lower lake water level. The increased area will provide more beaches for recreational activities on the west side of the spit.

Opportunity: The Big Creek wetland impoundments will provide interim habitats for a wide variety of plants and animals in the event of rapid water level changes (Robinson [Table 1]).

Threat/Opportunity: A change in water depth will have a major impact on marinas and private slips particularly for boaters who gain access through the marsh. There will be increased pressure to clear navigation channels in the marsh. A small drop in lake water levels will result in a significant increase in the size of the boundaries of the protected areas due to shallow nature of the Bay.

Threat: Reduced lake levels will cause inshore marshes to dry out and the marshes may migrate lakeward. This water level drop may encourage successional plants to colonize the area and there will be more woodland on the spit.

Water Movement - Lacustrine Changes

Threat: The current water movements are responsible for the maintenance of the spit beaches and circulation within the Bay. Changes to sediment supply brought about by changes in water level may have an impact on the dynamics of the Point.

5.3 Lake Erie - Pelee National Park

5.3.1 Introduction

Pelee National Park encompasses 1,564 ha at the western end of Lake Erie as a 17 km long spit extending south to the 42nd parallel, which is the most southern part of mainland Canada (Figure 28). The nearest town is Leamington. The park includes a significant deciduous Carolinian forest with many species that are otherwise rare in Ontario and a large marsh on the easterly margin of the spit. It is famous for being a staging area for migratory birds and is a Mecca for birders. About 70% of the park is wetland and about 30% forest, dune and successional lands that are changing from previous agricultural uses.

The park is comprised of several park zones that include the Marsh and East Barrier Beach, the Northwest Beach, and the Ridge and Trough Swamp Forest (Parks Canada 1995). A Historical Zone encompasses a small part of the park and includes old farm buildings associated with early settlement of the land. Park infrastructure is located in the Development Zone and includes campgrounds, beach areas, the park store, roads, and administration and maintenance buildings.

5.3.2 Physical Description

The peninsula is the most significant landform, created from the deposition of sand up to 75 m thick on top of a ridge of Devonian limestone. In addition, two sandbars have formed: a narrow treeless eastern ridge and a larger, wooded western bar. An extensive nationally significant wetland has formed between the ridges. The sand peninsula juts out 17 km into Lake Erie, where the sand spit tip is prone to erosion (Figure 29). With the lack of ice cover in 2006 the tip was eroded again in a major storm on March 13, 2006. This has happened previously and the tip and beaches are a dynamic system subject to change.

5.3.3 Biological Description

The majority of the park is marsh (approximately 11 km^2) and while it is a major part of the park, it was once part of a much larger system extending around on the north shore of Lake Erie to Wheatley. Much of the other marshland has been dyked and drained for agricultural purposes. The marsh's size, biodiversity and importance to staging and breeding waterfowl contributed to its being designated as a RAMSAR site and Important Bird Area (IBA). It is also a major staging area for about 20,000 migratory Monarch butterflies. The marsh area contains several large open water areas and many small pools that make it an important area for breeding birds, reptiles, amphibians and fish. There are a number of vertebrate species that are found in few other places in Canada such as the Eastern Mole, Southern Flying Squirrel, Prothonotary Warbler, Yellow-breasted Chat, Louisiana Waterthrush, and Warmouth. The offshore waters provide important habitats for some 10,000 Common Merganser and 50,000 Red-breasted Mergansers. A number of COSEWIC and COSSARO species inhabit the park and some of these may be affected by climate change.

The swamp forest and dune slacks at Pelee are very susceptible to fluctuating Lake Erie water levels. For example, in the 1970's high water levels resulted in the flooding of the White Elm and combined with wind throw resulted in the thinning out of the swamp. However, with lower lake levels in the past decade and warmer years, succession is resulting in the reforestation of this area.

The Carolinian forest on the western spit is composed of many species that are rare in Canada, including the Honey Locust, Chinquapin Oak, Swamp White Oak, Chestnut Oak, Tulip-tree, Red Mulberry, Sycamore, Blue Ash, and Sassafras. Hackberry is a sub-dominant in a number of the forest community types at Pelee and, while not rare in southern Ontario, is nevertheless a characteristic southern species. Small patches of Red Cedar savannah on the eastern side of the spit between the forest and the swamp forest provide habitat for the rare Prickly Pear Cactus and a number of sparrows and other open country birds.

The forest provides a major feeding area for migrating birds in the spring after their crossing of Lake Erie, and birds landing at the spit make their way down through the forested area, refuelling before continuing their journeys to their breeding areas. At least 370 species have been sighted in the park and surrounding area en route to South America, the Arctic, Europe and Asia. At least 100 species of birds nest in the park and the Carolinian forest provides habitat for species such as the Prothonotary Warbler, Carolina Wren, Henslow’s Sparrow and Yellow-breasted Chat. Pelee attracts a large number of birders, particularly during the spring migration period.

While many species of insects and other invertebrates live in the park, Pelee is best known as an important staging habitat for Monarch Butterflies, which gather each autumn en route to winter habitat in Mexico.

Twenty eight species of reptiles and amphibians have been recorded in the park. Common species include the American Toad, Green Frog, Leopard Frog and the Bullfrog. The eastern barrier ridge provides an important nesting area for the Spiny Softshell, Blanding’s Turtle, the common Midland Painted Turtle and the Snapping Turtle.

Thirty-four fish species inhabit the marsh which, besides providing habitat for warm water fish, also provides important nursery areas for offshore species. Characteristic fish species inhabiting surrounding waters include Northern Pike, Walleye, Smallmouth Bass, Yellow Perch, White Perch, Bullheads, and Sunfish.

Resident mammals include the Chipmunk, Mink, Beaver, Muskrat, Red Fox, Coyote, and Raccoon. A resident herd of White-tailed Deer has significantly impacted understorey vegetation in the park and has to be harvested from time to time.

5.3.4 Recreation

Pelee National Park provides recreational opportunities primarily for day users; group camping is still permitted, although it is being phased out. At present there are 1,100 parking spaces in the park; generally Parks Canada closes the gate when 1,000 vehicles have entered the park. The annual number of visitors to the park ranges from 410,000 to 540,000 and, because of the fragile nature and limited size of the park, there are no plans to try and increase the number of visitors other than by extending the shoulder seasons. Interpretive programs are regularly scheduled during the spring bird migration period and in the fall for the migrating monarch butterflies. A number of program activities and the park shop are coordinated with help from the Friends of Point Pelee.

5.3.5 Land Use Planning and Management

The Point Pelee National Park Management Plan (Parks Canada 1995) is currently being updated in consultation with the public and stakeholders. It addresses a number of features and processes that may be affected by climate, although no direct reference to climate change is made in the 1995 document. Some park structures such as the park's stores compound near the Marsh Boardwalk are due for removal and parking is being reorganized.

5.3.6 The Changing Climate: Projections for the 21st Century

Since the early part of the 20th century the climate has warmed and precipitation has increased in this area. For example, at Rondeau Provincial Park the mean current temperature increased 0.3^{0}C during the period 1923 to 1999 relative to the 1961 to 1990 average temperatures, the warmest periods on record are in the 1950's to about 1960 and the early and late 1990's. Annual mean and minimum temperatures have significantly increased by 0.7°C since the early 1900's, with a somewhat smaller but non-significant increase in maximum temperature for the same period. At Pelee Island, non-significant increases have been observed in annual precipitation and rainfall since the 1890's (156 and 257 mm) while annual snowfall showed a non-significant decrease of 54 cm.

By the mid 21st century, warming of approximately 3° to 4°C at Pelee National Park, accompanied by an increase in total annual precipitation by 1 to 14%, is projected by the four GCM scenarios described in Section 2.2. As discussed in Section 5.2.6, climate change in the 21st century is also expected to bring an increase in frequency and severity of extreme weather events, a decline in Lake Erie water levels, reduction in winter lake ice cover and decrease in heavy lake-effect snow effects.

5.3.7 Threats and Opportunities Resulting from Climate Change: Adaptation Options

Air Temperature

Opportunity: Longer shoulder seasons in spring and fall will increase the length of the warm weather operating season, which may result in increased day use during periods when the park can handle additional visitors (Hui and Huang 2000). Increased operating periods likely will require changes to budgeting and staffing in the park. In addition, management strategies that address potential impacts from increased human activities on the park's ecosystems may be required particularly in light of some of the restoration activities underway.

Opportunity/Treat: Increased temperatures may result in the expansion of Carolinian species in southern Ontario, providing dispersal areas for species from the park. Specific habitats like the red-cedar savannah may expand with drier weather.

Threat: The warming winter temperatures will contrive to reduce the ice-in season and the dynamic shoreline will be more susceptible to equinoctial gales and storm events.

Threat: Increased temperature and altered precipitation patterns will affect the success of trees planted during restoration projects. Therefore, park's staff will need to account for the physiology and adaptability in a new climate.

Precipitation Changes

Opportunity: Extended dry periods during the summer or longer and more serious drought may result in larger numbers of people coming to the park to utilize the beaches during the summer months.

Opportunity: Species such as the prickly pear cactus may do better and the dry savannah habitat may expand increasing the amount of this type of habitat in Canada.

Threat: Fire may become an issue in late summer with higher temperatures and during any periods of extended dry weather and low water levels. Park staff will need to develop a plan to manage the park under altered fire hazard conditions.

Wind Changes

Opportunity: Emerging wind patterns may improve sailboat and beach sailing.

Opportunity: Emerging wind patterns could result in a more active dune system. On the other hand, with lowered water levels the dune system will migrate lakeward and the walks from the parking lots to the beach will be longer. This may require the extension of boardwalks.

Threat: Emerging wind patterns may damage wind sensitive trees along shorelines and in wooded areas, including some of the trees susceptible to wind throw such as poplars and maples. Parks Canada may need to plant and/or manage for wind resistant vegetation along the shoreline and allocate more staff for clean up of downed trees prior to the spring birding season.

Threat: The spit was blown out in March 2006 by a severe windstorm and if a series of storms batter the tip, there may well be damage to trails and infrastructure. The spit may rebuild in time but a more flexible system may need to be installed.

Water Temperature Changes

Opportunity: Longer swimming season as a result of warmer water will lead to increased park usage in the summer months.

Threat/Opportunity: Loss of some species from and the addition of new species to the sport fishery. Changes in fish community structure and function may require changes to recreational fishing regulations.

Threat: Water quality degradation caused by increased distribution and abundance of algae and impacts from pollution. Parks Canada may need to allocate more resources to beach cleaning and may have to close beaches if water quality becomes an issue.

Threat: Warmer water is likely to permit more rapid colonization by non-native species.

Water Level Changes

Opportunity: Increased beach area with a decline in lake water levels. The increased area will provide more beaches for recreational activities on the west side of the park.

Threat/Opportunity: Changes to the swamp ecosystem which may move lakeward as new shallow areas are created. Part of the swamp ecosystem will dry out if lake levels drop. Terrestrial plant species, particularly annuals, will invade these new “upland” areas. This water level drop may encourage successional plants to colonize the area. The marsh boardwalk may require extension in response to the outward reformation of the marsh.

Threat/Opportunity: A change in the park boundary as defined by water depth. A major potential impact of climate change will be on the terrestrial boundaries of the park. A small drop in lake water levels will result in a significant increase in the size of the park. Park boundaries will need to be redrawn and integrated with park Management plans.

Water Movement - Lacustrine Changes

Threat: The current water movements are responsible for the maintenance of the spit and beaches of the park. Changes to sediment supply caused by changes in water level may have an impact on the dynamics of the beach and dune system in the park.

5.4 Lake St. Clair - Walpole Island

5.4.1 Introduction

Lake St. Clair links Lake Huron and Lake Erie. Lake Huron drains into Lake St. Clair via the St. Clair River and is the largest estuary or delta system in the Great Lakes. This small shallow lake encompasses 694 km^2 with an average depth of 3 m. The Lake drains through the Detroit River into Lake Erie. Windsor (population 305,000) and Detroit (population 951,000) are located on the shores of the Detroit River. Upstream, or north of Lake St. Clair lies Sarnia (population 87,000) a major petrochemical city. The Walpole First Nation (population approximately 1,840) occupies the Walpole, Squirrel and St. Anne Islands, an area of approximately 17,000 ha (137 km^2) of coastal marsh, grassland and oak savanna which is a significant habitat mosaic found no where else in Canada (Figure 30). The Walpole First Nation has lived in the area for generations and depends on farming and the coastal waters for its livelihood.

5.4.2 Physical Description

Much of the natural coast line of Lake St Clair has been dyked and impacted by agriculture. About one sixth of the land mass is occupied by forest, savanna and prairie habitats and another sixth is devoted to agriculture. The remaining two thirds is comprised of wetlands, sloughs, channels and the adjacent shallow lake waters (Wake 1997).

The most significant feature of the Lake St. Clair wetlands and surrounding shoreline vegetation is the shallow nature of the lake and the very gradual gradients that occur on the lake bottom (Figure 31). Accordingly, small drops in water level have profound effects on the location of the “edge” of the lake. The high water levels of the 1980's resulted in flooding and storm damage to coastal properties while the low water levels of the late 1990's and early years of the 21st century have caused problems for the shipping industry. This means that the 13 marinas on the Canadian side of the Lake and the St. Clair River with more than 2300 boat slips are potentially affected by water level fluctuations (Figure 31). Compounding natural low water levels are seiche effects caused by strong winds that may drop the water level by several feet, leaving boats stranded in shallow waters.

Lake St. Clair is used extensively by Canadian and American fishers - more than 60% of anglers travel into Ontario waters from U.S. waters to fish for walleye, yellow perch, smallmouth bass and muskellunge.

A 40 mile channel has been dredged between the St. Clair River and the Detroit River to a depth of 9 m to permit the passage of freighters between the Upper and Lower Great Lakes (Figure 31). The channel is dredged every two years and since 1970 the material has been disposed of in confined disposal facilities because of high levels of mercury and other pollutants.

5.4.3 Biological Description

Eastern Lake St. Clair lies within the Lake Erie Lowlands Ecoregion and contains the Walpole Island First Nation, the Lake St. Clair Marshes, and the Lake St. Clair National Wildlife Area. This area is comprised of some of the most diverse and rich ecosystems in Canada (Herdendorf et al. 1986).

The Walpole First Nation manages agricultural lands, marshes, wet and dry, prairie meadows, savannas and forest on the three islands constituting the Reserve (Resources Futures International 2004). Over 800 species of vascular plant have been recorded of which 100 are rare (Wake 1997). Significant areas of natural grassland occur on the islands as well, including Southern Slender Ladies Tresses, Prairie Rose, Colicroot, Spiked Blazing Star, Prairie Dock and Showy Goldenrod. The forest is an oak savanna habitat perpetuated by fire (Hoffman and Lamb, 1980 in Eagles & Beechey, 1985). Plant communities include: oak-hickory forest; Silver Maple and varied wetland forest types; marsh; wet and dry prairie meadow systems (Hoffman and Lamb, 1980; in Eagles and Beechey, 1985). The southern end of Walpole Island forms an extensive wetland complex of cattail marshes which grade into wet prairie and drier prairie. The area is comprised of extensive wet-mesic and wet prairies bordered by one of the largest moist savanna complexes in Ontario. The savannas are dominated by Bur Oak, Swamp White Oak, Shagbark Hickory and other less common hickories. Forest openings are dominated by the richest variety of moist prairie species found in Ontario and include extensive numbers of rare plants, including White Gentian, Oval Ladies'-tresses and Small White Ladies' Slipper (Woodliffe and Allen 1990).

The **Lake St. Clair Marshes** are of international significance where large numbers of waterfowl stage during spring and fall migration and breed. (Cheskey and Wilson 2001). Changing water levels have had major impacts on the proportion of emergent cattail marsh and submerged beds of Muskgrass and other waterweeds, which in turn negatively impacts muskrat habitat and the food and breeding habitat for waterfowl.

The **St. Clair National Wildlife Area** is a nature reserve located on eastern Lake St. Clair west of Chatham. The cattail marshes and small ponds along the lake shore provide important stopover habitat for migrating waterfowl, including large numbers of Tundra Swans. The marshes also provide habitat for Yellow-headed Blackbird, King Rail, forster's Tern and Least Bittern. Several turtle species inhabit the NWA, including the eastern Spiny Softshell Turtle and Blanding's Turtle. This site has been recognized as a Wetland of International Significance under the Ramsar Convention.

5.4.4 Recreation

Lake St Clair and the surrounding coastal areas provide significant recreational opportunities for fishers, hunters, boaters, and naturalists.

5.4.5 Land Use Planning and Management

The eastern Lake St. Clair coastal zone is managed by a number of agencies and organizations. For example, Walpole First Nation is responsible for the administration of its lands and has been a leader in sustainable living initiatives (Smith and Weir 2002). The Lake St. Clair Marsh, IBA, and Wildlife Area are managed jointly by a number of agencies including the Canadian Wildlife Service, Bird Studies Canada, the Municipality of Chatham Kent, the Essex Conservation Authority, Ducks Unlimited Canada, and a number of NGOs and private organizations.

5.4.6 The Changing Climate: Projections for the 21st Century

The Windsor region has also warmed and shown increases in precipitation since the early part of the 20th century. Annual minimum temperatures have increased significantly by 0.7°C since the early 1900's, with somewhat smaller but non-significant increases in mean and maximum temperatures. Since the late 1890's, annual total precipitation, rainfall and snowfall have increased significantly at Windsor: 132 mm, 92 mm, and 40 cm, respectively.

Based on the four GCM scenarios described in Section 2.2, by 2050 annual warming of approximately 3° to 4°C can be expected in the region, with an increase in total annual precipitation by 1 to 14%, is projected by the four GCM scenarios described in Section 2.2. As discussed in Section 5.2.6, climate change in the 21st century is also expected to bring an increase in frequency and severity of extreme weather events. Lake St. Clair and Lake Erie water levels are expected to decline. Winter ice coverage on St. Clair is projected to diminish significantly and it may become navigable year round.

5.4.7 Threats and Opportunities Resulting from Climate Change: Adaptation Options

<u>Air Temperature</u>

Opportunity: Longer shoulder seasons in spring and fall will increase the length of the warm-weather recreational opportunities. This will benefit the local economy.

Opportunity: A longer growing season could provide increased economic benefits for local farmers.

Opportunity: Increased temperatures may result in the expansion of Carolinian species in southern Ontario. The area around eastern Lake St. Clair will provide an important source of plants and animals providing there are suitable areas to the north and east that they can colonize.

Threat: A warm climate may alter prey life history traits and create a predator-prey dysjunct, which could lead to significant changes in the presence/absence of species in each ecosystem.

Threat: Warmer winter temperatures will continue to reduce ice cover and the dynamic shoreline will be more susceptible to equinoctial gales and storm events with no ice cover.

Threat: Increased temperature and altered precipitation patterns will alter tree species 'climatic range', which will need to be addressed in afforestation and reforestation programs.

Threat: The increased risk of fire will require management. A warmer climate with potentially more intense and frequent droughts could generate more frequent and longer periods of severe fire hazard.

Precipitation Changes

Opportunity: Extended dry periods during the summers may result in larger numbers of people coming to the area to utilize the boating opportunities during the summer months.

Opportunity/Threat: The extended dry periods in mid to late summer may well result in more savanna communities that are well adapted to fire regimes, replacing forested communities.

Threat: There will be an increased need for irrigation during the summer.

Wind Changes

Opportunity: Emerging wind patterns may improve sailboat and beach sailing opportunities.

Threat: Emerging wind patterns may damage wind sensitive trees along shorelines and in wooded areas, including some of the trees susceptible to wind throw. Land management agencies and organizations, and private landowners may need to plant and/or manage for wind resistant vegetation along the shoreline and spend more on maintenance prior to the spring birding season.

Threat: Increasing wind-caused seiche effects may hamper shipping activity and limit shipping to prescribed, dredged routes.

Water Temperature Changes

Opportunity: Longer swimming season as a result of warmer water will lead to increased park usage in the summer months.

Threat: Water quality degradation caused by increased distribution and abundance of algae and other impacts from pollution may result from warmer water temperatures.

Threat/Opportunity: Changes in fish community structure and function may impact recreational fishing. For example, cool water and cold water species are at risk with warming water temperatures while warm species will do much better.

Threat: Warmer water is likely to permit more rapid colonization by non-native species, particularly Ponto Caspian species which evolved in warmer waters (MacIssac [Table 1])

Water Level Changes

Threat/Opportunity: Reduced lake levels may cause in-shore marsh to dry out. Additionally, the marsh ecosystem boundaries may migrate lakeward. Existing marshland may dry out and evolve into prairie communities or be converted into agricultural uses.

Threat/Opportunity: With declines in water levels there will be changes to property boundaries which will have legal implications. For example, where legal descriptions indicate the property extends to high water mark, a 1 m drop in lake level would result in considerable lakeward expansion of property boundaries by 1 to 6 km (Lee et al. 1996).

Threat: There will be continued pressure to dredge the main channel through Lake St. Clair to permit continued use by freighters. This has major repercussions to water levels in Lakes Huron and Michigan which are already believed to be at low levels as a result of dredging through the Lake St. Clair system (Baird and Associates 2005).

Threat: There is considerable shoreline development for houses and clearing of wetland vegetation and dredging of channels has a major impact on the coastal area. Access to the water is a major issue and changing water levels are likely to have major repercussions on the coastal zone and ownership issues.

Threat: There will likely be substantial changes to the viability of marinas in the vicinity as only those with deeper water access are likely to afford dredging.

Water Movement - Lacustrine Changes

Threat: The current water movements are believed to be altered by the continued dredging of the main channel.

Threat: Changes to sediment supply brought about by changes in agricultural practices within the watershed may have an impact on the nearshore environment of the marshes.

6.0 LAKE HURON

6.1 Climate

6.1.1 Temperature

The coastal temperature and precipitation patterns of the Lake Huron region are strongly influenced by the Lake and the predominant west and northwest off-lake wind flows (Phillips, 1990). Inland, the higher elevation of the Dundalk Highlands also influences the climate in this area. Within this modified continental climate, the Lake Huron region experiences a large range in annual mean temperature (Figure 32). In the north of the region, annual mean temperatures for the 1971 to 2000 period are close to 4°C, with the near shore temperatures gradually increasing southward to 8°C in the Sarnia area. A colder pool of temperatures is also observed over the Dundalk Highlands, where higher elevation contributes to annual temperatures that are as cold as those in the northerly parts of the region (Brown et al. 1980).

The July mean temperature in the nearshore lake environment varies between 18°C and 21°C with the warmest temperatures on the southern shores near Sarnia (Figure 33). Somewhat cooler temperatures, 18°C to 19°C, are observed over the Dundalk Highlands. Winds, including lake breezes, off Lake Huron and Georgian Bay, serve to cool the shoreline environments during the day in the spring and summer. The higher elevations of the Highlands result in somewhat cooler temperatures in this area as well. The extreme maximum temperatures found in the Lake Huron shoreline environment vary from 33.9°C near Gore Bay, to a high of 39.5°C in the Sarnia area, while the average number of days per year with temperatures greater than 30°C range from zero to 19 days for those same locations, respectively (Environment Canada, 2004).

The January mean temperature for the region ranges from -9°C in the north, to -5°C in the south (Figure 34). The moderating effect of the lake is evident on Manitoulin Island, the Bruce Peninsula and the eastern shoreline. The influence of elevation is evident with the colder temperatures over the Dundalks. The extreme minimum temperature recorded in the region is -43°C in the Parry Sound area to -29°C in the Sarnia area, while the average number of days per year with temperatures less than -30°C ranges from 7 to zero days for the same locations, respectively (Environment Canada, 2004a).

6.1.2 Historical Temperature Trends

Historical temperature records indicate that mean and minimum temperatures have significantly increased approximately 1°C and 1°C to 2°C, respectively, over the last 65 to 80 years, at three of the four selected locations (Figure 35). Only the Brucefield station in the south of the region shows a statistically significant increase in maximum temperature as well, approximately 1°C over a 90 year period, while the only significant increase at Beatrice is in maximum temperature (0.8° over 123 years). With the exception of Beatrice where the maximum temperatures have increased the most, the greatest warming has been in minimum temperatures. The temperature data used in the analysis of Beatrice and Brucefield is based on historical monthly temperature data from Environment Canada's National Climate Data Archive. These stations were selected for their long temperature record in a region lacking stations with homogenized temperature data. For the temperature trend analysis at the remaining three stations, data was obtained from Environment Canada's Homogenized Temperature Dataset, described in Section 4.1.2 (Mekis and Hogg, 1999; Environment Canada, 2006; Vincent and Mekis, 2006).

6.1.3 Precipitation

Precipitation in the Lake Huron region is significantly influenced by offlake/onshore enhancement and topography, resulting in a wide range in annual precipitation over the basin. Annual mean precipitation averages near 1,200 mm to the lee of central Lake Huron and east of Georgian Bay in the Muskoka Highlands, representing some of the highest values of annual precipitation in Ontario. A local maximum in precipitation is also observed over the higher elevations of the Dundalk Highlands. The minimum annual totals are observed over Manitoulin Island and in the Sarnia area at the south end of the lake where 800 to 850 mm of precipitation falls in an average year (Figure 36). Seasonally, precipitation is higher in the winter months than summer (Brown et al, 1980). Cold arctic air blowing over open waters during the late fall/winter can generate heavy lake-effect snow/snow squalls to the lee of Lake Huron and Georgian Bay. Although west and northwest winds are the predominant flows in the region, northerly flows can produce lake-effect snows off southern Lake Huron and Georgian Bay, while southwest winds can generate snow squalls over the Bruce Peninsula and to the lee of Georgian Bay. In the summer, severe thunderstorms can be generated inland within the Lake Huron lake breeze frontal zone, which can also converge with the Lake Erie lake breeze.

Rainfall in an average year ranges from approximately 625 mm over Manitoulin Island to 750 to 800 mm in the southern part of the region, while snowfall totals range from a minimum of 125 cm in the southern part of the region to a maximum over the Bruce Peninsula, 415 mm at Wiarton. The rain to snow ratio varies considerably across the region. Rainfall contributes a maximum of approximately 85% to the total annual precipitation in the south (i.e., Sarnia) and a minimum of around 70% at Wiarton in the snow belt area of the Bruce Peninsula (Figure 37).

The extreme daily rainfall amounts in the region range from 74 mm in the Parry Sound area, to 159 mm in the area south of Brucefield (Environment Canada, 2004b). In general, lower extremes of rainfall are found in the northern part of the region. Extreme daily snowfall totals range from a low of 32 cm in the south, to a high of 68 cm at Muskoka (Environment Canada, 2004c).

6.1.4 Historical Precipitation Trends

Total annual precipitation and rainfall have significantly increased at all three of the selected climate stations in the past century. Annual precipitation has increased by about 180 to 250 mm over the past 80 to 100+ years, while upward trends in rainfall over the same period range from 95 to 235 mm. There has also been a smaller non-significant increasing trend in snowfall at two stations, with a significant upward trend of approximately 130 cm over 100 years at Lucknow and little change at Beatrice (Figure 38). The precipitation trend analyses at the four stations used data from Environment Canada's Adjusted Precipitation Dataset, described in Section 4.1.2 (Mekis and Hogg 1999; Environment Canada, 2006; Vincent and Mekis, 2006).

6.1.5 Wind

Wind speed and direction are affected by the prevailing winds associated with weather systems, local topography (i.e., upland regions), obstructions and lake/land induced flows. Wind direction and speed can therefore be expected to vary significantly across the Lake Huron region. As in most areas of Ontario, wind speeds are generally higher in the winter months than summer. Lake/land breezes are also common during the spring and summer months. Of all the Great Lakes lake breezes, case studies conducted by Environment Canada have shown that the Lake Huron breeze penetrates the farthest inland, with the greatest extent being about 100 km from its southern shore to Lake Erie.

As described in Section 4.1.5, Environment Canada has developed the Canadian Wind Energy Atlas (2004) which has modelled mean annual wind speeds at a 30 m elevation and 5 km horizontal resolution. These wind speeds are generally higher than those recorded at a standard wind instrument measurement height of 10 m. A modelled wind climatology map for the Lake Huron region is provided in Figure 39. Maximum average annual wind speeds of 7.5 m/s (27 km/h) are found over the mid lake areas of the region, while the eastern shore of the lake, in a prevailing westerly flow, has average annual wind speeds of 6.5 to 7 m/s (23 to 25 km/h). Elevated wind speeds also extend inland including the Dundalk Highland area south of Georgian Bay.

6.1.6 Historical Wind Trends

As described in Section 4.1.6, Environment Canada-Ontario has investigated trends in historical wind observations across Ontario. At the two selected airport locations in the Lake Huron region, there has been a general decrease in the annual and seasonal mean and peak wind speeds over the 1974 to 2004 period, and approximately half of these trends are significantly significant (Figure 40). The incidence of winds greater than 60 km/h has shown a decrease annually, with little change or decreases during the seasons, while the percentage of calms has shown both increases and decreases but only some of these trends are statistically significant.

6.2 Lake Huron – Goderich

6.2.1 Introduction

Goderich is located on the eastern shore of Lake Huron approximately 230 km west of Toronto. The town of 7,600 people is organized around a harbour that provides access to ocean going vessels up to 222 m in length. This harbour has been dredged to an average depth of 7.3 m and is the only deep water harbour on the eastern side of Lake Huron (Figure 41).

Approximately 100 ships use the harbour every year. Goderich is the site of the largest salt mine (Sifto) in the world that is located 518 m beneath the town and extends 6.4 km out beneath

Lake Huron. About 75 ships are used to transport salt and 25 are used to transport grain annually. There is a grain terminal that provides a shipping location and handles 44,000 tonnes/yr.

Immediately north of the harbour is the mouth of the Maitland River on which there are two marinas (Maitland Inlet Marina, Maitland Valley Marina and Snug Harbour) providing berths for 300 boats.

South of the harbour, Goderich beach provides swimming areas, play areas and a lakeshore walkway for residents and visitors. Two groynes extend out from the shoreline, to retain beach sand and provide a safe swimming area (Figure 42).

The area is a major recreational destination for western Ontario. There is a Falls Conservation Area on the Maitland River a few kilometres in land with 185 camp sites. Salmon, Trout and Bass fishing are popular spring and fall activities.

6.2.2 Physical Description

The south eastern Lake Huron coast is relatively homogeneous, although a few rock outcrops do exist. For much of its length, the coast consists of sandy beaches backed by bluffs of varying heights. The offshore area is relatively shallow and therefore a shipping hazard. For example, in 2001, a bulk carrier hit bottom (7.34 m) some 1.25 nautical miles west of the harbour (Transport Safety Board of Canada 2001). The shoals and channels are marked, but are subject to change caused by littoral drift sediments (TSBC 2001, Schwartz et al. 2004).

The Maitland River enters Lake Huron at Goderich and was probably one of the reasons for the area’s initial settlement. It has a catchment area of 32,000 km^2 and a major run-off in spring.

6.2.3 Biological Description

Goderich is located in the Great Lakes-St-Lawrence Forest Region. Most of the natural vegetation in the area was cleared in the latter part of the nineteenth century. Currently, only remnant pockets of forest remain. Because of the high energy coast line, there are no extensive areas of wetlands along this shoreline.

The mouths of the creeks and rivers that enter Lake Huron may be fringed with wetlands though the lower reaches of the Maitland River have been altered with the development of marina and harbour facilities. However, significant spawning habitat for bass and trout remains upstream.

Principal recreational activities include boating, swimming and fishing. There are limited winter activities.

6.2.4 The Changing Climate: Projections for the 21st Century

Since the early 1900's, temperatures at the Brucefield climate station, located southeast of Goderich, have shown significant and consistent increases in annual mean, maximum and maximum temperatures of about 1°C. Due to a significant number of missing daily precipitation observations at Brucefield, no corresponding precipitation trend analysis could be undertaken for this station. However, at Owen Sound, total annual precipitation and rainfall have shown significant increases of 253 and 234 mm, respectively, since the late 1800's, while annual snowfall has shown little change (+18 cm) over the same 109 year period.

The GCM output from the four climate change scenarios described in Section 2.2 projects annual warming of 2° to 4°C in the Goderich area by the 2050's. Total annual precipitation is expected to increase by approximately 2 to 12% by the same period. In addition to the changes in the annual average temperature and precipitation, extreme precipitation is likely to become more frequent and intense while there is also an increased risk of drought and more hot days. Mean annual Lake Huron water levels could decrease by as much as 1 m by the middle of this century and up to 1.4 m by late in the century. A significant reduction in heavy lake-effect snow off the eastern shores of Lake Huron is expected winter temperatures warm (Kunkel et al., 2000). However, there is also the possibility that in the near future with Lake Huron and Georgian Bay potentially remaining ice-free for a longer period during the year, lake-effect snowfall could actually increase.

6.2.5 Threats and Opportunities Resulting from Climate Change: Adaptation Options

<u>**Air Temperature**</u>

Opportunity: Warmer temperatures will result in longer farming and recreational season. This should help to provide for a longer economically active season for local business.

Opportunity: There may be an extension of the recreational season for hotels and bed and breakfasts in the town.

Opportunity: Growing seasons are expected to shift which may provide increased opportunities for an increased diversity of crops.

Threat: Warmer winter temperatures will result in changed rain/ice/snow regime. This may well affect the use of salt on roads that drain into the river and harbour.

Threat: Increased temperatures may affect the success of trees planted in shoreline environments.

Threat: The increased number of hot days could result in conditions conducive to a higher incidence of poor air quality days. Some of the poorest air quality in Ontario occurs along the eastern Lake Huron shore, affected by lake-land breeze circulations. In 2002, the highest annual mean of ground-level ozone in Ontario was measured at Tiverton, a rural air monitoring site along the eastern shoreline.

Precipitation

Threat: Increased rainfall will increase the flow rates of some of the streams and rivers increasing scouring and sediment deposits near the harbour mouth.

Wind

Opportunity/Threat: Potentially more hazardous conditions for shipping that will tend to use the extended seasons. The Lake Huron shoreline has few harbours, and it may be necessary to develop an improved wind advisory system.

Threat: There may have to be an improvement to marinas and other coastal facilities to protect against more frequent storms.

Water Temperature

Opportunity: Warmer water temperatures could result in a longer summer swimming season.

Opportunity: The fishing season could become longer, depending upon water temperature changes and warm water fisheries could increase.

Threat: A longer growing season for aquatic algae may lead to greater algal problems depending on nutrient availability. Warmer temperatures will also increase frequency and extent of noxious blue-green algae which will reduce water use for swimming and increase water treatment costs for municipal water supplies.

Water Levels

Opportunity: A decrease in erosion of the bluffs for some land owners due to lower water levels.

Threat: Major impact on access to Goderich harbour and marinas. A small decrease in water levels will require further dredging if existing fleet is to continue to use harbour. Potential adaptation will be to reduce draft of ships using the Great Lakes.

Threat: The three marinas may be dredged and thus adapt to changing water levels.

Water Movement - Lacustrine Changes

Opportunity/Threat: There may be need to review the use of groynes and other structures to protect shoreline and infrastructure.

Threat: There may be changes to water flow along the shoreline affecting bathymetry. This will have a major impact on access of fully loaded freighters to harbour (Transport Safety Board of Canada 2001).

Threat: There may be need to review location of water intake pipes for the town.

6.3 Lake Huron - Sturgeon Bay

6.3.1 Introduction

Sturgeon Bay is located in the northern part of Georgian Bay (Figure 43) which is 320 km long by 80 km wide and encompasses 15,000 sq km of eastern Lake Huron. Georgian Bay is separated from Lake Huron by Manitoulin Island and by the Bruce Peninsula. The eastern shore is sculpted by an extensive archipelago of rocky islands. The Township of the Archipelago with offices in Parry Sound (population approximately 7,000) serves the people of the Georgian Bay coastline and lake communities. Georgian Bay is a significant recreational area. Thousands of homes and cottages (many accessed only by water) dot the landscape. Five provincial parks and one national park have been established in the area.

6.3.2 Physical Description

The Georgian Bay coast is formed from a complex series of bays, inlets, sounds, islands and shoals lying along the edge of the Canadian Shield bedrock, which rises as low lying hills and ridges on the adjacent mainland. Many rivers drain inland ecosystems. Some rivers such as the Severn and French are significant recreational routes for boaters.

Located north of Parry Sound, Sturgeon Bay is one of many enclosed bays along the coastline that will be significantly impacted by climate change and is used as an example of the existing conditions of Georgian Bay. A major feature of the area is the large number of summer homes scattered along the coastline that support a major influx of people during the summer months increasing the population by three to five times. Much of the area is accessible only by boats.

6.3.3 Biological Description

The Georgian Bay coastal terrestrial ecosystems support a rich mosaic of forest, wetlands, and rocky habitat types with associated biodiversity. The vegetation varies between the exposed dry sites on many islands and upland rocky areas that are dominated by White Pine and Red Oak, and the areas with deeper soils that include Sugar Maple, Basswood, Red Ash, Black Ash, Yellow Birch, White Birch Jack Pine and Eastern White Cedar. Historically, the areas were forested with much larger stands of White Pine, Hemlock that were harvested in the nineteenth and early twentieth centuries. Many of the small islands near the outer shoreline support stunted and wind-swept pines, depicted in paintings by the Group of Seven.

There are many wetlands throughout Georgian Bay that include large stands of Wild Rice, reeds, Yellow and White Waterlily, Arrowleaf, Pickerelweed, Wild Calla, Water Arum

(Figure 44a). Small bogs are scattered throughout the area as well. Many occupy depressions and hollows carved out by glaciers. In addition, some bogs have been created by Beaver, which have created improvements with dams. These ponds are often deep, stagnant and acidic, and are inhabited by a unique community of plants and animals. The mouths of the many creeks and rivers that enter Georgian Bay are often fringed with wetlands that serve as nursery areas for fish and other wildlife.

In some wetlands, sphagnum moss forms floating mats that float out over water channels. The sphagnum mats provide a substrate for species such as Rose Pogonia and Calopogon or grass pink, two orchids whose blooms brighten up the bogs in June. Leatherleaf, Labrador Tea, Sweet Gale and wild Cranberry also grow on these floating "mattresses." and along the shorelines. As these plants die, sink to the wetland bed and decay, oxygen levels decline and create anoxic conditions, which are unsuitable for fish.

Georgian Bay is notable for its high level of biodiversity, particularly amphibians and reptiles. Common species include Painted and Snapping Turtles that are often encountered by people visiting coastal habitats. More secretive turtles such as the Blanding's and Spotted Turtle are more difficult to observe. The endangered Eastern Massasauga rattlesnake occurs along the coast and has been studied at Georgian Bay Islands National Park and Massassauga Provincial Park.

Leopard Frog and Green Frog are common throughout the area while Spring Peepers, Mink, Chorus and Bullfrogs can often be heard in the spring. Other amphibians inhabiting the area include Red-spotted Newt and Mudpuppy.

Characteristic fish species in the deep cooler waters in the outer parts of the archipelago include Whitefish, Walleye, White Bass, White Perch, Gizzard Shad and Muskellunge. The warmer waters of the sheltered bays and inlets are inhabited by Smallmouth Bass, Rock Bass Pumkinseed and a host of other forage fish.

6.3.4 Recreation

Sturgeon Bay Provincial Park provides 81 campsites, 31 of which have electricity. Many campsites provide a view of the beach and most are situated in a white pine and poplar forest.

There are approximately many other provincial parks in the vicinity together with an ever increasing number of year round residents (Gray [Table 1]). The major recreational activities include boating, swimming and fishing. In winter, people snowmobile, cross-country ski and snowshoe.

6.3.5 Land Use Planning and Management

Land use planning in the Sturgeon Bay area and in the many other communities in the archipelago is managed by the Township of the Archipelago (Mason [Table 1]). Because much of the land is Crown Land, the Ministry of Natural Resources also is engaged in planning and management activities throughout the area. Although most residential lots are located on the eastern shore of Sturgeon Bay, some are located on islands within the Bay (Figure 43a).

Some form of evaluation of the carrying capacity of the many inlets and bays throughout Georgian Bay needs to be undertaken to determine what is sustainable to ensure the maintenance of water quality objectives and preservation of the unique ecology of the archipelago.

Approximately 330,000 ha have been designated as a Biosphere Reserve which includes the area known as the Thirty Thousand Islands.

6.3.6 The Changing Climate: Projections for the 21st Century

An analysis of temperature and precipitation trends at Beatrice east of Georgian Bay provides insight into how the climate has been changing in this region over the past century. The annual maximum temperature at this climate station has warmed significantly by 0.8°C, with smaller but non-significant increases of 0.5° and 0.2°C in mean and minimum temperatures, respectively, since the late 1800's. Since the 1890's, total annual precipitation and rainfall have increased significantly at Beatrice by 219 and 215 mm, respectively, while annual snowfall has shown no change over the 107 year period.

The four GCM climate change scenarios described in Section 2.2 project annual warming of 2° to 4°C in the Parry Sound region by the middle of this century. Total annual precipitation is expected to increase by approximately 2 to 12% by the 2050's. As described in Section 6.2.4, Lake Huron mean annual water levels are expected to decline, while extreme weather events such as heavy precipitation, drought and hot days could increase in frequency and severity. Heavy lake-effect snow off Georgian Bay should be reduced in the future climate.

6.3.7 Threats and Opportunities Resulting from Climate Change: Adaptation Options

__Air Temperature__

Opportunity: Warm spring and fall temperatures will result in longer cottage and recreational season. This will provide for a longer economically active season for local business.

Threat: The presence of many lots on inlets require water access and with declining water levels, there is a major pressure to dredge such inlets which results in the destruction of wetlands that contribute to the ecological health of the area.

Threat: Winter recreation use will be affected by longer periods of warmer weather in spring and fall. These new conditions may impact availability of winter recreation opportunities such as snowmobiling and winter fishing (Mason [Table 1]).

Threat: Potentially more ice storms with climate warming, and increased winter storm damage to exposed buildings along the coast.

Threat: Increased temperatures may affect the success of trees planted in restoration of habitats. Future climate should be addressed during species selection.

Precipitation

Opportunity: Some of the small hydro-generating facilities in the area that utilize small rivers flowing into Lake Huron may have more water for power generation. The timing of water releases may be important to maintain water levels in associated lakes and sufficient water flows to maintain fish spawning habitat.

Threat: Increased intensity and frequency of extreme rainfall events will increase the flow rates of some of the streams and rivers and increase the risk of flooding.

Threat: Increased fire hazards (Gray [Table 1]) due to warmer temperatures and the risk of more frequent and serious drought conditions There may have to be changes in use of campgrounds and fire pits in the late summer if fire hazard levels increase as they are expected to and a closed season for camp fires may need to be instituted.

Wind

Opportunity: Emerging wind patterns could lead to Improved sailing conditions.

Opportunity/Threat: Wind farms may or may not be able to generate more power locally, depending on the changes that occur in winds in the future climate. An increased frequency of high winds beyond the “cut-off” turbine threshold and/or an increase in very light winds could result in a reduction in available wind energy potential. If there is an increase in the frequency of winds within favourable operating turbine thresholds, this could result in an increase in available wind for wind power production.

Threat: More damage to wind sensitive trees along shoreline and on islands with more intense winter storms and the risk of an increase in extreme weather.

Threat: Potentially more hazardous conditions for boaters and it may be necessary to develop improved wind advisory system.

Water Temperature Changes

Opportunity: Longer periods of warmer weather will potentially lead to an increase in swimming season.

Threat: Longer growing season for aquatic algae leading to greater algal problems (Figure 44b). Warmer temperatures will also increase frequency and extent of noxious blue-green algae which will reduce water use for swimming.

Opportunity/Threat: Changes to fishing seasons, modify open seasons based on fish biology and potential changes in fish communities.

Water Level Changes

Opportunity/Threat: Change in property boundaries for some land owners due to lower water levels.

Threat: Lower water levels will affect municipal water intake pipes and require extensions into the lake.

Threat: Decreased access to many properties on islands and inlets (Mason [Table 1]).

Threat: Modify some marinas; others may need to be closed. Maybe some inlets can be deepened, but blasting channels will be limited in scope. Private docks on some properties may no longer be accessible.

Threat: Marshes may dry out and replacement wetlands may not develop due to steep littoral zone (Muter [Table 1]).

Water Movement - Lacustrine Changes

Threat: There may be changes to water flow into some bays due to seiche effects. This may affect circulation in Sturgeon Bay and other enclosed bays and channels in Georgian Bay (Scheifer [Table 1]).

Land Use Policy Changes

Opportunity: Improve sewage treatment and inspection.

Opportunity: Expand coordination and data sharing between levels of government (Mason [Table 1]).

Opportunity/Threat: There will need to be a limit to the expansion of cottage development.

Opportunity/Threat: Develop regulations regarding property boundaries at water level.

7.0 LAKE SUPERIOR

7.1 Climate

7.1.1 Temperature

The Lake Superior coastal region climate is strongly affected by the temperature of the Great Lakes' largest and deepest body of water. The average annual water temperature is approximately 4.5°C and the lake rarely freezes over. The annual 1971 to 2000 normal air temperature contours (Figure 45) demonstrate the effect of the lake. In addition, there is a height of land running parallel to the north coast which also affects the observed temperature pattern (Chapman and Thomas, 1968). In this modified continental climate, annual temperatures near the lake (2°C to 3°C except near 4°C at Sault Ste. Marie) are on average warmer than those inland at the same latitude. Generally this effect keeps coastal areas 3°C to 5°C above inland areas in the winter and cooler by about the same amount in the summer (Phillips, 1990). The warmest temperatures are found the farthest south in the Sault Ste. Marie area where the annual temperature is between 4°C and 5°C. Summers are generally warm to hot while winters are cold.

The summer season temperatures along the coastline are highly modified by the cooler lake temperature (Figure 46). The northeastern shore of the lake is particularly affected by onshore summertime breezes, with Wawa and Marathon recording cooler average temperatures than the western and southeastern ends of the lake near Thunder Bay and Sault Ste. Marie, respectively. The extreme maximum temperatures recorded Thunder Bay, 40.3°C, rivals the highest maxima, 40.6°C, recorded in southwestern Ontario. In contrast, the record high temperature of 33.1°C in Wawa is the lowest extreme maximum temperature that has been recorded in the climate observing network in Ontario (Environment Canada, 2004). With an offshore wind, the modifying effect of the lake is lost, allowing the temperature to reach such extremes. The average number of days per year with temperatures over 30°C range from zero on the north and east shore to 6 days in the Thunder Bay area, and 4 days at Sault Ste. Marie.

In the winter season, the moderating influence of the lake is again evident (Figure 47), with the coldest temperatures inland away from the lake. January mean temperatures of -14°C to -15°C are recorded at the western end of the lake in Thunder Bay and along the north and east shore, while the warmest January average temperatures, -10.5°C, are observed in the southeast at Sault Ste. Marie. The extreme minimum temperatures in the region are among the coldest in the province. A minimum of -46°C has been recorded in the Thunder Bay area, with -50°C at Wawa, and -39°C at Sault Ste. Marie (Environment Canada, 2004b). The average number of days per year with temperatures below -30°C ranges from a low of only 2 days for Sault Ste. Marie, to a high of 16 days in Thunder Bay.

7.1.2 Historical Temperature Trends

The temperature trends at four selected stations in this region show a significant increase of approximately 1°C over the past 60 to 100 years in mean temperatures and a greater increase in minimum temperatures of up to 1.6°C over the past 60 to 100 years (Figure 48). There is no significant trend found in the annual maximum temperature, although all trends show small increases. The temperature data used in the trend analysis was retrieved from Environment Canada's Temperature Database, as described in Section 4.1.2 (Mekis and Hogg 1999; Environment Canada, 2006; Vincent and Mekis, 2006).

7.1.3 Precipitation

Precipitation in the Lake Superior region is strongly influenced by the lake. Mean annual precipitation varies substantially across the region from a minimum of about 710 mm in Thunder Bay to a maximum of over 1,250 mm in the coastal region between Wawa and Sault Ste. Marie, where lake-effect snow contributes significantly to the total precipitation. This area receives the highest precipitation totals in Ontario due to the lake enhancement. The pattern of annual precipitation totals (Figure 49) clearly shows the effect of the lake on the downwind (eastern) half of the region. West-southwest winds over the ice-free areas of Lake Superior in the winter generate significant snow squall activity over the north and central areas of the Superior coastline, while west-northwest winds can bring heavy lake-effect to the Sault Ste. Marie area.

Rainfall contributes approximately 65% to the total annual precipitation in Sault Ste. Marie, with snowfall a significant 35% in this snow belt region. In contrast, approximately 78% of total precipitation in Thunder Bay falls as rain (Figure 50). The extreme daily rainfall (snowfall) amounts recorded in the region are 131 mm (64 cm) in the Thunder Bay area and 117 mm (61 cm) in Sault Ste. Marie (Environment Canada, 2004c).

7.1.4 Historical Precipitation Trends

Trends in annual precipitation at five selected stations in the region are displayed in Figure 51. Annual rainfall is increasing at all stations, but only two of these trends are significant. Trends in snowfall are mixed, with the three western stations showing upward trends (two are significant) of approximately 65 to 170 cm over 70 to 100 years, respectively. In contrast, in the east, annual snowfall is decreasing significantly at Wawa Airport by approximately 240 cm over 88 years with little change at Sault Ste. Marie. The rain and snow contribute to increasing trends in total annual precipitation (two are significant) in the western region of approximately 200 mm over 100 years. These increases are not seen in the east: a downward but non-significant trend in total annual precipitation is observed at Wawa and there is generally no trend at Sault Ste. Marie. All of the data used in the analysis was provided by Environment Canada's Adjusted Precipitation Dataset, described in Section 4.1.2 (Mekis and Hogg 1999; Environment Canada, 2006; Vincent and Mekis, 2006).

7.1.5 Wind

Wind speed and direction are influenced by the overlying synoptic flow, smaller scale weather phenomena (i.e., thunderstorms), local effects of topography, obstructions and lake/land induced breezes. Wind is therefore a highly variable parameter over short distances. As in most areas of Ontario, wind speeds are generally higher in the winter months than summer. Lake/land breezes are also common during the spring and summer months.

As described in Section 4.1.5, mean annual wind speeds at a 30 m elevation have been computed and mapped by Environment Canada for the Canadian Wind Energy Atlas (2004). The wind speeds are modelled at a 5 km horizontal resolution, and the speeds at 30 m can generally expected to be higher than those at a standard wind instrument height of 10 m. A sample map for the Lake Superior region is shown in Figure 52. The maximum annual wind speed found over the lake is greater than 8 m/s (29 km/h), with mean annual winds generally around 5 m/s (18 km/h) in the near-shore environment.

7.1.6 Historical Wind Trends

As described in Section 4.1.6, Environment Canada-Ontario has investigated trends in historical wind observations across Ontario. At the two selected airport locations in the Lake Superior region, there has been a general decrease in observed wind speeds over the 1974 to 2004 periods (Figure 53). Annual and seasonal average and maximum winds have decreased significantly at Sault Ste. Marie, while at Thunder Bay average winds have shown little change or decreased and maximum winds have generally increased. Percent calms and winds less than 15 km/h have increased significantly over the same period at Sault Ste. Marie, while generally decreasing at Thunder Bay. Annually, winds in excess of 60 km/h have decreased significantly at Sault Ste. Marie, while significantly increasing at Thunder Bay.

7.2 Lake Superior - Sault Ste. Marie

7.2.1 Introduction

Sault Ste. Marie is located between Lake Superior and Lakes Huron and Michigan approximately 690 km north west of Toronto and 680 km south east of Thunder Bay. This city of 79,000 is located on the north shore of the St. Mary's River which serves as part of the international boundary between Canada and the United States (Figure 54). The 112 km long river also connects Lake Superior to Lake Huron and is used by large cargo vessels up to 309 m long and 32 m wide. Sault Ste. Marie's economy is based on forestry, tourism, the steel industry, government and retail. The provincial Ministry of Natural Resources and the Canadian Forestry Service maintain research laboratories in Sault Ste. Marie as well.

Approximately 12,000 vessels use the St. Mary's River locks every year to transport aggregates, coal, iron ore and salt with grain, fertilizers and other commodities (Figure 55). There are hydroelectric generating stations on both the US and Canadian sides of the River. The two cities of Sault Ste. Marie are connected by a bridge which is occasionally closed due to high winds. Sault Ste. Marie is a major distribution and supply centre for north central Ontario and the bridge provides a major access point for Americans coming north for recreation or business in the area. The St. Mary's River was designated an Area of Concern in 1989 due to degradation of fish and wildlife populations, the occurrence of fish tumours, degradation of the benthos, beach closings and other factors.

7.2.2 Physical Description

The St. Mary's River joins Lakes Huron and Michigan with Lake Superior. Prior to development, the river included rapids that have been eliminated by the various locks, control structures and power stations that divert water through turbines. The water level of Lake Superior is regulated by the International Lake Superior Board of Control and maintained between 182.76 m and 183.86 m. If the Lake Superior water level falls below 183.4 m, water is not released (McAuley [Table 1]) so that shipping can be maintained through the St. Mary's River.

7.2.3 Biological Description

Sault Ste. Marie is located in the Great Lakes-St-Lawrence Forest Region. A significant amount of local forest was cleared in the latter part of the nineteenth century and some farms were established.

Because of the high energy coast line, there are no extensive areas of wetlands along the shoreline in the vicinity of Sault Ste. Marie. The river mouths play an important role in providing fish nursery habitat. In addition, Manitoulin Island provides considerable protection to the North Channel of Lake Huron and here there are more quiet inlets where coastal fisheries and aquaculture operations can thrive.

7.2.4 Land Use Planning and Management

Land use planning in Sault Ste. Marie is the responsibility of the municipal government. Because of a declining population there is more concern with attracting business to the area than dealing with the impacts of expansion.

The Sault Ste. Marie Region Conservation Authority was formed in 1963 and works to alleviate flood risks and ensure protection of drinking water within the region. Because of dwellings located in flood prone areas, the increasing occurrence of flooding from major storm events is a real issue and the Authority is using a watershed-based approach to assist in managing the flood risk.

7.2.5 The Changing Climate: Projections for the 21st Century

Since the 1960's, annual mean and minimum temperatures have warmed significantly at Sault Ste. Marie by 0.7°C and 0.8°C, respectively, while maximum temperatures have shown a non-significant increase of 0.7°C. Total annual precipitation, rainfall and snowfall have shown little change at Sault Ste. Marie over the same 42 year period (8 mm, 13 mm, and -4 cm, respectively).

Based on the GCM output from the four climate change scenarios described in Section 2.2, the projected annual warming in the Sault Ste. Marie area by 2050 is in the range of 2^o to 3.5^{o}C by the middle of the 21st century. Total annual precipitation is projected to increase by 2 to 10% by the 2050's. In addition to the changes in the annual average temperature and precipitation, extreme precipitation is likely to be more frequent and intense while there is also an increased risk of drought. Declines in Lake Superior mean annual water levels of approximately 0.3 and 0.4 m are projected by the mid and late 21st century. Although analysis by Kunkel et al. (2000) suggests that there will be a significant reduction in heavy lake-effect snow for traditional snow belt areas of Lake Huron and Lake Erie, the same study indicates that there may be little change in the frequency of heavy lake-effect snow on the northeastern shores of Lake Superior. Mean winter temperatures in this region are projected to remain below freezing and there is little change projected in the number of below freezing days and the frequency of other variables favourable to the formation of heavy off-lake snow events.

7.2.6 Threats and Opportunities Resulting from Climate Change: Adaptation Options

Air Temperature

Opportunity: Warmer temperatures will result in longer farming and summer fishing season. There may be an extension of the summer recreational season for hotels and B&Bs in the town.

Opportunity: Growing seasons are expected to increase which may provide increased opportunities for an increased diversity of crops.

Threat/Opportunity: Increased temperatures may affect the success of trees planted in shoreline environments. Commercial forestry replanting programs may require adjustment to ensure that the planted stock is suitable for existing and future climates.

Threat: Warmer winter temperatures will result in a shorter winter season impacting negatively on the winter sports of snowmobiling, skiing and ice fishing. This will provide challenges for local business to adapt to a more variable climate.

Threat: Warmer winter temperatures will result in changed rain/ice/snow regimes. There will be potentially more ice storms with climate warming, and increased winter storm damage with more intense winter storms.

Precipitation Changes

Opportunity: An increased frequency of intense rainfall will increase the flow rates of some of the streams and rivers. This may provide greater hydroelectric generation capacity during some periods of the year.

Threat: With increases in extreme weather (i.e., increased number and intensity of rainfall events), upgrades and replacement to existing infrastructure such as the sewer systems may be required.

Threat: There could be an increased risk of ice storms affecting above ground utilities and buildings.

Threat: Increased risk of severe rainstorms will increase the risk of flooding.

Threat: An increased frequency of drought conditions may lead to a greater frequency of forest fires in the region.

Wind Changes

Opportunity/Threat: Depending on how winds change in the future climate, there could be an increase or decrease in wind energy potential on the eastern shore of Lake Superior. Increased wind energy potential would make it more economically viable for the construction of wind turbine farms.

Threat: Emerging wind patterns will potentially cause more hazardous conditions for shipping. It will be necessary to improve real time wind advisory systems.

Water Temperature Changes

Opportunities: Increased fish rearing season for aquaculture operations in the area with increased productivity.

Opportunity: The improvements made to sewage treatment and industrial waste water on both sides of the river should result in continued improvement to the shoreline habitats and benthic organisms in this part of the coastal environment.

Threats: A longer growing season may cause increased algal problems. Warmer temperatures will also increase frequency and extent of noxious blue-green algae which may reduce water use for swimming.

Water Level Changes

Threats: Water levels potentially could drop by 12 to 36 cm by 2050. This will have a major impact on shipping through the St. Mary's River (Hartmann 1990). Further dredging may be necessary though contaminated sediments represent a potential hazard. Potential adaptation strategies include the reduction of the draft of ships using the Great Lakes.

Threats: Lower water volumes in Lake Superior will affect hydro-electric generation at Sault Ste. Marie.

7.3 Lake Superior - Pukaskwa National Park

7.3.1 Introduction

Pukaskwa National Park is a wilderness park located on the eastern shore of Lake Superior approximately half way between Sault Ste. Marie and Thunder Bay (Figure 56). The 1,880 km^2

wilderness park contains 120 km of Lake Superior coastline. The park office is located at Heron Bay on the north side of the park and about 20 km from the town of Marathon. The park was created in 1978 and protects a representative area of the central boreal forests and the rugged coastline of Lake Superior. There is a difficult 60 km coastal trail that follows part of the park shoreline and links a number of backcountry campsites. There is a campground (67 camp sites) at Hattie Cove located at the north end of the park which can be accessed via Highway 627, the only road access into the park. About 10,000 people visit Pukaskwa each year.

7.3.2 Physical Description

The rugged pre-Cambrian shield country is cooled by the cold waters of Lake Superior which have a major impact on the habitat of plants and animals some of which have Arctic affinities. Because of the rugged nature of the terrain, the park has never been logged. The rugged coastline is a mixture of cobble beaches and rocky cliffs and shores with a number of rivers draining the hinterland. The people who lived here 5,000 to 10,000 years ago probably made the puzzling rock structures called the Pukaskwa Pits along the cobble beaches (Figure 57). Each pit is 1 to 2.5 m long with 1.5 m high walls. One might speculate on their usefulness as hunting or fishing shelters, or possibly lookouts or observation posts.

7.3.3 Biological Description

Dominant features include the waters and coastline of Lake Superior and the rivers that flow into it, and the boreal forest which comprises the majority of the park. Important tree species include Tamarack, Jack Pine, Poplar, Birch, White Spruce, Black Spruce and Balsam Fir.

Bogs and fens in the park support Black Spruce, Labrador Tea, blueberries, Bog Rosemary and Cloudberries which grow well in the acidic soil. Because of the high energy coast line, there are no extensive wetlands. However, rare arctic-alpine plants such as Encrusted Saxifrage, Franklin’s Lady Slipper, and Pitcher’s Thistle grow on some exposed sites.

A small population of Woodland Caribou inhabits the park. Other mammals include Black Bear, Moose, Lynx and Wolf. Migratory birds such as warblers arrive in spring and many species nest within the park’s forests. Ducks and shorebirds occur along the beaches and rivers and Oiseau is the best location to observe herons nesting in their heronry.

7.3.4 Land Use Planning and Management

Parks Canada cares for the park under the auspices of a management plan which guides all human activities in the park. It is now well known that the boreal forest is driven by a fire regime to ensure its health, and fire is being introduced to the park as a management tool. As a means of gauging the state of Pukaskwa's health, park biologists have selected 10 ecological "indicators" -- including song birds, several rare plants, caribou, water, forest health and air quality -- the status of which they monitor regularly.

7.3.5 The Changing Climate: Projections for the 21st Century

Since the 1940's, annual mean and minimum temperatures have warmed significantly at Wawa by 0.8° and 1.6°C, respectively, while maximum temperatures have shown little change (0.2°C) over the same period. Total annual precipitation has shown a non-significant decrease of 76 mm since the early 1900's, while rainfall and snowfall have increased (144 mm) and decreased (242 cm), respectively over the same period.

By 2050, annual warming of 3^{o} to 4^{o}C and precipitation increases of 1 to 9% are projected by the GCM scenarios described in Section 2.2. As noted in Section 7.2.5, declines in Lake Superior water level are projected for the 21st century, as well as likely increases in the severity and frequency of extreme weather events. However, the frequency of heavy lake-effect snowfalls is expected to show little change.

7.3.6 Threats and Opportunities Resulting from Climate Change: Adaptation Options

<u>**Air Temperature**</u>

Opportunity: Warmer temperatures will result in a longer tourist season which would result in more camping and hiking opportunities.

Threat: Increased human use resulting from longer shoulder seasons may negatively impact the hiking trails and campgrounds.

Threat: The increased temperatures may alter or eliminate arctic flora habitats in the park.

<u>**Precipitation Changes**</u>

Opportunity: An increase in intense rainfall will increase the flow rates of some of the streams and rivers.

Threat/Opportunity: The likelihood of fires in the late summer will likely increase (Hui and Huang 2000) which may assist park management activities but reduce the availability of the park to visitors.

Threat: Altered precipitation patterns may impact the distribution and abundance of flora and fauna.

<u>**Wind Changes**</u>

Opportunity: Emerging wind patterns could result in increased wind speeds on the eastern shore of Lake Superior which would provide a more dynamic coastline but be a potential hazard to recreational boaters.

Water Temperature Changes

Opportunities: It may take a very long time before climate change affects the overall water temperature of Lake Superior, due to its great depth and northern location. This should preserve the cold water fisheries for the foreseeable future.

Water Level Changes

Opportunities/Threats: Because of the steep rocky shoreline of Pukaskwa National Park, the relatively small changes predicted for water levels are unlikely to have any measurable effects.

7.4 Lake Superior - Thunder Bay

7.4.1 Introduction

French trading posts were established in 1679 and 1717 in the Thunder Bay area and became key transportation and supply centres. Mining development in the mid-19th century in northwestern Ontario made it an important supply centre and the arrival of the Canadian Pacific Railway in 1875 made it a key stop in the transcontinental railway. The port became very important for the shipping of wheat in the latter part of the nineteenth century and grain elevators were built to handle the ever increasing shipping of wheat to Europe. The Kaministiquia River was dredged in 1873 to facilitate ships carrying iron ore, coal, grain and other freight into the Fort William industrial centre and a large breakwater was built. Logging and forestry operations used the city as a major centre and in 1917 the first pulp and paper mill was built in Port Arthur. Eventually four mills were built in the city. Heavy industry in the city was developed during the world wars and heavy manufacturing has continued to be a major component of the local economy. Thunder Bay continued to be an important hub until the Trans-Canada highway provided an alternative method for transporting goods across the country. Since that time, the importance of the port and railway has declined. Thunder Bay was created in 1970 by merging the cities of Fort William with Port Arthur. Thunder Bay is the second largest city in northern Ontario with a population of approximately 110,000 and the population is declining (Figure 58).

Currently 9 of 14 beneficial uses (GLWQA 1987) are impaired in the Thunder Bay AOC. The greatest impacts are a result of the industrial and urban development along the Thunder Bay waterfront and the Kaministiquia River watershed. Much of the industrial land within the harbour has been constructed through a combination of draining and filling of shoreline areas, including wetlands which were degraded and reduced in area. Dredging, waste disposal, channelization, and the release of a number of pollutants have eliminated a significant portion of good quality habitat along the waterfront. The consequences have been a loss of species abundance and diversity, reduced recreational opportunities, and a decline in the aesthetic value of the area (Thunder Bay RAP).

7.4.2 Physical Description

The former Fort William part of the city is built on flat alluvial land which has a river delta at its mouth composed of Mission Island and McKellar Island. The McKellar River flows between the islands. The former Port Arthur part of the city is more typical of the Canadian Shield with gently sloping hills and a thin soil lying over the Canadian Shield bedrock. The actual marine Thunder Bay is large and extends around to the Sibley peninsula and the Sleeping Giant, a large diabase butte whose sides form the tallest cliffs in Ontario.

7.4.3 Biological Description

There are five harbour marshes in Thunder Bay: Northern Wood Preservers, Neebing, McKellar Island, Mission Island and Chippewa. Depending on water levels, they are significant as staging and breeding areas for waterfowl. There is also an abundance of benthic life and fish providing the marshes with potential as recreational areas with numerous functions. The Mission Island Marsh is a provincially significant wetland while all five wetlands are important biologically. The marsh area of the harbour represents a major portion of Canadian wetlands in the Lake Superior basin. There is both a commercial and sport fishery in the area (Environment Canada 2003, Lakehead Region Conservation Authority 1986).

Rehabilitation projects undertaken by the City of Thunder Bay, in the lower reaches of the Kaministiquia River, represent an integrative approach to waterfront development and habitat restoration (Figure 59). Shoreline degradation had left the area void of ecological, recreational, and economic value. The Kaministiquia River Heritage Park was developed to restore the environmental integrity and natural history of the region. The park features a scenic overlook and riverfront promenade running alongside an existing wetland area (North Shore Remedial Action Plan 1998). The Current River has been impacted by industrial activities and remedial plans to enhance Walleye spawning habitat have proven reasonably successful (Geiling et al. 1996).

Various fish and wildlife habitat rehabilitation projects have been completed in the waterfront wetlands and along tributary streams. Projects have included improving walleye spawning habitat, restoring habitat diversity along floodways, enhancing habitat diversity within dredged navigation channels creating nearshore nursery habitat and wetland sites, and alleviating barriers to fish migration. These efforts will increase the extent of productive aquatic and terrestrial habitat by rehabilitating and protecting wetland and riparian environments. Attempts to improve salmon access to the upper reaches of the Current River have not been successful; however upgrades at the Bowater pulp and paper mill have improved water quality allowing fish migrations in the Kam River (Environment Canada 2003).

Migratory birds are monitored at the Thunder Cape Bird Observatory which is located at the southern tip of the Sibley Peninsula at the southern end of the Sleeping Giant. The location of the observatory at a major landfall for migrating birds provides an excellent indication of the numbers of birds migrating into northern Ontario in the spring and leaving in the fall. At least

156 species have been banded and 290 species recorded at the observatory between 1991 and 2003.

7.4.4 Land Use Planning and Management

The City of Thunder Bay developed a master plan for the parks of Thunder Bay in 2000. This included an analysis of the natural features and current role of parks. Urban shaping, as well as the community and schools, are taken into account. A summary is presented of the topography, soils, drainage, vegetation and resources in Thunder Bay parks. Storm water management, sewage treatment and clean up of industrial residues are also major actions taken by the city in conjunction with other stakeholders under the RAP program

The Remedial Action Plan (RAP) discusses the environmental conditions in Thunder Bay caused by major industries plus the municipality. In the rivers, water quality, sediments, benthic communities and other biota including fish have been studied and the results discussed. The remedial measures performed by a few of the mills and the city have resulted in improved coastal aquatic habitats.

The Lakehead Conservation Authority is a community-based environmental agency responsible for the wise management of renewable natural resources in the watersheds. The Conservation Authority undertakes a broad range of programs, including: flood control; floodplain management; wetland protection; erosion control; reforestation; conservation lands; and conservation education.

7.4.5 The Changing Climate: Projections for the 21st Century

Since the late 1800's, annual mean and minimum temperatures have warmed significantly at Thunder Bay by 1.0° and 1.6°C, respectively, while maximum temperatures have shown a non-significant increase of 0.5°C. Total annual precipitation and snowfall have increased significantly since the late 1800's while rainfall has shown a non-significant increase of 58 mm during this period.

Based on the GCM output from the four climate change scenarios described in Section 2.2, the projected annual warming in the Thunder Bay area by 2050 is in the range of 2^{o} to 4^{o}C by 2050. Total annual precipitation is projected to increase by up to 10% to a possible decrease of 1% by the middle of the century. As described in Section 7.2.5, Lake Superior average annual water levels are expected to decline in the 21st century while extreme weather events are likely to become more frequent and intense. However, the frequency of heavy lake-effect snowfalls in this significant Lake Superior snow belt region is expected to show little change

7.4.6 Threats and Opportunities Resulting from Climate Change: Adaptation Options

Air Temperature

Opportunity: Warmer temperatures will result in a longer tourist season which would result in more camping and hiking opportunities in northern Ontario.

Precipitation Changes

Threat: With increases in extreme weather (i.e., increased number and intensity of rainfall events), upgrades and replacements to existing infrastructure such as the sewer systems may be required.

Opportunity: Increased intense rainfall will increase the flow rates of some of the streams and rivers.

Opportunity: The improvements made to sewage treatment and industrial waste water on both sides of the river should result in continued improvement to the shoreline habitats and benthic organisms in this part of the coastal environment.

Threat/Opportunity: The likelihood of fires in the late summer will likely increase which may be a threat in some of the surrounding parks.

Wind Changes

Threat: Emerging wind patterns could result in a more dynamic coastline on the western shore of Lake Superior but be a potential hazard to commercial and recreational boaters.

Water Temperature Changes

Opportunities: It may take a very long time before climate change affects the overall water temperature of Lake Superior, due to its great depth and northern location. It may therefore be used in cooling systems for the city such as the system recently installed in Toronto.

Water Level Changes

Opportunity: Lower water levels may permit some of the wetland restoration projects to extend lakeward in the more protected areas.

Opportunities/Threats: Because of the relatively shallow depths along much of the shoreline of Thunder Bay the small changes predicted for water levels may have an impact on marina operations.

8.0 DISCUSSION

We have summarized the adaptation options that have been brought to our attention during workshops and during the course of the project. We have not attempted to provide detailed projections for each of the case study sites, rather we have indicated the historical ranges and possible effects that projected climates may have.

8.1 Agriculture

Agricultural production is of key importance to the region. In Ontario, it is valued at $10 billion, while it contributes more than $40 billion to the economy in the six U.S. Great Lakes states. Agricultural production is directly impacted by climatic variations and extremes. For example, the 2001 drought was the worst to affect southern Ontario since 1988, resulting in $300 million in crop production losses for Ontario (Wheaton et al., 2005).

Under climate change, warmer temperatures and changes in precipitation patterns (including the projection of more frequent and intense drought and flooding events) will have a significant impact on agriculture. Higher intensity precipitation events can lead to increased crop damage and soil erosion in agricultural fields. The sediments, nutrients, and pesticides could then be carried to nearby streams or lakes, degrading water quality. (In the Great Lakes region, there has been considerable effort to reduce pollution from these non-point agricultural sources). Demand for water by the agricultural sector is expected to increase to maintain productivity during periods of drought, while other sectors will also likely have increased demand. Pest and disease incidence could increase in a warmer climate. By the end of the 21st century, the projected increase in the number of insect generations per season, along with the projected increase of pesticide applications across the Great Lakes could have a large economic consequence. Growers could face increase of up to double (U.S. $192/ha) their 1998 production costs. Winter freeze-thaw events, which could increase in a changing climate, can have dire consequences on the agriculture industry.

Warmer temperatures will enable warm weather crops to be grown more extensively in Ontario particularly around the shores of the southern Great Lakes. The north shore of Lake Ontario will undoubtedly become warmer and because of the rapid growth of urban development in the Golden Horseshoe, only the eastern part of the north shore will be able to develop more valuable vegetables and soft fruits. In particular the farm lands of Prince Edward County are surrounded by Lake Ontario and so the climate is moderated already. Recent establishment of grape growing and wineries in the coastal areas may benefit from warming trends, though severe winter storms can still have a major impact on sensitive varieties. The wine growing areas in the Niagara Region and along the north shore of Lake Erie may benefit from milder weather permitting more sensitive varieties of crops to flourish. However, the rapid expansion of ice wine production may suffer as the conditions for harvesting grapes during the early winter may not be sufficiently cold. Such operations could conceivably be moved to Prince Edward County or to locations on the Lake Huron shore.

Varieties of crops are already being selected to reflect the changed climate and a network of agricultural advisors are able to assist farmers in making suitable selections. The greenhouse industry has benefited significantly from warmer temperatures and the much lower fuel bills for greenhouses around the western end of Lake Ontario and on the north shore of Lake Erie allows greenhouse operations to thrive and market successfully to the United States, as well as to local markets in Ontario. The warmer waters assist in ameliorating temperature swings in coastal areas and will assist in dampening some of the more extreme temperature swings seen in inland locations. Agricultural production in northern locations around the Great Lakes is unlikely to change significantly due to the distance to markets and the shrinking human population at centres such as Sault Ste. Marie and Thunder Bay. However, opportunities along the shores of Lake Huron south of the pre-Cambrian Shield where soils are suitable may be able to expand into higher value crops.

Other adaptation options associated with agriculture relate to the management of water and the probable dry periods during late summer when irrigation will be necessary for many crops. Earlier ripening varieties may be one adaptation option due to a shift in the seasons. Where water is taken directly from the lakes or from wells that depend on lake levels for recharge, the extension of water intake pipes or the deepening of wells may be necessary. Changes in irrigation and drainage techniques (Broad [Table 1]) and the protection of water courses from fertilizer and pesticide run-offs are of major concern in a number of areas around the southern Great Lakes and have been addressed in some of the remedial action plans. A lowering of water levels in the Great Lakes may allow some coastal marshes to be converted to agricultural uses such as occur in south western Ontario although the majority of suitable sites have probably already been dyked and drained. To adapt to increasing storm events, the protection of water courses may be more urgent, with wider riparian protection zones to prevent soils being washed into water courses. Such soil transportation will lead to siltation of drainage channels and streams requiring more frequent dredging unless improved soil management practices are used.

Increasing winds in the coastal zone may have an impact on soil erosion, particularly in coastal counties such as Lambton, Essex and Kent. The introduction and expansion of windbreaks and hedgerows may do much to alleviate soil erosion in some of these areas and is an example of an adaptation option that will have multiple benefits. Increasing wind and wave effects are likely to impact dykes where they are present to protect low lying agricultural areas and more frequent dyke maintenance may be required. Some advantage should be gained from generally lower water levels that should preclude overtopping during major storm events.

8.2 Fisheries

Fish communities and the aquatic ecosystems which support them in the Great Lakes are potentially influenced by two primary climate factors - temperature and precipitation. Changes in air temperature will influence seasonal water temperatures, thermal stratification of the water column, dissolved oxygen levels in some areas, stream temperatures, especially during the critical summer low flow period, and the extent and duration of winter ice cover. Changes in precipitation quantities and storm events will influence water levels in the lakes, which can be critical in wetland habitats, as well as stream flows and resulting stream morphology.

We know that natural ecosystems, both aquatic and terrestrial, exhibit high levels of complexity in the relationships between species, and all physical, chemical and biological components of their environment. Because of this, the effects of physical habitat changes, such as seasonal water temperatures or water levels, can have either direct effects on fish species and communities, or more subtle indirect effects such as through food chains or reproductive systems. This discussion will focus only on the most direct and likely most important, cause-and-effect relationships between climate change and Great Lakes fisheries resources.

Temperature

At the largest scale, an increase in average surface water temperatures in the Great Lakes will favour a shift in fish species community structure from those adapted to colder water to those better suited to warmer waters (Casselman; Doka and Minns; Scheifer; Stanley [Table 1]). While the major lake basins are large and deep enough to retain substantial areas of coldwater habitat during the summer, the productive littoral zone will likely achieve higher average summer water temperatures and retain these for a longer period of time. This should favour many of the warmwater fish species, such as the bass, sunfishes, carp, and many of the smaller forage species. Longer periods of warm water will likely also increase primary production in the littoral zone through a longer growing season for aquatic plants. This would also tend to favour many of the warmwater fish species which utilize this type of littoral zone.

This type of shift in fish species composition will tend to favour many of the exotic species being introduced into the Great Lakes. These come from two primary sources – through inter-basin connections, such as at Chicago, and through the discharge of untreated bilge water from large ships entering the Great Lakes from around the globe (MacIssac et al. 2002 [Table 1]). In the first case, a direct connection with the Mississippi watershed has facilitated a northward expansion of warmwater fish from the south as habitat conditions become more favourable. Several of the sunfish species are a good example of this northern range extension. In the second instance, exotic (non-North American) species in shipping bilge water have successively established large populations in the Great Lakes in the past two decades. Many of these favour warmer water habitats. These exotic species are at all trophic levels, including plants, plankton, molluscs, forage fish and large fish species. These have already had a major impact on aquatic ecosystems in the Great Lakes, and this could increase as warmwater habitats become increasingly more suited to these newly introduced species. One of the adoptive strategies for this is obvious: provide permanent and reliable barriers to fish migration into the Great Lakes through canals linking southern watersheds, and require the treatment of all bilge water to kill any biota prior to discharge.

Longer and warmer summers over the past decade have been shown to alter the pattern of thermal stratification in a number of bays along the Georgian Bay coast. As waters warm earlier in the spring, thermal stratification begins earlier and lasts longer into the fall. The thermocline (zone of rapid water temperature change) is thus in place for a longer period of time, isolating the cold deepwater zone (hypolimnion) from mixing with the warmer surface waters (Brandt et al. 2002, Fang and Stefan 2002, King et al. 1997). This can result in increased late-summer de-oxygenation of these deep waters, reducing or eliminating their suitability for supporting coldwater fish species, such as lake trout or whitefish. Warmer summers also have the effect of pushing the thermocline deeper in the water column, reducing the volume of the deepwater zone and compounding this negative effect on coldwater fish species. An associated effect involves the release of phosphorus from deep lake sediments when exposed to anoxic water above them. Longer periods of anoxia, as described above, can lead to increased release of phosphorus to the water which, when later mixed with surface waters, can stimulate massive blooms of plankton and algae. In Sturgeon Bay, along the Georgian Bay coast, this type of phosphorus cycling from deep basin sediments has resulted in large blooms of blue-green algae during recent summers, and subsequent public health warnings for humans and their pets to avoid water contact activities (Scheifer [Table 1]).

Net-cage aquaculture in the Great Lakes is centred in the northern Georgian Bay area and involves the growing of rainbow trout in surface waters of the lake. Warmer water temperatures in recent years have placed a greater stress on these fish during mid-summer, reducing growth rates, increasing disease issues and, in some cases, increasing mortality. This industry is now investigating the use of deeper or submersible net cages to avoid the growing problem of excessive surface water temperatures for rainbow trout during the summer (Meeker [Table 1]).

Warmer summer temperatures also have a major impact on the suitability of Great Lakes tributary streams to support the reproduction of migratory salmonid fish species, such as the trout and salmon which depend on these. The normal limiting condition on these “coldwater” streams is the water temperatures which exist during the critical mid-summer low flow period. Greatly reduced survival of juvenile trout has been seen on streams during warmer summers, especially when this is combined with periods of low rainfall which also reduces the volume of stream flow. This can have a major impact on important trout and salmon populations in the Great Lakes.

Warmer winters may reduce the period of ice cover on some of the Great Lakes. While this may not have a direct effect on fish communities, if increased water evaporation during the winter has the effect of reducing summer water levels, this can have a large negative effect on many fish species, especially those depending on wetland habitats which have been damaged by lower water levels.

Precipitation

Changes in precipitation quantities, seasonality and the occurrence of more severe storm events can all have an effect on Great Lakes fish communities and aquatic ecosystems. A reduction in water levels in the middle Great Lakes over the past decade has had a negative effect on important wetlands, and all of the fish and other wildlife which rely on them. Most Great Lakes wetlands have evolved in response to water levels which vary within a comparatively broad natural range. When water levels fall below the more normal low extreme, or fall much more rapidly than normal, as has occurred over the past six to seven years in Lake Huron, wetland habitats can be significantly altered. In the case of fish use, productive capacity can be greatly diminished. Climate factors which may contribute to the lowering of water levels in the current and future climates could include reduced annual precipitation, increased evaporation of warmer summer waters and winter evaporation because of reduced ice cover (Lofgren et al. 2001).

As mentioned above, stream flows and temperatures are critical for salmon and trout survival during the low flow summer period. If reduced summer precipitation results in lower minimum summer stream flows, this can reduce the natural carrying capacity of these streams for juvenile trout. If this is combined with higher summer water temperatures, as mentioned above, the ability of these streams to support trout reproduction can be greatly diminished. This would have a major negative effect on salmon and trout populations in the Great Lakes.

Another potential effect on tributary streams relates to the size and frequency of more extreme storm events that are expected under climate change. Heavy rainfall can lead to increased frequency and magnitude of extreme high flow conditions, which can damage natural stream morphology. This includes bank erosion, channel widening, and siltation of gravel beds and estuaries. These all result in a reduction of habitat quality and productive capacity for trout and other important fish species utilizing these tributary streams.

8.3 Forestry

The coastal forestry operations are not unduly affected by climate change in that in southern Ontario such operations in the coastal region are very limited and are generally covered by park operations or by municipalities (Tyerman [Table 1]). In northern areas around the shores of northern Lake Huron and Lake Superior, the change in species composition is likely to be slow unless affected by such factors as increasing wild fires or insect infestations. A warming climate should see the expansion of the Carolinian Zone northward, but such movement will depend on whether species are wind dispersed or whether human interventions are used to assist northward movement of native species. Projections of warmer summers combined with the risk of extended periods of dry weather may suggest that drought and fire resistant tolerant species become commoner. Also when fire occurs, the land is essentially cleared and may be recolonized with pioneer species better adapted to warmer climates.

The potential for increased frequency of major wind events is likely to have an impact on coastal forestry, in particular in parks and other high value areas, where blowdowns can cause severe damage to facilities and private property (Gray and Mulrooney [Table 1]). Wind hardy species should be planted in coastal areas and increases in management budgets may be required to cope with windfalls.

Some tree species (pines and maples) are sensitive to airborne pollutants and a combination of increased pollutants and a changing climate will likely impact forestry productivity. Already some areas are subject to this pollutant load, so while the effect is indirect, damage to forestry will be exacerbated by climate change.

8.4 Municipal

Municipalities have some of the greatest tasks ahead of them in dealing with climate change. While there will be some benefits of climate change such as warmer temperatures so that a winter heating costs will be lower, there will be significant challenges related to public health and safety including the need to reassess emergency measures planning to deal with more frequent major storm events, the pressing need to replace/upgrade municipal infrastructure in response to climate change demands, impacts on both capital and operational budgets generated by public demands to deal with private/public property impacts (Auld et al. 2006a). Meeting these new challenges will require municipalities to understand the nature of these forecasted changes and plan for the anticipated impacts.

The infrastructure associated with harbours, ports, waterfront parks, beaches and water intake pipes and sewage treatment plants will all be affected to varying degrees. Increased temperatures will have one benefit in that salt use in winter on town roads should be reduced, particularly in southern towns. General heating costs in the winter should be reduced for both private and public buildings and facilities. However, it is expected that cooling costs associated with air conditioning use will increase during summer months. Associated with the increased summer temperatures there can be expected an ever increasing number of smog alert days as high daily temperatures facilitate the production of ozone and other photochemical components of smog. Smog concentrations that cross the Great Lakes from the United States are not attenuated by the crossing and due to ever increasing urban and rural development in eastern North America, smog alerts are expected to increase and municipalities will be required to develop management techniques to reduce the impacts by curtailing such activities as mowing lawns with gasoline powered mowers. Changing winter temperatures may well result in more icing conditions that damage not only utilities but street trees resulting in additional costs for clearance. Also icing conditions on flood control devices have caused problems in the recent past and new designs may be needed to protect equipment from such conditions.

The most obvious impact of climate change may be the increased frequency of rain storm events that result in overloaded storm sewer systems and pollutants reaching streams, rivers and lakes. Increased storm events erode stream and river valleys banks, resulting in increased sediment transport often causing changes to navigation channels and harbours and ports. Roads, culverts and other infrastructure that use river flood plains are at increased risk and the expected increase in repairing or replacing infrastructure can be expected to be very high. Private and public properties will be affected by slope stability and potential building envelopes marginalized or eliminated. This changing landscape will create new complex challenges for municipal building approvals and fill regulation, and require new arrangements with agencies such as Conservation Authorities for permitting standards. In some cases, the operating procedures for dams, weirs and water impoundments may need to be altered to adjust to new weather patterns. To reduce the risks of infrastructure damage or failure under a changing climate, a review of building codes, climatic design criteria and infrastructure standards will need to be undertaken with new codes and standards implemented, as required. This would include, for example, a review of ice loads, peak wind design criteria, rainfall intensity, duration and frequency data used in design of municipal water infrastructure, as well as a review of snowload criteria, particularly in areas subject to lake effect snow fall. It should be noted that many of the negative climatic impacts are not caused by average conditions but by extreme events and it behooves municipalities to bring this to the attention of engineers, planning staff and elected officials (Kreutwizer 1988).

Water treatment facilities may need to be upgraded because of the impact of blue green algae on water tainting and these may represent significant costs that will have to be incurred. This may result in a need for improved sewage treatment facilities particularly in more rural areas where leaking septic fields lead to growth of algae in the near shore waters. Lower water levels will also require that water intake pipes be extended lakeward, particularly in those communities that have relatively shallow coastal waters such as Port Rowan. Water demand can be expected to increase during the late summer months and water restrictions may be imposed to cope with the additional demand.

Property boundaries are often defined in Ontario by the high water mark, and where water levels drop to new lows demands from property owners to allow for additional structures in this new “beach” area can be expected. Numerous jurisdictions need to address water access issues and ownership of riparian lands (Lambden and de Rijcke 1996). This is a highly divisive issue and requires all levels of government that have jurisdiction on riparian areas to agree to fair and reasonable laws that protect the public interest, as well as acknowledge past practices and laws.

For some coastal municipalities, drifting sand is a major issue and is caused by buildings encroaching onto natural dune systems. The natural ecosystems bind and control drifting sand, but human structures do not, and in many areas, where lower water levels will expose additional beachfront, more sand will be available to be blown into communities by greater equinoctial storms.

In general, municipalities should audit infrastructure and programs that may be affected by climate change and begin to explore a range of management techniques that can be utilized as a response to climate change. This should include energy conservation measures, backup power generation, emergency measures planning; a community based emergency backup system, and reviewing capital and operational budgets.

8.5 Power Generation

Many power facilities have been constructed in or near to the Great Lakes coastal zone. The Darlington and Pickering nuclear power plants are located on the shores of Lake Ontario and the Bruce nuclear plant is located on Lake Huron. Four of Ontario’s four coal generating plants are located on the Great Lakes: Lake Ontario (Lakeview), Lake Erie (Nanticoke), St. Clair River (Lambton), and Lake Superior (Thunder Bay). A number of run-of-the-river hydro-power stations have been constructed on rivers that drain into or between Great Lakes. For example, a significant amount of power is generated through turbines at Cornwall, Niagara, and Sault Ste. Marie and a reduction of water levels would decrease this amount by up to 15% (Krantzberg [Table 1]). The Ontario Government is committed to the development and implementation of alternative energy, including wind power. The Great Lakes and the Great Lakes coastline provide most of the best opportunities for wind power projects in Ontario. Coastal projects like the Prince Wind Farm near Sault Ste. Marie currently are being designed and developed. It is anticipated that offshore wind farms will be constructed in the Great Lakes as well, particularly in the eastern basin of Lake Ontario and the southern tip of Lake Erie.

With warmer winters, there is a risk of an increase in ice storms. As was demonstrated during the 1998 Ontario-Quebec ice storm, significant damage to all kinds of infrastructure including power lines and towers can occur. Power generation facilities established on or adjacent to the Great Lakes should be designed to withstand the impacts of freezing rain and extreme winds.

Increases in air temperature and warmer weather for longer periods will erode the efficiency of cable and towers to transmit electricity. In the absence of an engineering solution, electricity abundance projections and associated demands may require modification.

Lower water levels will potentially cause water short-falls at hydro-electric facilities in Canada and United States during some periods in the year. Given that facilities in Ontario are run-of-the-river operations, production targets and user demand may require adjustment during these periods.

With warmer water temperature, cooling efficiencies in plants that draw water from the Great Lakes will be reduced and will need to be factored into plant operations and maintenance.

8.6 Recreation

Millions of Ontarians and visitors participate in recreational activities along the Great Lakes coast throughout the year. Many areas that are managed as national, provincial, and municipal parks and public beaches provide quality recreational opportunities. For example, approximately 20% of all provincial parks in Ontario are connected to Great Lakes coastal areas. While most of the parks are small and collectively account for only 5% of the total area of provincial park land in Ontario, they are used by 53% of all people who visit provincial parks (OMNR 2003, 2004). Given that many of these coastal parks and other recreation areas are close to large urban centres in southern Ontario, and given that the human population in many of these urban centres will continue to increase during the 21st century, more people will seek access to these parks in the future (Gray and Mulrooney [Table 1])

Marinas and public docks provide watercraft mooring facilities and access to water on all Great Lakes. In central and northern Ontario, the ‘Great Lakes Heritage Coast’ stretches 2,900 km along spectacular landscapes and shoreline from southern Georgian Bay to the Canada-US border on Lake Superior, and encompasses 1.1 million ha including communities like Thunder Bay, Red Rock, Nipigon, Marathon, Wawa, Sault Ste. Marie, Killarney, Parry Sound, and Port Severn. The Heritage Coast is managed to protect scenic beauty, natural ecosystems, and to promote recreation, tourism and other economic benefits through a network of parks and protected areas. The national park system endeavours to protect representative ecosystems.

Climate change will result in many alterations to protected ecosystems (Scott et al. 2002) and will require substantial changes to the park system in the coming century.

In addition to increased demand for use of coastal areas for recreation, longer periods of warm weather will provide extended opportunities for camping, hiking, wildlife viewing, and water-based activities such as boating and water skiing, canoeing and kayaking, and swimming. As well, natural resource management agencies and organizations may need to mitigate the impacts of increased human activity on vegetation in parks, protected areas, and on Crown lands and address water quality issues resulting from warmer water.

A longer and warmer summer season with associated warmer water temperatures may exacerbate recreation-related water quality problems in several Great Lakes communities, particularly in communities with public beaches where bacterial contamination has historically been a problem. Communities may need to aggressively address emerging water contamination issues with more sophisticated treatment facilities and contingency measures in the event of the accidental release of contaminated water. Longer warmer water periods will cause a reduction in the length of the ice-in period during the winter months. And given that ice cover serves to reduce the severity of winter storms along the coast, it is anticipated that there will be an increase in the severity of winter storms experienced by coastal communities.

A shorter and warmer winter season will mean that people living in southern Ontario potentially will need to travel further north to pursue winter activities such as cross-country and downhill skiing, snowmobiling, and ice fishing. And in some areas where winter weather becomes increasingly more unpredictable, some tourist operators will need to adjust their services and programs to reflect these changing weather patterns. On the other hand, given that some coastal areas in central and northern Ontario potentially will receive more snow in the near future as a result of an increase in lake effect snowfall, winter-based recreational industries may benefit in these areas. However, this benefit will be reduced and gradually disappear in most of these traditional snowbelt areas as winter temperatures continue to warm and the frequency of lake-effect snow events decreases during this century.

In addition to water quality issues, warmer water temperatures potentially will change the distribution and abundance of fish populations and the location and type of recreational fishing opportunities. For example, in some coastal areas in the southern Great Lakes, warm water species like bass may become more abundant and available while cool water species like walleye, may become less abundant and less available to recreational fishers. In addition, warmer water temperatures may promote the spread of invasive species which in turn may impact important Great Lakes fish species. Ponto-Caspian invasive species from Europe which are historically adapted to warmer water temperatures than traditionally provided by the Great Lakes are of particular concern (MacIssac [Table 1]).

In response to climate change, water levels are forecasted to drop in coastal area lakes, streams, and rivers, as well as the Great Lakes. While lower water levels will increase the amount of beach land and material available for active dune systems (e.g., Presqu'ile Provincial Park) (Tyerman [Table 1]), a variety of ecological and water access issues will require attention by natural resource management agency staff at Federal, Provincial, and Municipal levels of government and private landowners. For example, while the expected lowering of water levels will increase beach area in many locations such as at Presqu'ile Provincial Park and Long Point Provincial Park, newly exposed lake sediments may result in increased sediment transport and dune formation, which in some communities could result in sand blowing into streets and onto residential and commercial properties requiring ongoing removal. In some cases, the exposed sediments may re-activate chemical pollutants that have been locked away for many years.

Lower water levels will limit access to some marinas and cottages. And given that natural fluctuation and potential long-term climate-induced draw-down likely will be one of the more uncertain aspects of the Great Lakes ecosystem, communities may be need to prepare management strategies designed to enable them to cope with a range of lower water levels that may persist for long periods of time.

Boating and fishing are major recreational activities throughout the Great Lakes and it is expected that there will continue to be a large demand for marinas, docks, and other aquatic facilities. Accordingly, proposals for new marinas should be based on water level calculations that include estimates of maximum climate-induced draw-down. For existing marinas, dredging may work in some cases. But some marinas may need to be closed and relocated if they are currently constructed along rocky harbours where dredging is impossible and blasting is not permitted. Cottage owners may need to acquire expandable dock systems.

There is the potential for increased sailing opportunities depending on the patterns of wind changes in the future climate. In addition, management agencies and organizations should use wind-resistant vegetation to minimize blow-downs and erosion along coastal shorelines and on adjacent areas. Stronger winds may also require improved harbour and marina facilities to protect boats during major storm events.

8.7 Transportation

The impact of warmer temperatures will most affect transportation during the winter months. At the moment large quantities of salt are used on roads in southern Ontario to melt snow and ice and there should be a reduction of this use with warmer winters. At Goderich for instance, efforts are being made to reduce the salt laden run off that enters the harbour and Toronto has made major changes in its snow dumping policies to reduce salt and contaminants entering the rivers and coastal waters.

Changes in precipitation patterns, including seasonality, amounts, intensity and type of precipitation impact the timing of controlling water flow through the main control devices on the Great Lakes at Cornwall, Niagara and Sault Ste. Marie. These are adaptations that can be made easily, though there will be implications to power generation. Increases in major rainfall events are already having impacts such as the August 2005 rain event in north Toronto that caused flooding and swept away the Finch Avenue crossing of Black Creek (Haley [Table 1]) causing disruption to traffic for many months. There are a number of coastal roads and bridges that are affected by weather conditions because of their proximity to the Great Lakes. Fog and ice storms are a serious consideration and weather advisories currently provide information when road conditions are very poor. Bridges such as the skyway in Burlington or the bridge across the St. Mary's River in Sault Ste. Marie are subject to closure during high wind storms. Some coastal roads are subject to flooding during major storms and again the actual roads and associated culverts and bridges may be blocked by debris brought down during severe storms. Increased wind combined with warmer winter temperatures and lower water levels is likely to see more sand being blown across coastal roads and into the streets and facilities of coastal communities. This is already occurring in many parks, as well as communities such as Grand Bend on Lake Huron, where new buildings have altered wind patterns that now entrain sand from the beaches and cause considerable sand accumulations in some locations. Another impact of wind that is impossible to control is the large scale Seiche effects on Lake Erie and to a lesser extent on the other Great Lakes. Such wind caused alterations to water levels have resulted in the grounding of ships particularly at the western end of Lake Erie that is particularly shallow.

Shipping is very dependent upon weather and the ability of ships of all sizes to enter and leave harbour safely is influenced by the weather. A change in climate is likely to put more ships at risk because of the use of ice free periods in the winter when severe storms are more likely to occur (Andersen [Table 1]). Potential adaptation to changing climate may result in a change of ship design and size and the limitation on the present systems of canals and locks have to be considered in the adaptation options (Andersen [Table 1]). At present there is also a quandary between using water for power generation and having enough water for shipping to navigate the many channels on the Great Lakes. The International Joint Commission (IJC) is responsible for providing the advisories regarding control structures and ensuring that all parties agree on changes in water levels that may need to be made. Lower water levels will affect coastal navigation and a recent occurrence of a ship grounding after leaving Goderich harbour, indicates how far out the influence may be felt beyond the actual harbour. Low water levels, particularly on Lake Huron affect many communities that are dependent upon water access such as those scattered up the Georgian Bay coast (Schiefer [Table 1]; Muter [Table 1]). Some harbours, marinas and ports are able to dredge the bottom to accommodate vessels (e.g., Hamilton Harbour), while others because of bedrock, bathymetry and size will be unable to adapt to lowered water levels (Hall [Table 1]). Adaptation options may well involve going to shallow draft craft, increased use of hovercraft or a withdrawal from these areas that no longer possess the coastal characteristics which makes them attractive.

8.8 Wildlife

Wildlife is used here to include all animals other than fish and relates particularly to birds and a number of invertebrates that occur naturally or have been introduced to the Great Lakes ecosystems. In most cases we have little direct impact on wildlife as birds and mammals will spread to where habitats are suitable and will die out in places where they are unsuitable. There are also many confounding factors such as introduced non-native species, pollutants, land use and disease that may affect wildlife populations. The timing of bird migration is caused in some species by a change in temperature and in others by changing day length. Short distance migrants that overwinter in the southern United States are more likely to be affected by changing air temperatures than long distance migrants from Central America. Warmer winters will allow waterbirds to overwinter on the southern Great Lakes and this will have a major impact on the food chains and ecology of the lakes. With introduced non-native species like zebra mussels and a largely ice free coastal zone in many parts of the southern Great Lakes, many ducks, geese and other birds are able to over winter without flying south to the Atlantic and Gulf coasts. An early spring with early leaf out will affect the phenology of plants that provide the food source for insects and ultimately food source for many neotropical migrant birds.

Warmer water temperatures together with available nutrients permit the growth of many blue-green algae such as *Microcystis* which is fouling beaches in the Georgian Bay area (Schiefer 2005 [Table 1]) and locations on Lakes Erie, Michigan, Huron and Ontario. Toxins produced by *Microcystis* may be accumulated in wildlife and it is believed that one of the causes of mortality in waterfowl may be due to poisoning with toxins. Warmer water temperatures and increased productivity in many coastal wetlands may permit species such as the introduced Mute Swan to expand its range northwards in Lake Huron. Currently this species is expanding rapidly on the southern Great Lakes and can be expected to move northwards (Petrie 2005 [Table 1]). Adaptation options to constrain such expansions may include hunting, as well as egg oiling, but so far attempts to limit the rapid population growth of the Double-crested Cormorant have been ineffective, probably because of the large number of forage fish available (Pekarik and Weseloh [Table 1]).

Lower water levels in the long-term may have major impacts on wetlands on the Great Lakes and thereby affect wildlife using them. This rather depends on whether the bathymetry and coastal processes allow wetlands to migrate lakeward or whether they are constrained (Muter [Table 1]; Doka and Minns [Table 1]).

8.9 Conclusions

This report has reviewed the potential impact of a changing climate on a number of coastal industries and activities. There are many factors besides climate such as land use, introduced non-native species and isostatic rebound that will impact coastal communities in the years to come. Many of these others factors work with or against each other and actual predictions may be impossible as the unexpected will always happen. However, prudence is required during major investments to coastal communities and having some understanding of the impacts that will likely occur in the coming years can be used to lessen the impacts of climate change. It is difficult to predict what will be the burning issues of the next decades, but it is likely that lower water levels will create all manner of jurisdictional problems. A local planner described the issue of riparian rights and boundaries as one of the most pressing issues of our times and that it was essential that the federal government take steps to address the issues or property rights in coastal areas. The presence of non-native species and the changing balance in the Great Lakes ecosystems will also have major implications to the resources of the coastal zone and how they are utilized by future generations.

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TABLE 1
WORKSHOP PRESENTATIONS

No.	Name	Affiliation	Title of Presentation	Location
1	Aasen,Christine and Tricia Westman	Sault Ste. Marie Conservation Authority	Sault Ste. Marie Conservation Authority	Sault Ste. Marie
2	Andersen, Tom	Seaway Marine Transport	Climate, Extreme Events and Shipping	Sault Ste. Marie
3	Auld, Heather, N. Comer, D. MacIver, J. Klassen	Adaptation Impacts Research Group, Meteorological Services Canada	Climate Change and the Great Lakes: the Lake Superior Story	Sault Ste. Marie
4	Bennett, John	Climate Action Network	The Role of Municipalities in Adapting to Climate Change	Toronto
5	Broad, Stephen	Ontario Greenhouse Gas Mitigation Program	Greenhouse Gas Mitigation Program for Canadian Agriculture	Long Point
6	Boysen, Eric	Ontario Ministry of Natural Resources	Renewable Energy in the Upper Great Lakes: Responding to Uncertainty	Sault Ste. Marie
7	Casselman, John	Queen's University and OMNR	Climate, Climate Change and Fish and Fisheries of the Great Lakes Basin	Toronto
8	Clamen, Murray	International Joint Commission	The International Joint Commission	Toronto
9	Cochrane, John	Sturgeon Bay Action Group	Sturgeon Bay Township/Association/Community	Sault Ste. Marie
10	Davidson-Arnott, Robin	University of Guelph	Beaches and Dunes	Belleville
11	Doka, Susan and C.K. Minns	Fisheries and Oceans Canada	Great Lakes Coastal Wetland Communities: Vulnerabilities to Climate Change and Response to Adaptation Changes	Long Point
12	Elder, Mary	Norfolk County Planning Department	Planning for the Future, Communities and Climate Change	Long Point
13	Fraser, John	Ontario Ministry of Natural Resources	Climate Change and Shoreline Processes	Belleville
14	Gray, Paul and D. Mulrooney	Ontario Ministry of Natural Resources	Recreation in Provincial Parks	Belleville
15	Gray, Paul	Ontario Ministry of Natural Resources	Recreation in Provincial Parks	Parry Sound
16	Haley, Don	Toronto and Region Conservation Authority	Infrastructure and Climate Change	Belleville
17	Haley, Don	Toronto and Region Conservation Authority	Infrastructure and Climate Change	Parry Sound
18	Haley, Don	Toronto and Region Conservation Authority	Infrastructure and Toronto Waterfront Revitalization	Toronto
19	Hall, John	Hamilton Fish and Wildlife Restoration Project	Hamilton Harbour Remedial Action Plan	Toronto
20	Hilsinger, Donna	Water Tower Inn, Sault Ste. Marie	Ecotourism in the Coastal Zone	Sault Ste. Marie
21	Klaassen, Joan	Meteorological Services Canada	Climate Change and the Great Lakes	Toronto
22	Krantzberg, Gail	International Joint Commission	Our Great Lakes: the Quality Quantity Connections	Parry Sound
23	MacIssac, Hugh	University of Windsor	Non-native species in the Coastal Great Lakes, a Challenge for the Future	Toronto

Note: **The numbers in Column 1 are provided as the reference numbers (superscript) in Tables 2 to 9**

TABLE 1
WORKSHOP PRESENTATIONS

No.	Name	Affiliation	Title of Presentation	Location
24	MacIver, Don, H. Auld, J. Klaassen, B. Tugwood and N. Comer	Meteorological Services Canada	Climate Variability, Extremes and Climate Change in Ontario	Belleville
25	MacIver, Don, H. Auld, J. Klaassen, and N. Comer	Meteorological Services Canada	Climate Variability, Extremes and Climate Change in Ontario	Parry Sound
26	MacIver, Don, H. Auld, J. Klaassen, N. Comer and D. Simpson	Meteorological Services Canada	Climate Variability, Extremes and Climate Change – Long Point	Long Point
27	MacIver, Don and H. Auld	Meteorological Services Canada	Climate Change: Creeping Environmental Impacts	Toronto
28	Mason, Greg	Parry Sound Planning Department	Planning- Conflict and Change: Policy Challenges	Parry Sound
29	McAuley, Tom	International Joint Commission, Ottawa	The International Joint Commission and Great Lakes Water Levels	Sault Ste. Marie
30	McNicol, Don and R. Russell	Canadian Wildlife Service	Wildlife	Belleville
31	Meeker, Mike	Northern Ontario Aquaculture Association	Lake Superior Fisheries and Coastal Aquaculture	Sault Ste. Marie
32	Mortsch, Linda and A. Hebb	AIRG, University of Waterloo	Climate Change Impacts on Great Lakes Coastal Wetlands	Belleville
33	Muter, Mary	Georgian Bay Association	Ecological Impacts of Low Water Levels for Eastern and Northern Georgian Bay	Parry Sound
34	Oliver, Jim	Long Point Conservation Authority	Water, Flood Protection, Hazard Lands: the Impacts of a Changing Climate	Long Point
35	Pekarik, Cynthia and C. Weseloh	Canadian Wildlife Service	Waterbirds and Climate Change on Georgian Bay	Parry Sound
36	Petrie, Scott	Bird Studies Canada	Impact of Invasive Species on Waterfowl	Long Point
37	Rivet, Julie	Pukaskwa National Park, National Parks	Pukaskwa National Park	Sault Ste. Marie
38	Ross, Ken	Canadian Wildlife Service	Climate Change and Wildlife	Belleville
39	Robinson, Jeff	Canadian wildlife Service	National Wildlife Areas and Wildlife at Long Point	Long Point
40	Schiefer, Karl	Ecometrix	Georgian Bay: Overview of Climate Change Issues	Parry Sound
41	Stanley, David	Stantec	Great Lakes and Ontario Fisheries in a Changing Climate	Belleville
42	Toninger, R.	Toronto and Region Conservation Authority	Habitat Restoration	Toronto
43	Tyerman, Don	Ontario Ministry of Natural Resources	Climate Change and Presqu'ile Park	Belleville

Note: **The numbers in Column 1 are provided as the reference numbers (superscript) in Tables 2 to 9**

TABLE 2
INCREASED COASTAL AIR TEMPERATURES

Sector	Impact	Natural Adaptation	Management Option
Agriculture	• Longer growing season for plants [5, 24]	• Increase in primary production, organic matter decomposition [32]	• Utilize productivity • Change in crops grown, more high value crops where soils appropriate [5]
Agriculture	• Increased evaporation, evapo-transpiration and probable drought conditions in late summer [34]	• Preferential growth by drought tolerant species	• Some water management may be possible in coastal communities [34]
Fisheries	• Reduction of ice on lakes	• NA	• Change in ice fishing season
Forestry	• Restructuring of species community composition and food webs	• Species that are wind or animal dispersed and find suitable habitats will colonize them replacing the more northern species. • Movement northwards of southern Carolinian species [24, 43]	• Planting species associated with the new climates • Plant trees that are more resistant to ice loads • May require species control of invasive plants until new communities are established [36]
Municipal	• Increased evaporation, evapo-transpiration and probable drought conditions in late summer [34]	• Preferential growth by drought tolerant species	• Some water management may be possible in coastal communities [34]
Municipal	• Changes in frequency of ice storms [24,]	• Species that are susceptible to ice damage such as Manitoba Maple will be reduced	• Build structures to withstand higher ice loads, plant trees that are more resistant to ice loads [3]
Municipal	• Spring run-off, flooding, ice jams [18]	• Scouring of valley floor, selection of resistant plants	• Infrastructure changes, ice jam removal
Recreation	• Higher usage of parks, beaches in coastal areas due to longer summer recreational season [8]	• Hardy species resistant to trampling etc. may survive better	• Regulation of park usage [15] • Also provision of services for coastal recreation communities [20, 28]
Recreation	• Reduction of snow, ice and winter sports[28]	• People will change location depending on where conditions are appropriate for sport [20]	• Changes in access to some coastal communities change in recreational and ice fishing seasons [28, 14]
Transportation	• Reduction of snow and ice	• Coastal areas more exposed to winter storms with reduced ice cover [13]	• Changes in access to some coastal communities
Transportation	• Changes in frequency of ice storms [2,21, 24, 14]	• People will change travel patterns	• Build structures to withstand higher ice loads [3]
Transportation	• Change in frequency of fog events [3, 24]	• NA	• Changes in navigation and road incidences [17]
Wildlife	• Earlier spring season and leaf out	• Bird species will migrate sooner in year [30]	• Changes in hunting seasons for some waterfowl
Wildlife	• Reduction of snow, ice	• Changes in migration of birds, insects etc. [30, 36]	• Potential changes ice fishing seasons [31]

Note: **The superscript numbers refer to presentations given at the five climate change workshops and are referenced in Table 1 (Column 1)**

TABLE 3
CHANGES IN PRECIPITATION (INCREASED ANNUAL PRECIPITATION)

Sector	Impact	Natural Adaptation	Management Option
Agriculture	• More annual rain; changes in irrigation and drainage practices [5, 34]	• NA	• Availability of field drainage for clay soils and irrigation for dry summers
Agriculture	• Impact on fertilizer regimes, and non-point nutrient loadings in coastal waters [5]	• NA	• Change fertilizer practices, green manures etc.[5]
Agriculture	• Increased sediment loads from inflowing rivers	• NA	• Dredging may need to be increased • Riparian planting for field drainage [34]
Fisheries	• Increased channel and coastal erosion due to more extreme events	• Potential changes in natural channels if surface water movements increase	• Modification of connecting channels, St. Mary's River, St. Clair River and St. Lawrence River
Fisheries	• Increase in flow rates for inflowing rivers [6]	• Fish species will move to areas where conditions are favourable	• Infrastructure changes for dams and fish weirs
Forestry	• Increased inputs of aerial contaminants [4]	• Presumably adaptation of species enduring higher acidity levels, higher ozone, Hg, etc.	• Reduce transport of aerial pollutants • Nuclear vs. coal fired generating stations
Forestry	• Change in fire hazards in late summer	• Species resilient to fire (jack pine) will be become more widespread	• Changes in budgets for fire management.
Municipal	• Increased frequency of extreme events [21]	• NA	• Infrastructure such as storm drains, catchment areas may need to be modified [18]
Municipal	• Potential increase in lake effect on easterly coastal areas may be as snow, rain or ice [3]	• NA	• Review of snow loadings for buildings in coastal areas [3]
Recreation	• Potential increase in lake effect on easterly coastal areas may be as snow, rain or ice [3]	• More tolerant plant species will do better	• Some areas in northern areas of Great Lakes will benefit from increased snowfall [6]
Power Generation	• Higher flow rates of water through Great Lakes ecosystems	• NA	• Potential for change in hydro generating regimes [6, 22]
Transportation	• Decreased water levels for shipping in late summer [2]	• NA	• Change operating procedures for water control devices St Mary's River, St. Lawrence and Niagara [8, 29]
Transportation	• Flooding low lying roads in coastal areas	• NA	• Redesign coastal roads where necessary
Wildlife	• Water level fluctuations may result in swamping of marsh bird nests [35]	• Species will adapt or move to more favourable locations	• Water level regulation in dyked impoundments[11]

Note: **The superscript numbers refer to presentations given at the five climate change workshops and are referenced in Table 1 (Column 1)**

TABLE 4
CHANGE IN WIND (EXTREME EVENTS)

Sector	Impact	Natural Adaptation	Management Option
Agriculture	• Soil erosion in coastal areas.	• Shoreline systems will adapt, potential reconfiguring of coastal zone [10]	• Change farming practices in coastal areas, hedgerows etc.[34]
Fisheries	• Change in seiche effects and water circulations in bays [40]		
Forestry	• Blow down trees [41]	• More wind resistant species will grow in coastal areas	• Plant more wind firm trees in coastal areas
Municipal	• Coastal infrastructure, wave regime [3, 13, 16]	• NA	• Armouring and shoreline structures, harbours may need to be modified • Zoning [3, 12, 28]
Municipal	• Impact on harbour structures [2]	• River mouth and harbour configurations	• Wind advisories [24, 25]
Municipal	• Changes in size of seiche effects	• May impact water circulation patterns in bays and wetland boundaries	
Municipal	• Potential greater build up of ice dams on lee shores	• None	• This might be relevant at mouth of Niagara River
Power Generation	• More wind energy available for coastal wind farms [6]	• None	• Increase number of coastal wind farms to take advantage of increased winds
Recreation	• Harbour protections etc.	• NA	• Change in sailing advisories etc.
Recreation	• Drifting sand in some communities	• Beach and dune systems may change in shape and extent	• Sand removal • Better planning for coastal buildings and infrastructure
Transportation	• Change in sediment transport (sand) Navigation hazard [3]	• NA	• Changes in navigation patterns, small boat warnings
Transportation	• Increase in seiche effects in Lakes Erie and St. Clair	• NA	• May affect navigation e.g., Lake St. Clair and Western Lake Erie when water levels drop due to seiche effects • Real time weather advisories and water depth gauges [2]
Wildlife	• Potentially more birds blown off course into Great Lakes area	• NA	• Provide more recreational opportunities for birders

Note: **The superscript numbers refer to presentations given at the five climate change workshops and are referenced in Table 1 (Column 1)**

TABLE 5
CHANGE IN WATER TEMPERATURE

Sector	Impact	Natural Adaptation	Management Option
Agriculture	• Warmer and longer growing season in coastal areas [5]	• Moderated coastal climate and expansion of Carolinian species northward [24]	• Change in crops grown in coastal areas (soft fruits, vegetables)
Fisheries	• Longer growing season for aquatic plants	• Increase in primary production, organic matter decomposition and food for invertebrates • Changes in spawning seasons [7]	• Utilize increased productivity
Fisheries	• Restructuring of species community composition (fish) [7], [38, 31, 41]	• Discuss fish temperature preferences 2^{o}C [7, 41]	• Change fisheries to adapt to new communities
Fisheries	• Food webs (algal blooms, bacteria, diatoms) [41]	• One study indicated that the mean total phytoplankton biomass did not increase during a warm period, cyanobacteria biomass increased dramatically • Important to take into account potential changes in species composition, since many cyanobacteria are toxic	• NA
Fisheries	• Oxygen concentration changes - Increase in length and depth of summer stratification will increase oxygen depletion in hypolimnion [38, 41]	• The formation of "dead low O_2 hypolimnion zone" occurs in some coastal areas, thereby changing species composition and decreasing productivity • Bottom dwelling invertebrates and fish (perch, walleye and catfish) risk suffocation due to O_2 deprivation [7]	• None, or artificial oxygenation in confined bays
Fisheries	• Decrease in habitat of cold stenothermic organisms [7, 41,]	• Movement of species to colder waters where possible. Increase in recruitment of small mouth bass [7, 41] • Increased recruitment and growth x14 for 3^{o} rise in temp [7]	• Modification of coastal aquaculture practices [31]
Municipal	• Higher water temperatures cause changes in water chemistry - bacterial release of phosphate and ammonium from the sediments	• Species may adapt to slow changes in water chemistry	• Control of nutrient inputs to lakes [28, 40] • Water treatment for drinking water may need to be upgraded
Recreation	• Reduction of ice cover and winter season [7, 11, 15, 28, 15]	• Coastal areas more exposed to winter storms with reduced ice cover	• Changes in access to some coastal communities change in recreational and fishing seasons
Transportation	• Load on shipboard machinery cooling systems [2]	• None	• Operation and redesign of cooling systems
Transportation	• Longer ice free navigation season [2]	• None	• Increase operating season, improves economics of shipping [2]
Power generation	• Changes to efficiencies of cooling waters for power stations, and buildings	• None	• Extend intake pipes below thermocline
Recreation	• Longer swimming season and coastal recreational activities [15, 9, 28]	• None	• Increased revenues from longer summer season • Clean up water quality
Wildlife	• Food webs (algal blooms, bacteria, diatoms) [40]	• Increase in algal blooms (toxic blooms & *Microcystis* linked to bird deaths in Great Lakes) [30, 35]	

Note: The superscript numbers refer to presentations given at the five climate change workshops and are referenced in Table 1 (Column 1)

TABLE 6
CHANGES IN LAKE WATER LEVELS

Sector	Impact	Natural Adaptation	Management Option
Agriculture	• Potential impact on irrigation intake pipes	• NA	• Regulate lake water levels • Extend water intake pipes [16]
Agriculture	• Drying of coastal marshes	• Change in plant communities	• Expansion of agriculture into marsh areas
Fisheries	• Change in location of littoral ecosystems [32] • Change in spawning and nursery areas [33]	• Species will move to appropriate depths [32] • Adjustment of shoreline ecosystems, if not constrained by ownership issues	• Protection of wetland ecosystems with dykes, pumping and active management [11, 19, 32]
Fisheries	• Low water levels will lead to increased eutrophication in shallow bays [40]	• Lake-ward movement of ecosystems may be possible in some unconstrained areas [33]	• Reduce nutrient inputs to bays
Fisheries	• Increase in the amount of UV radiation to which aquatic organisms may be exposed in shallow bays	• Species will adapt	• Management of shoreline ecosystems, through dykes, water pumping or impoundment [7, 11]
Municipal	• Property ownership issues of new littoral lands [19, 28]	• NA	• Ownership issues • Determine method of delineating legal shoreline boundaries, very relevant on shallow sloping shorelines, not on steep rocky shorelines
Municipal	• There could be increased scouring of coastal river mouths because of gradient change [16]	• River morphology will adapt to new regimes	• None
Municipal	• Change in exposure of littoral infrastructure, groynes, intake pipes etc. to storm events [3]	• None	• Engineer new structures
Power generation	• Change in available water for power generation [6, 8]	• NA	• Change in operating procedures
Recreation	• Exposure and movement of newly exposed sand and silts to wind [10]	• Creation of new beach and dune systems[10]	• Control as much as possible erosive forces
Recreation	• Potential closure of marinas [28]	• NA	• Dredging or blasting in some cases [40] • Closure of some marinas and boat slips
Transportation	• Reduction in navigation channels [2] and access to some marinas, ports, private properties and industrial installations [40]	• NA	• Dredging or blasting [40] • Change in ship size and design [2] • Change in loading for ships
Transportation	• New shoals and islets formed [35]	• NA	• Dredging or blasting [40] • Use of smaller boats and ships [28]
Wildlife	• Drying out of some wetland systems [32] • Loss of wetland habitats [11, 12]	• Wetlands become meadows [38]	• Dyking and pumping to maintain wetlands [32]

Note: The superscript numbers refer to presentations given at the five climate change workshops and are referenced in Table 1 (Column 1)

TABLE 7
CHANGES IN WATER FLOW – COASTAL RIVERINE (WATER FLOW RATES FROM RIVERS CHANGE)

Sector	Impact	Natural Adaptation	Management Option
Agriculture	• Decrease in water quality because of high sediment load [13, 16, 34]	• NA	• Dams and weirs may be used to control flow rates and reduce sediment loads • Control of inputs of pollutants (fertilizers, pesticides) to rivers
Fisheries	• Improved water quality on rocky watersheds. Storm events flush out sediments and associated contaminants. Geology highly relevant [33]	• In rocky terrain, increased water movement results in increased oxygenation - better for salmonids [40]	• Adjustment of riverine ecosystems [17] • Technical and policy matters regarding lake-level management should be reviewed
Fisheries	• Increased scouring of river banks[18]	• Meander belts change in dimension	• Armouring banks in lower reaches
Fisheries	• Decreased flow could make spawning habitats less accessible	• Changes in community composition	• Regulate flow for spawning periods where possible
Fisheries	• Decreased water quality where sediments easily eroded: geology highly relevant [33] • As flows decrease, so does the ability of water systems to tolerate pollutants (water inputs dilute pollutants) • Decreased water flows can decrease the amount of all ochthonous DOC which is important as food supply for invertebrates.	• Species requiring clear waters replaced by those adapted to murky waters • Changes in species associated with water quality, salmonids to cyprinids: macrophytes to blue green algae	• Dams and weirs may be used to control flow rates and reduce sediment loads
Municipal	• Extreme events and flooding [13, 17, 18]	• Development of flood plain plant communities resistant to flood events	• Control of development in hazard lands[1, 12, 16]
Municipal	• As flows increase, so does the ability of water systems to tolerate pollutants (additional water dilute pollutants)	• NA	• Adapt water taking and waste water discharge in coastal riverine situations
Municipal	• Decreased flows lead to longer residence times and deposition of sediments in mouths of rivers	• Silting of river mouths, formation of inshore bars, creation of riverine marshes	• Dredging where necessary [16]
Power Generation	• Impact on dam structures with extreme events [18]	• NA	• Modify dam operational schedules [6]
Power Generation	• Increased power generating capacity [6]	• NA	• Modify operational procedures [6]
Recreation	• May impact use of marinas in river mouths	• NA	• Dredging where necessary

Note: The superscript numbers refer to presentations given at the five climate change workshops and are referenced in Table 1 (Column 1)

TABLE 8
CHANGES IN WATER MOVEMENT – COASTAL LACUSTRINE

Sector	Impact	Natural Adaptation	Management Option
Fisheries	• This may alter the movement of water along the coastline, diverting coastal movements further offshore and changing location of sediment deposition • Decrease in water quality because of high sediment load deposited in delta or nearshore environment.	• Change in river mouth morphology and associated wetlands • In some cases, rivers contribute materials for shoreline accretion down current.	• Dams and weirs may be used to control flow rates and control sediment loads entering lakes • Groynes and sea walls may change coastal movement of sediments [10]
Fisheries		• In rocky terrain, increased water movement results in increased oxygenation - better for salmonids	• Adjustment of shoreline ecosystems • Technical and policy matters regarding water controls should be reviewed
Municipal	• Change in coastal water movement.	• In urban or intensive agricultural areas, may result in more beach closures due to high bacterial counts	• Manage source and non-point source pollutants
Municipal	• Coastal currents are responsible for the erosion and accretion of coastal features one can expect to see change [10]	• There will be a change in the littoral zone depending on sediment type and availability	• Use of groynes, sea walls etc. to trap or deflect sediments [18]
Recreation	• Changes in water movement associated with waves affects coastal ecosystems	• Changes in barrier beaches, dune systems and other coastal land forms	• Use of groynes, sea walls etc. to dampen effects and protect shoreline
Transportation	• Changes in currents and wave regimes affect harbour use [2]		• Alter harbour walls, charts, navigation aids etc.

Note: The superscript numbers refer to presentations given at the five climate change workshops and are referenced in Table 1 (Column 1)

TABLE 9
CHANGE IN WIND SPEED AND STORM EVENTS (SCALE AND FREQUENCY)

Sector	Impact	Natural Adaptation	Management Option
Agriculture	• Increased wave action on dykes	• Breakdown of dykes	• Reinforce and maintenance of dykes
Agriculture	• Blowing of topsoil in coastal areas	• Colonization of soil	• Planting of windbreaks and better soil management
Fisheries	• Increased wave action on littoral zone	• Change in substrate for some coastal spawning species, species will move to new locations	• Use of offshore structures to protect littoral zone
Municipal	• Drifting sand in coastal car parks	• NA	• Wind protection and relocation of parking and facilities
Municipal	• Destroyed buildings in exposed areas [14]	• NA	• Weather advisories
Municipal	• Increased frequency of severe events	• NA	• Hardening of shorelines where infrastructure is vulnerable
Power generation	• Potential increase in energy capacity of wind farms	• NA	• Increased energy available for coastal windfarms [6]
Recreation	• Impact on beaches	• Increased erosion	• Develop management plans to allow for increased wind velocities
Recreation	• Sports such as sailing may be impacted	• Changes in size of dune systems, beach profiles etc.	• Improved forecasts for boats and for navigation
Recreation	• Damage to recreational vehicles in parks [14]	• NA	• Use of wind firm tree management in park areas
Transportation	• Impact on shipping in fall and spring [2]	• NA	• Improved forecasts for boats and for navigation

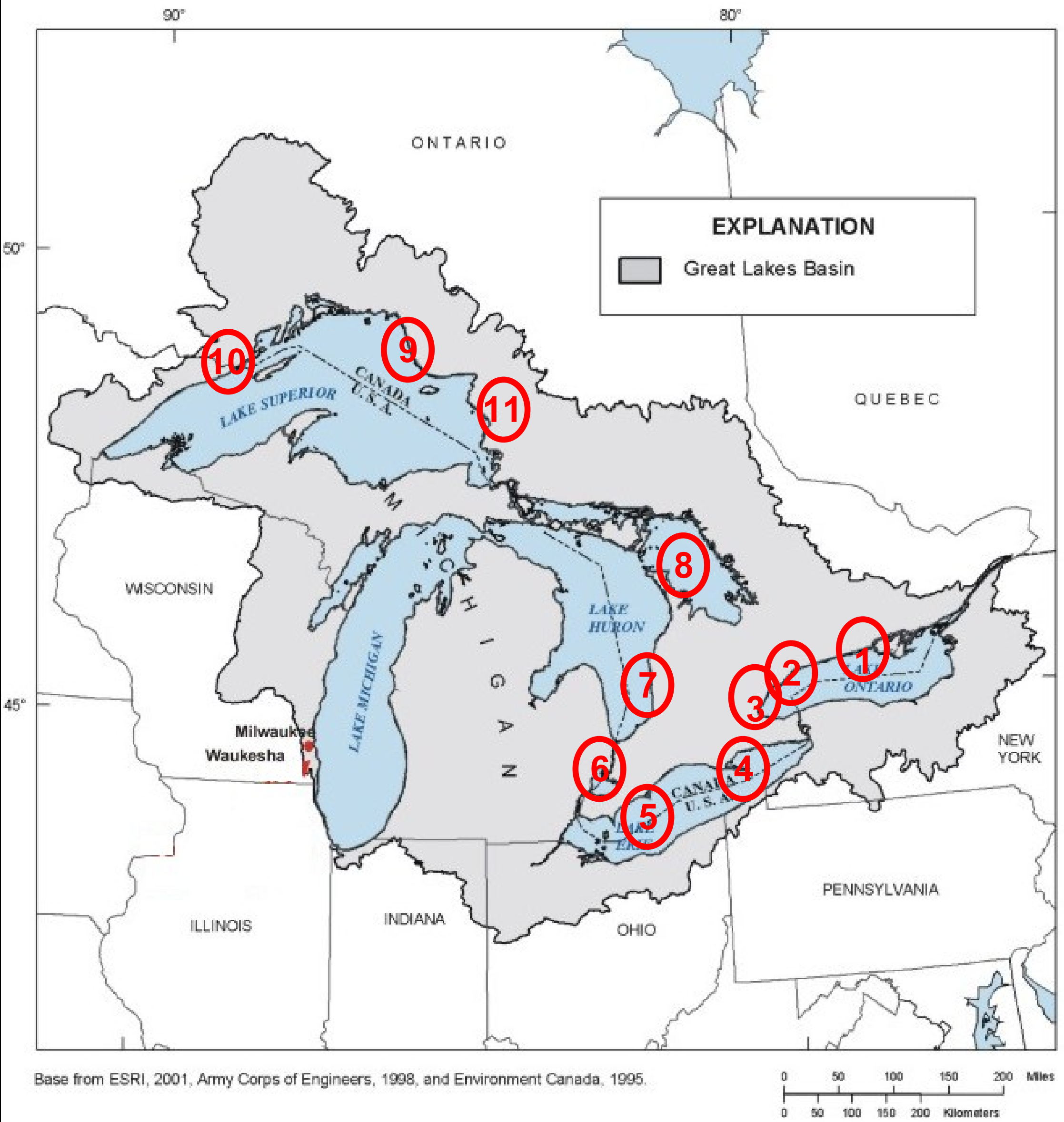
Note: The superscript numbers refer to presentations given at the five climate change workshops and are referenced in Table 1 (Column 1)

TABLE 10
SUMMARY OF AREA-AVERAGED, GCM TEMPERATURE CHANGE (T-°C) AND PRECIPITATION CHANGE (P-%) FOR THE FOUR LOSLR STUDY CLIMATE CHANGE SCENARIOS

GCM	Climate Element	Annual	Winter (December-January-February)	Spring (March-April-May)	Summer (June-July-August)	Fall (September-October-November)
HadCM3 A1F1	T	+3.99	+3.90	+3.57	+4.44	+4.07
Warm and wet	P	+10.33	+21.52	+19.18	+3.06	+4.67
GCCM2 A21	T	+3.24	+4.32	+3.26	+3.17	+2.21
Warm and dry	P	+1.4	+4.38	+4.39	-1.6	+1.28
HadCM3 B22	T	+2.84	+3.33	+2.35	+3.08	+2.60
Not as warm and wet	P	+12.51	+20.81	+19.93	+7.7	+8.00
CGCM2 B23	T	+2.24	+3.17	+2.57	+2.32	+1.6
Not as warm and dry	P	+2.84	+5.33	+6.6	+0.10	+1.35

(Source: Mortsch et al., 2005.)

Figures



1. Presqu'ile
2. Toronto
3. Hamilton
4. Long Point
5. Point Pelee
6. Lake St. Clair
7. Goderich
8. Sturgeon Bay
9. Pukaswa National Park
10. Thunder Bay
11. Sault Ste. Marie

Figure 1: Map of Great Lakes showing Case Study Areas.

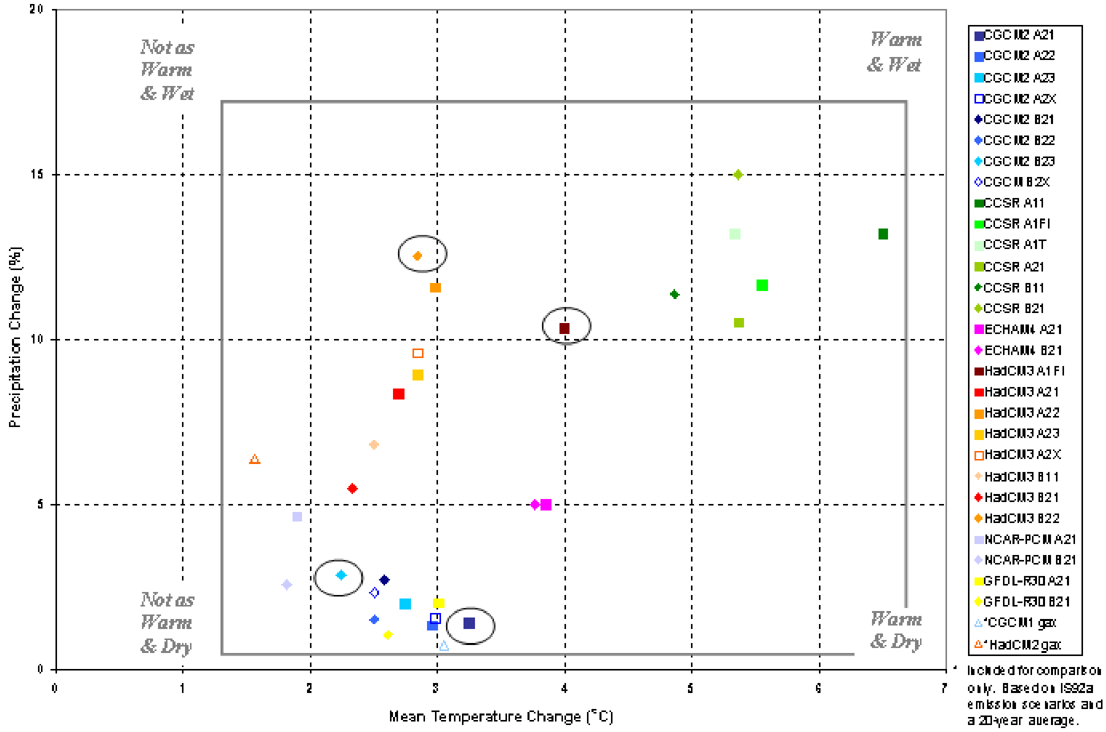


Figure 1a. Candidate SRES-based GCM climate change scenarios – based on annual area-averages for 2050 (Mortsch et al., 2005).

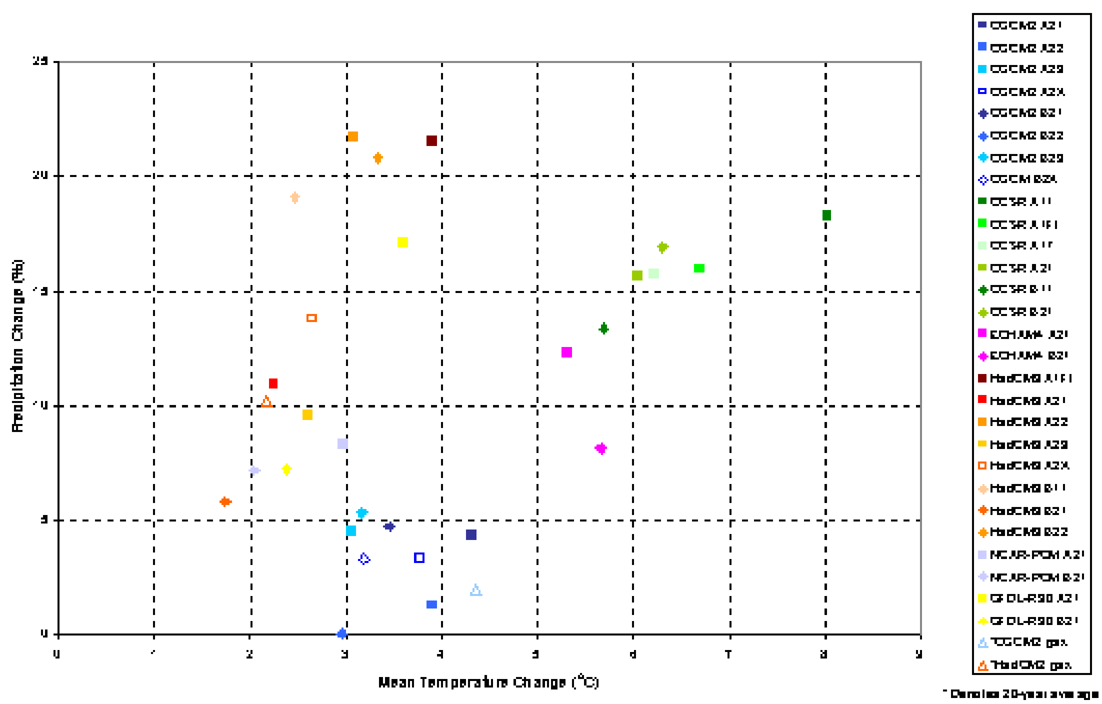


Figure 1b. Mean winter (December, January and February) GCM temperature and precipitation change fields for the Great Lakes-St. Lawrence Basin for 2050 (Mortsch et al., 2005).

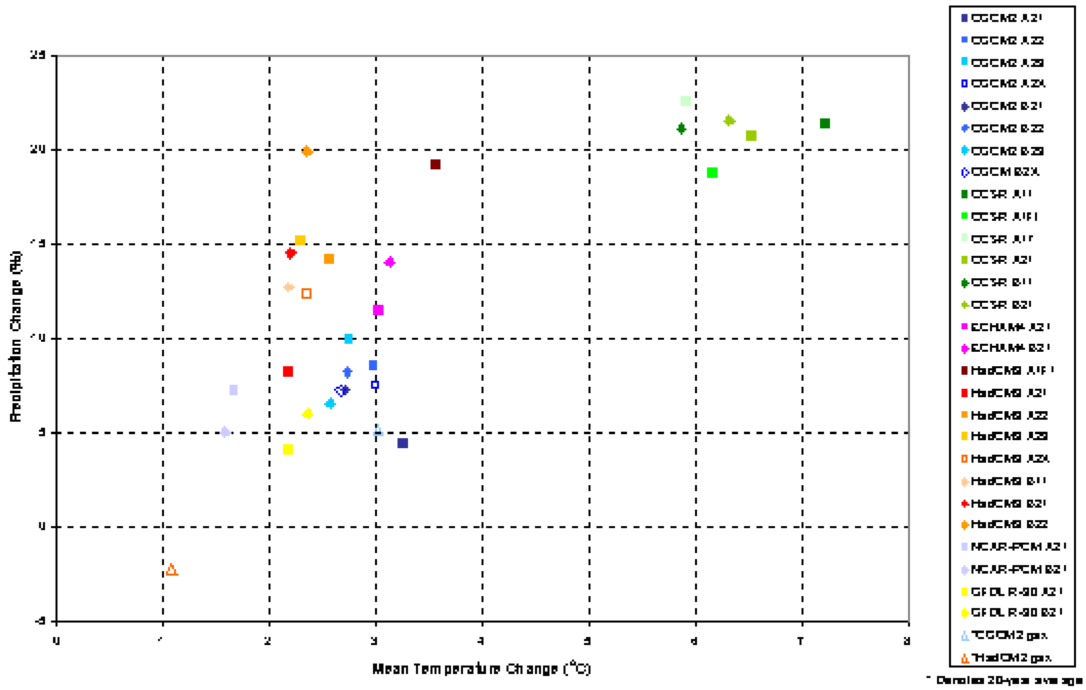


Figure 1c. Mean spring (March, April and May) GCM temperature and precipitation change fields for the Great Lakes-St. Lawrence Basin for 2050 (Mortsch et al., 2005).

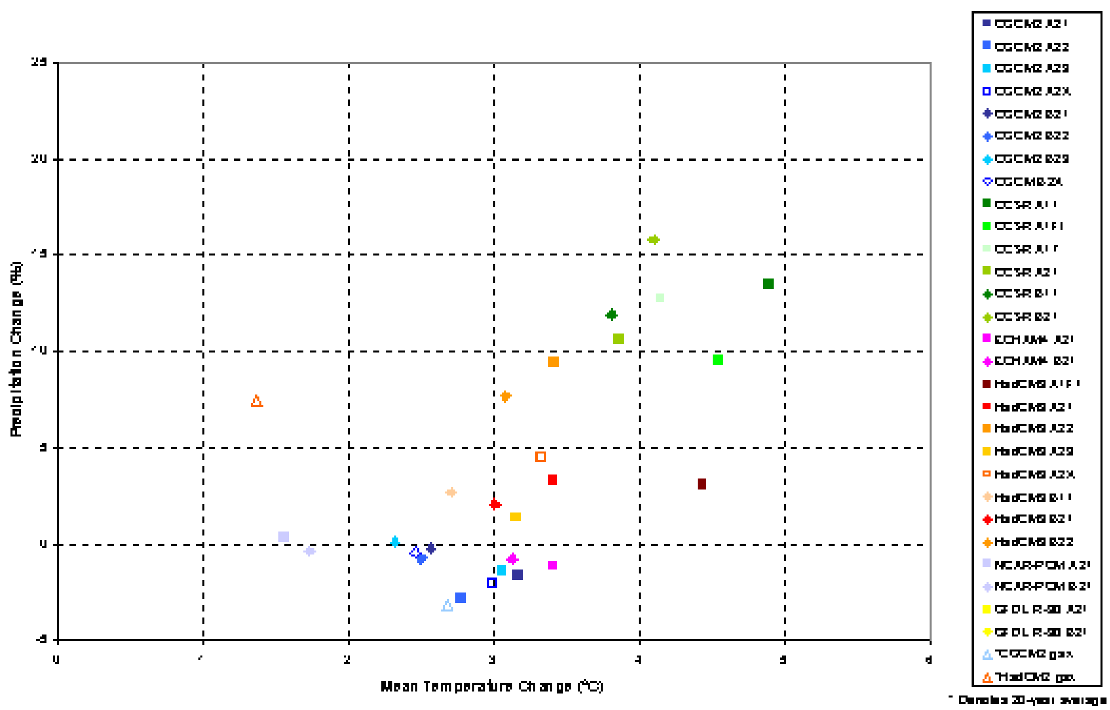


Figure 1d. Mean summer (June, July and August) GCM temperature and precipitation change fields for the Great Lakes-St. Lawrence Basin for 2050 (Mortsch et al., 2005).

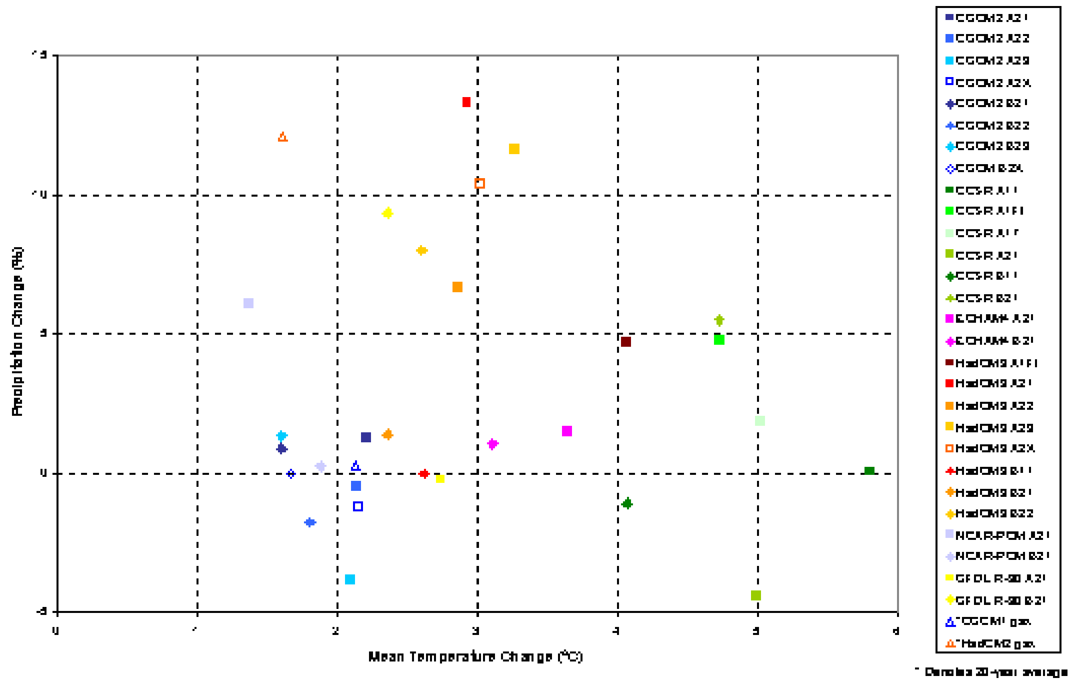


Figure 1e. Mean fall (September, October and November) GCM temperature and precipitation change fields for the Great Lakes-St. Lawrence Basin for 2050 (Mortsch et al., 2005).

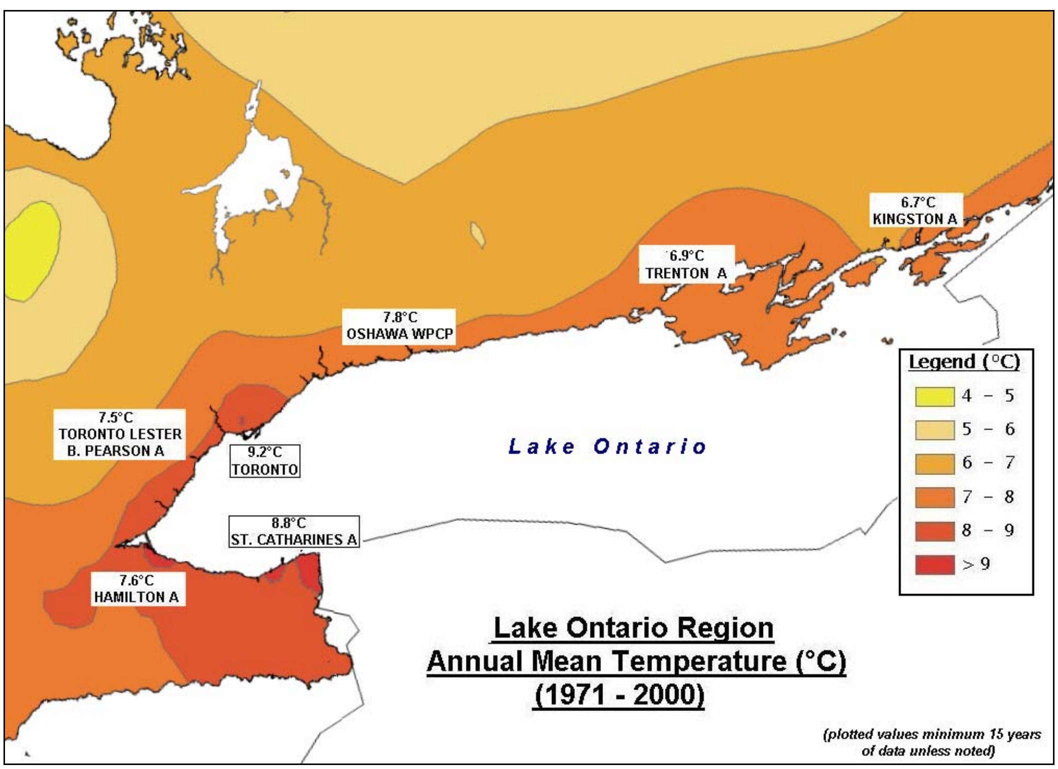


Figure 2: Lake Ontario Annual Mean Temperature (Environment Canada, 2005).

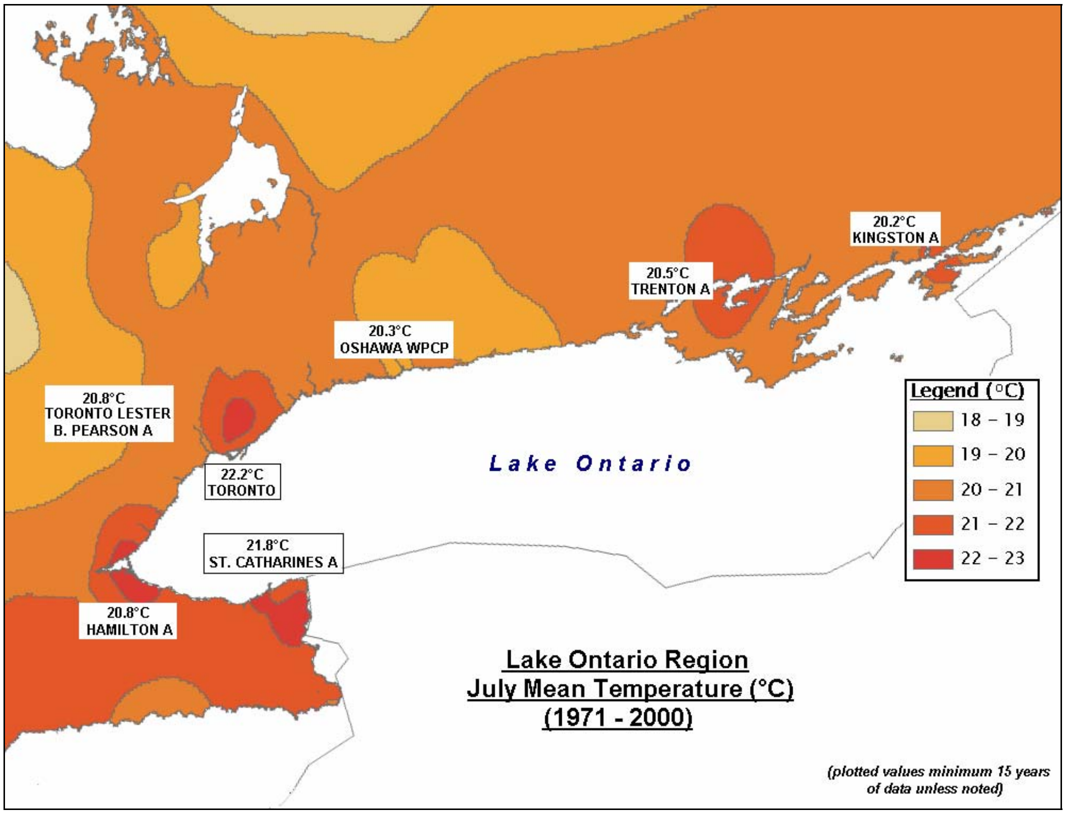


Figure 3: Lake Ontario July Mean Temperature (Environment Canada, 2005).

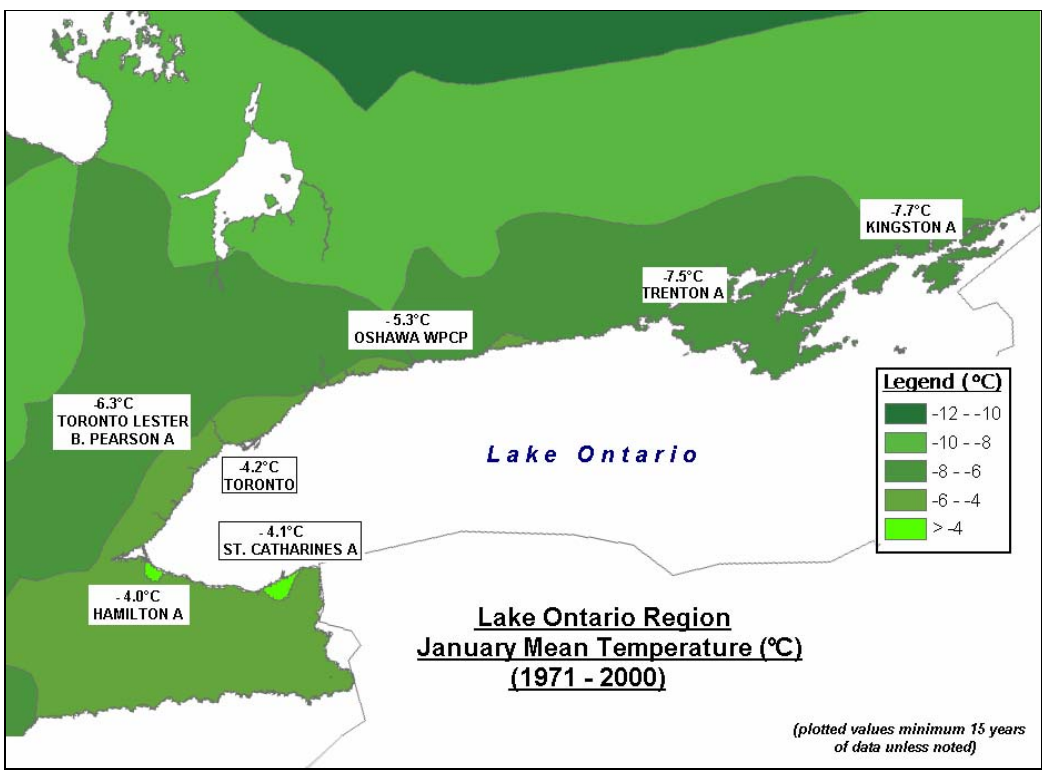


Figure 4: Lake Ontario January Mean Temperature (Environment Canada, 2005).

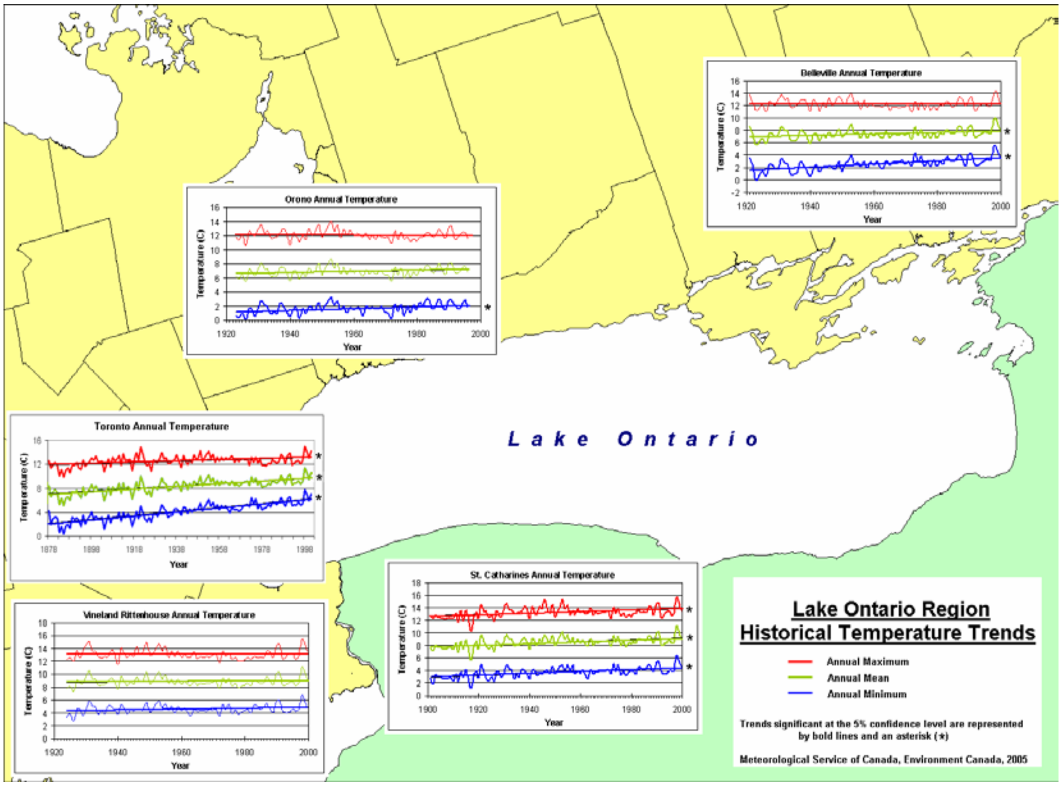


Figure 5: Lake Ontario Historical Temperature Trends (Environment Canada 2005a).

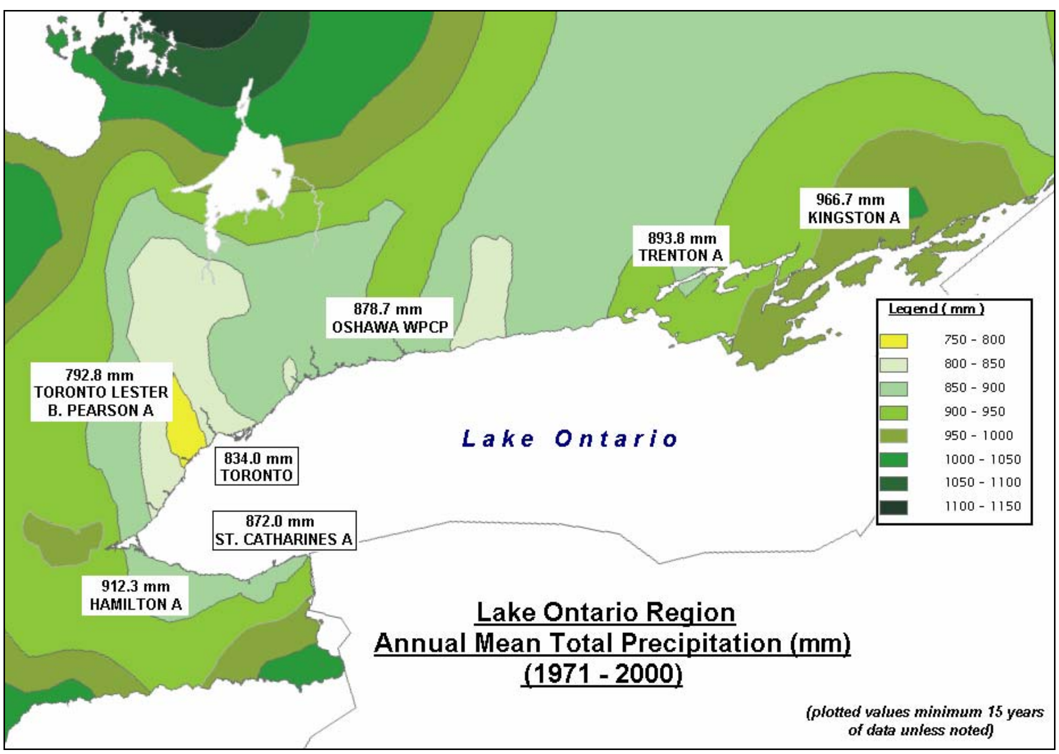


Figure 6: Lake Ontario Annual Precipitation (Environment Canada, 2005).

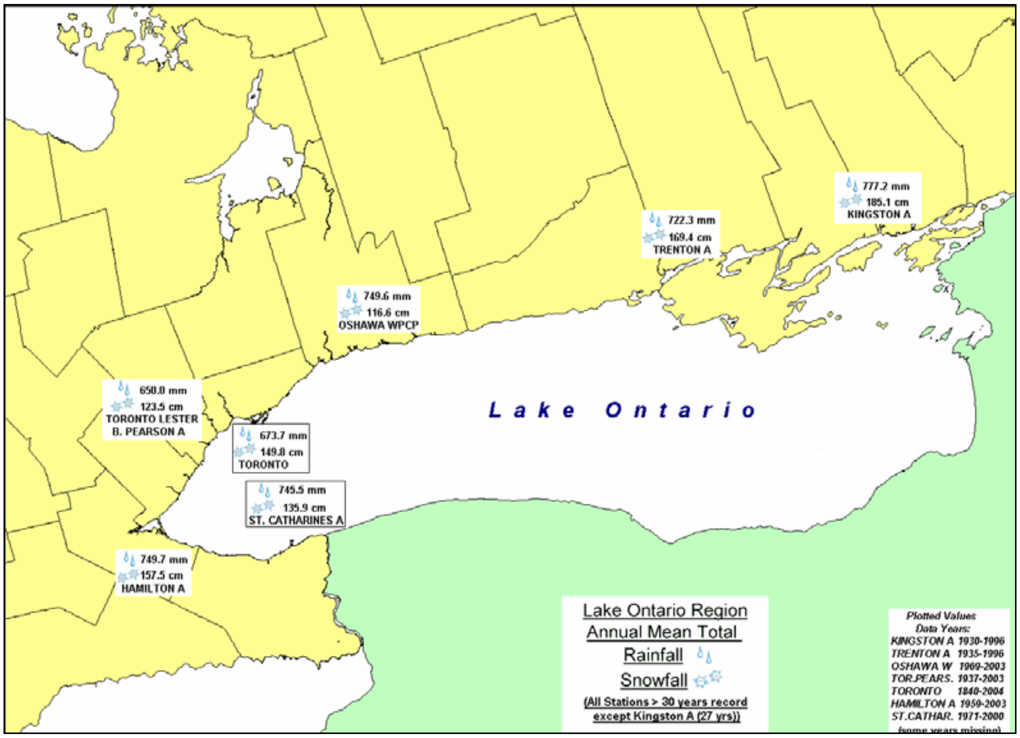


Figure 7: Lake Ontario Annual Rainfall and Snowfall (Environment Canada, 2005).

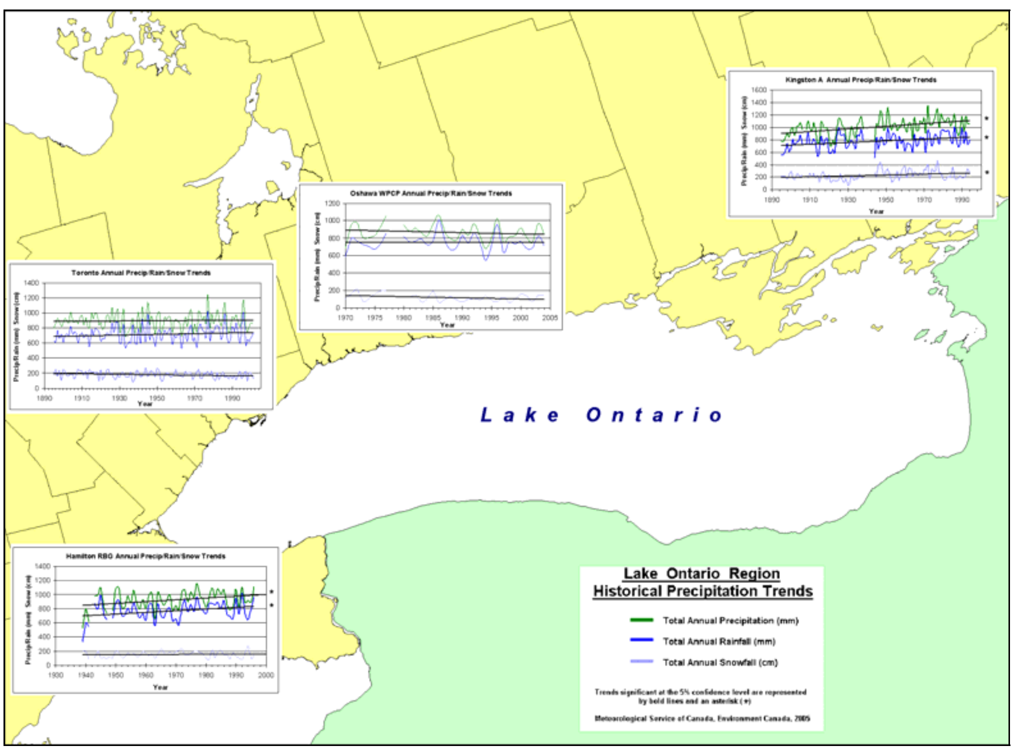


Figure 8: Lake Ontario Historical Precipitation Trends (Environment Canada, 2005).

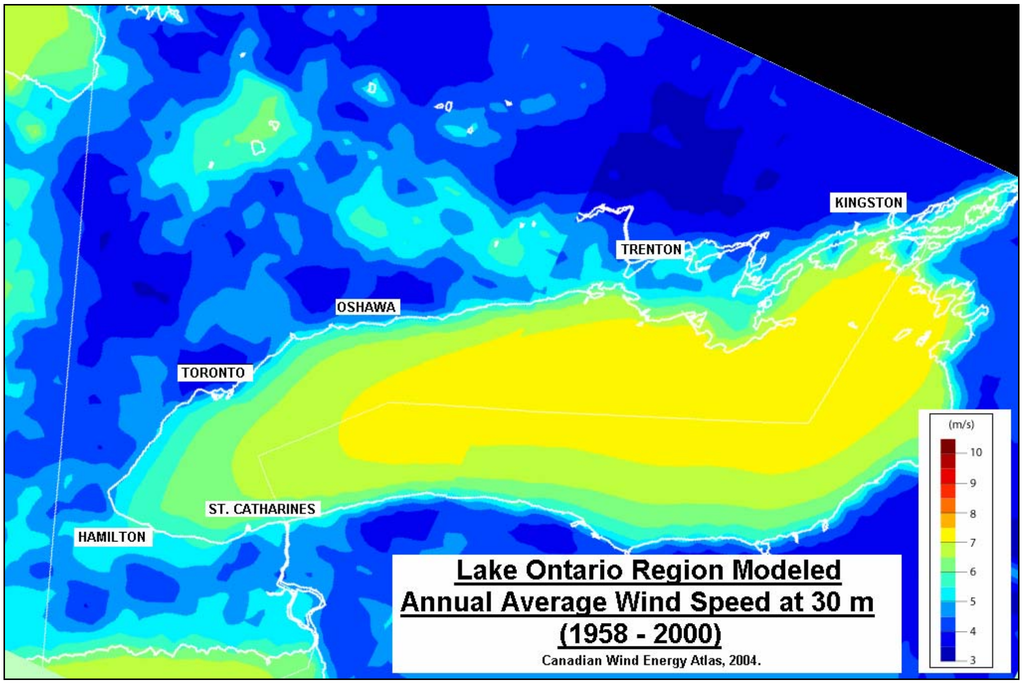


Figure 9: Lake Ontario Modeled Annual Wind Speed (Canadian Wind Energy Atlas, 2004).

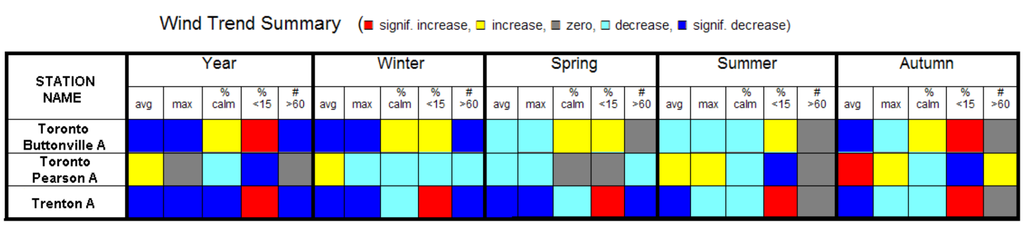


Figure 10: Lake Ontario Wind Trend Summary 1974-2004 (Environment Canada, 2005).

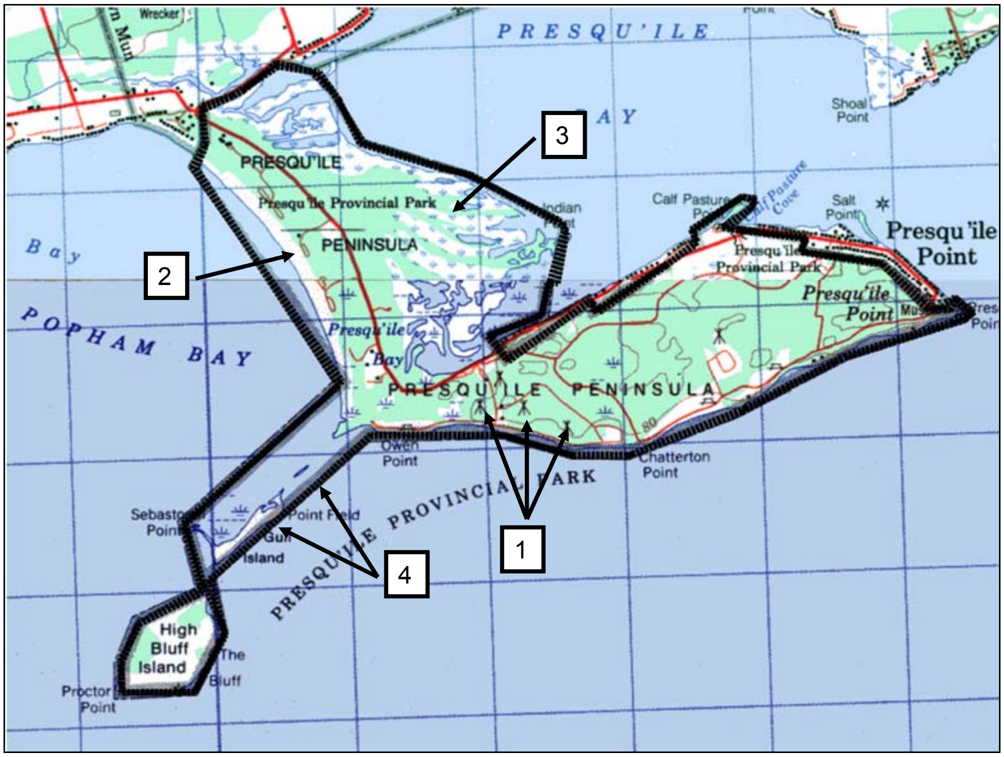


Figure 11: Presqu'ile Provincial Park Study Area. Areas are denoted as follows; 1 = Camping areas, 2 = Beach areas, 3 = Marsh areas, 4 = Land connection to Gull Island.


Figure 12: Presqu'ile Provincial Park, islands connected to mainland (Taylor 2005).

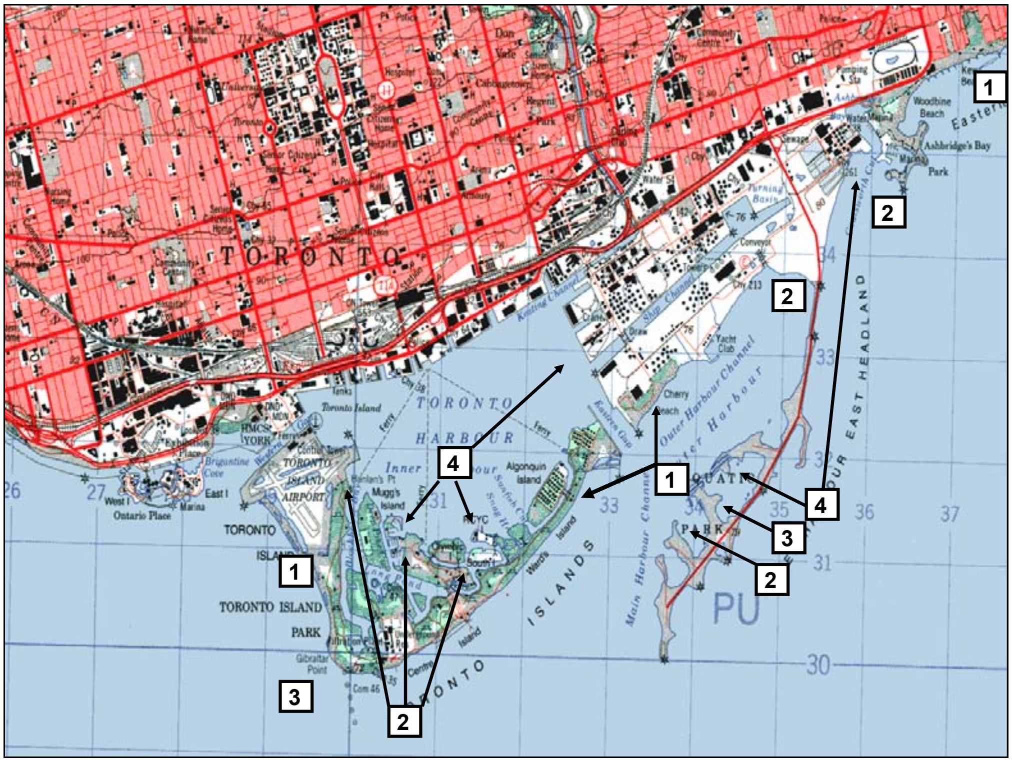


Figure 13: Toronto Study Area. Areas are denoted as follows; (1) Beaches; (2) Marinas; (3) Wetlands; (4) Sedimentation.


Figure 14: After a Severe Storm Event (August 2005): Eroded Culverts and Road, Finch Avenue: Toronto (D. Haley)

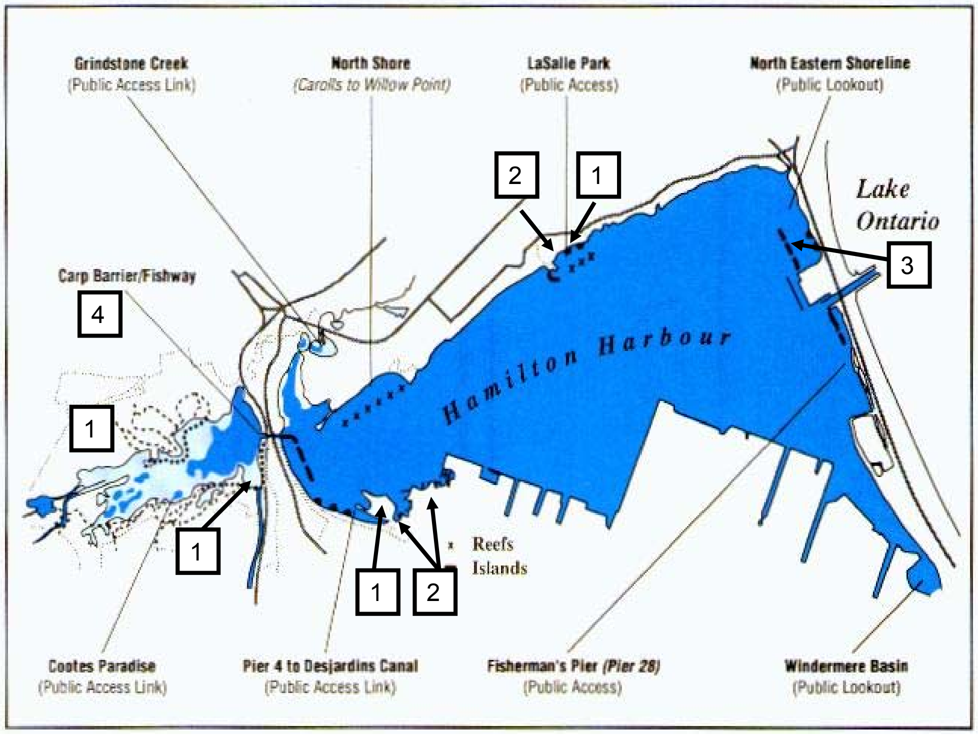


Figure 15: Hamilton Harbour Study Area. Areas are denoted as follows: (1) Public parks; (2) Marina's; (3) Colonial waterbird habitat (4) Carp barrier (J. Hall).

Figure 16a: Northeastern Shoreline Wildlife Islands. Hamilton Harbour (J. Hall).

Figure 16b: Hamilton Harbour, Double-crested Cormorants and Ring-billed Gulls nesting on Artificial Islands (M. Taylor).

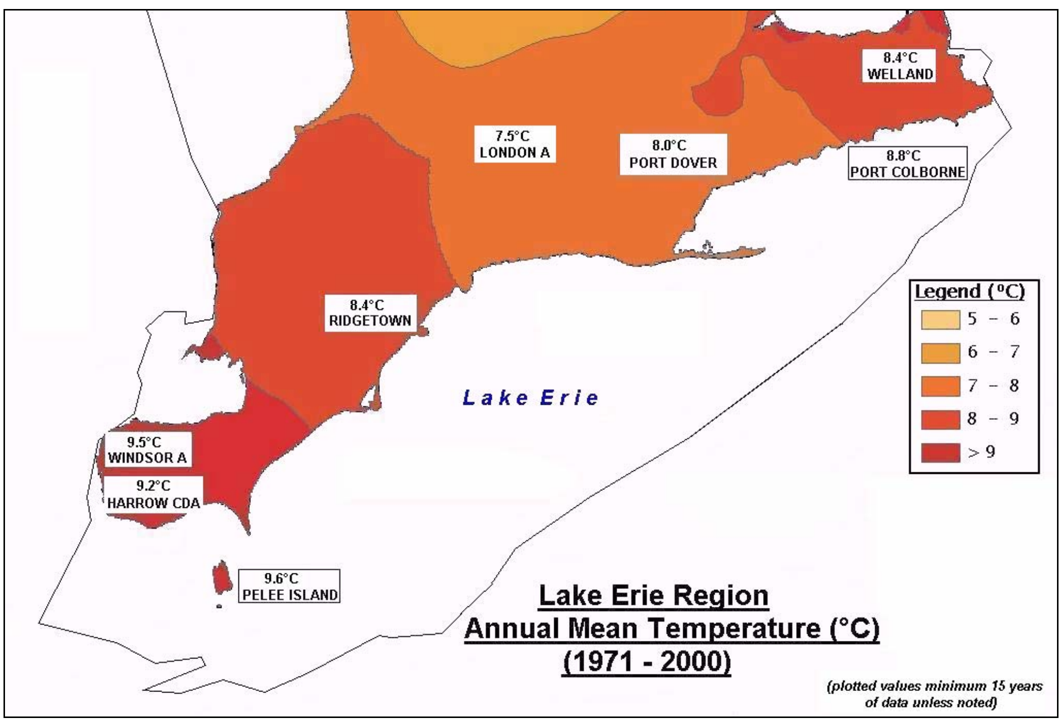


Figure 17: Lake Erie Annual Mean Temperature (Environment Canada, 2005).

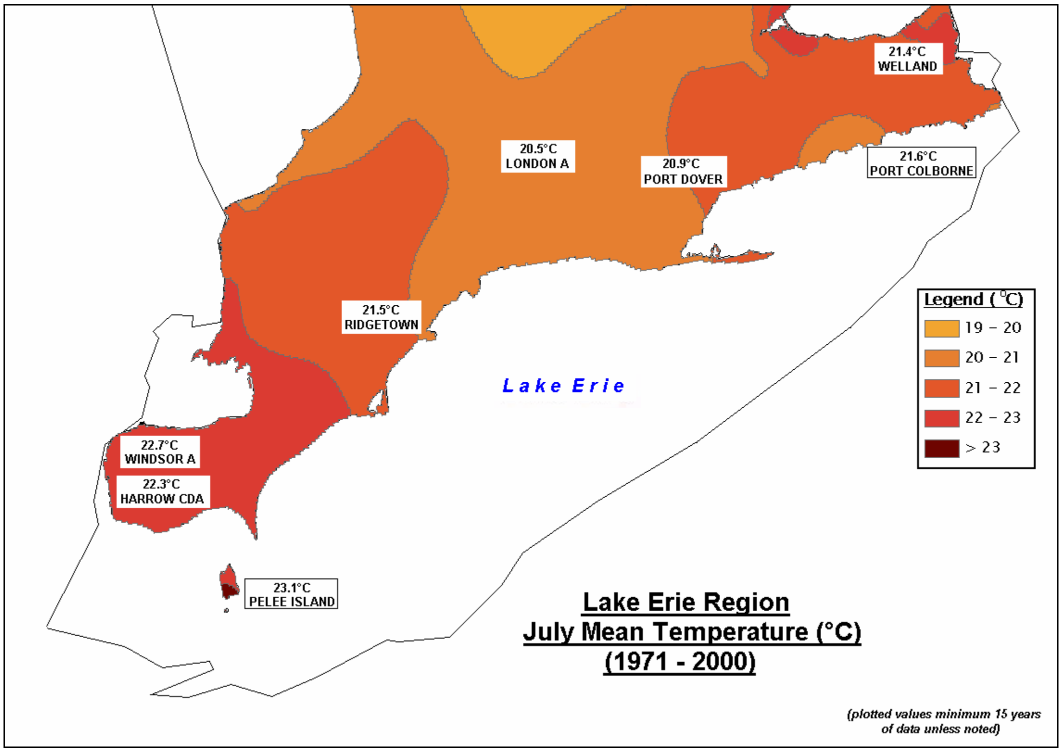


Figure 18: Lake Erie July Mean Temperature (Environment Canada, 2005).

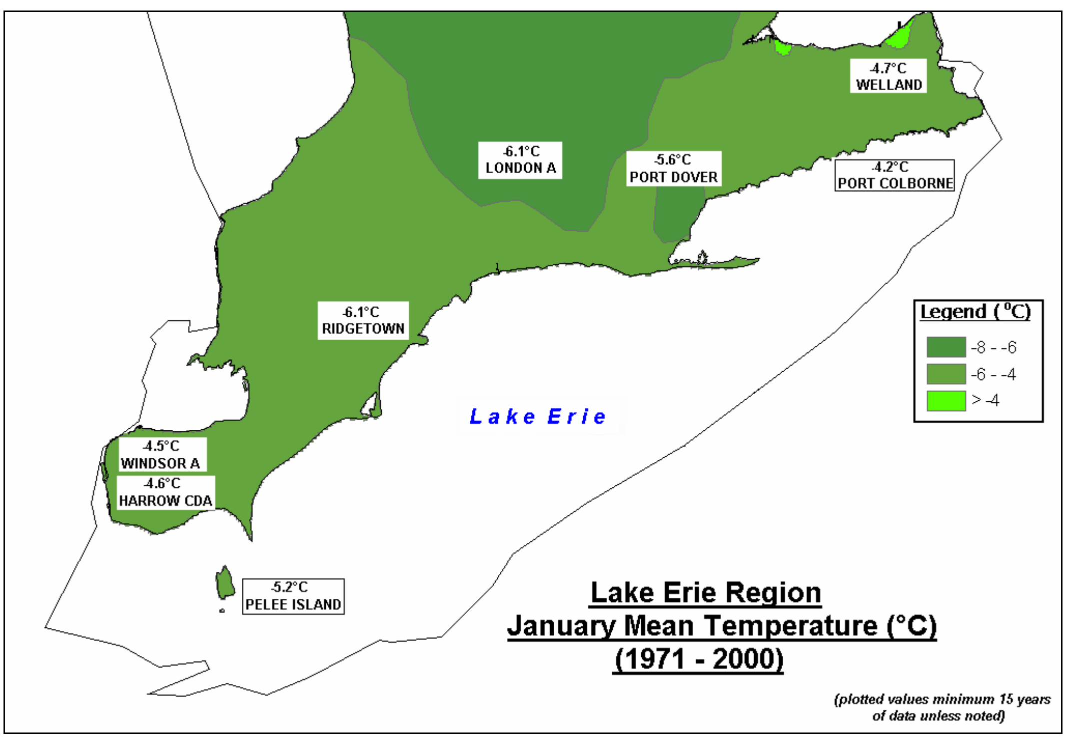


Figure 19: Lake Erie January Mean Temperature (Environment Canada, 2005).

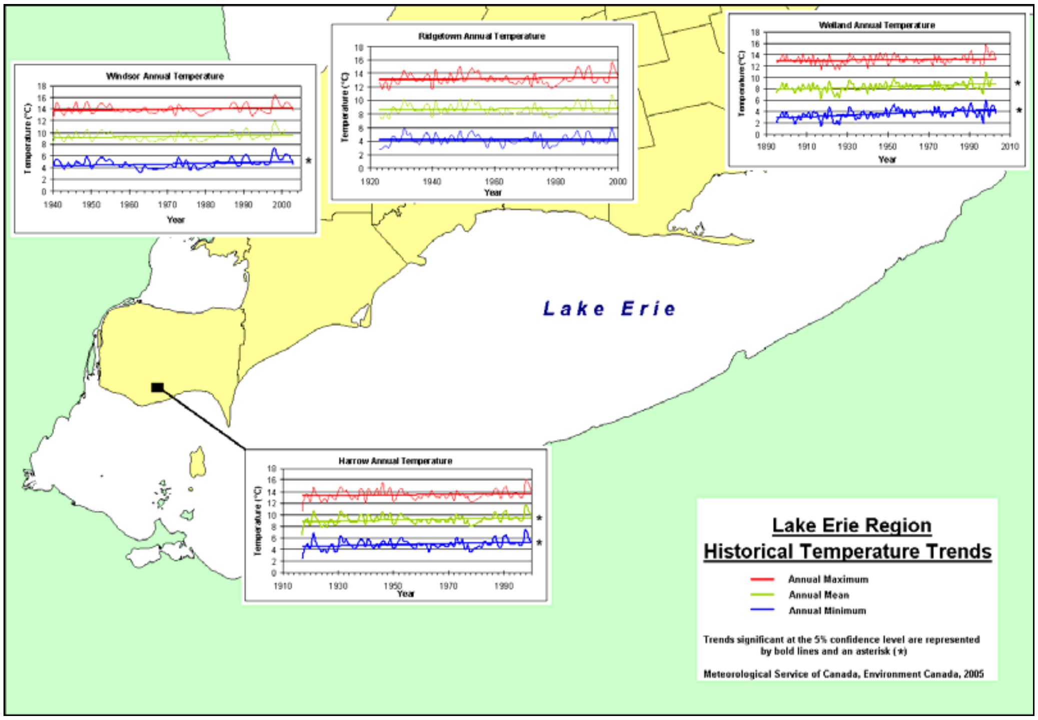


Figure 20: Lake Erie Historical Temperature Trends (Environment Canada, 2005a).

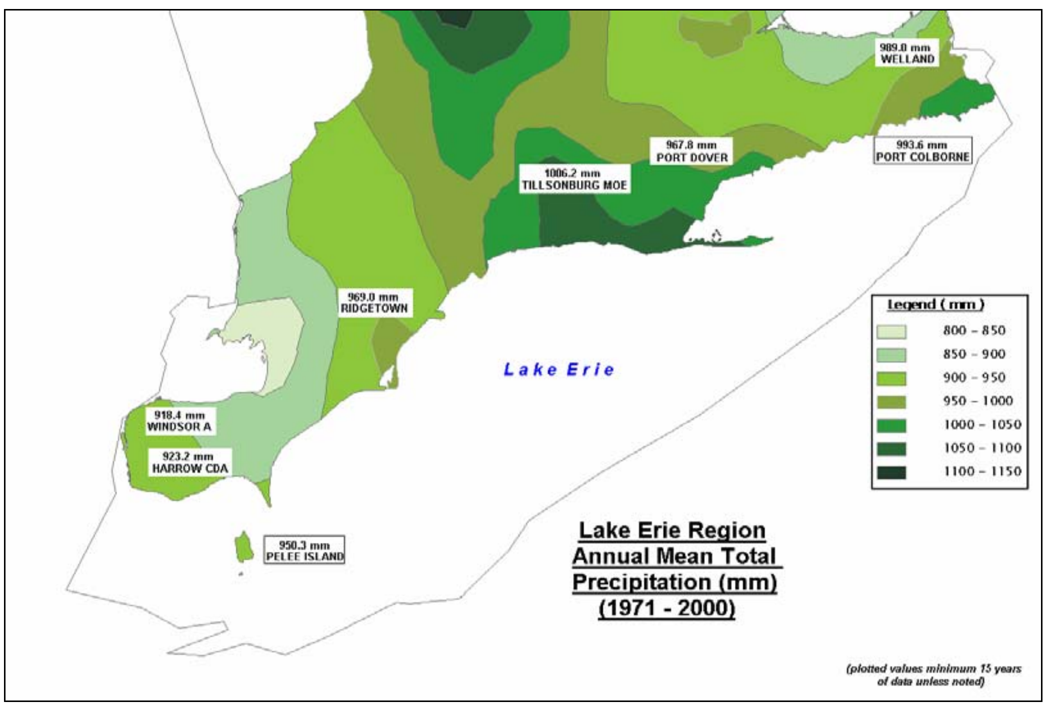


Figure 21: Lake Erie Annual Precipitation (Environment Canada, 2005).

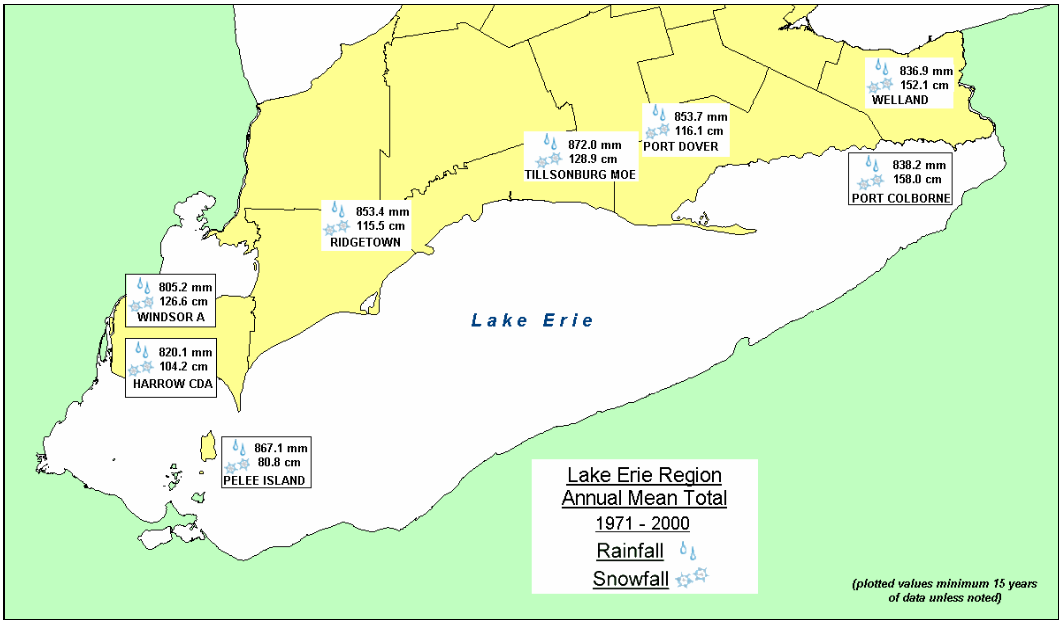


Figure 22: Lake Erie Annual Rainfall and Snowfall (Environment Canada, 2005).

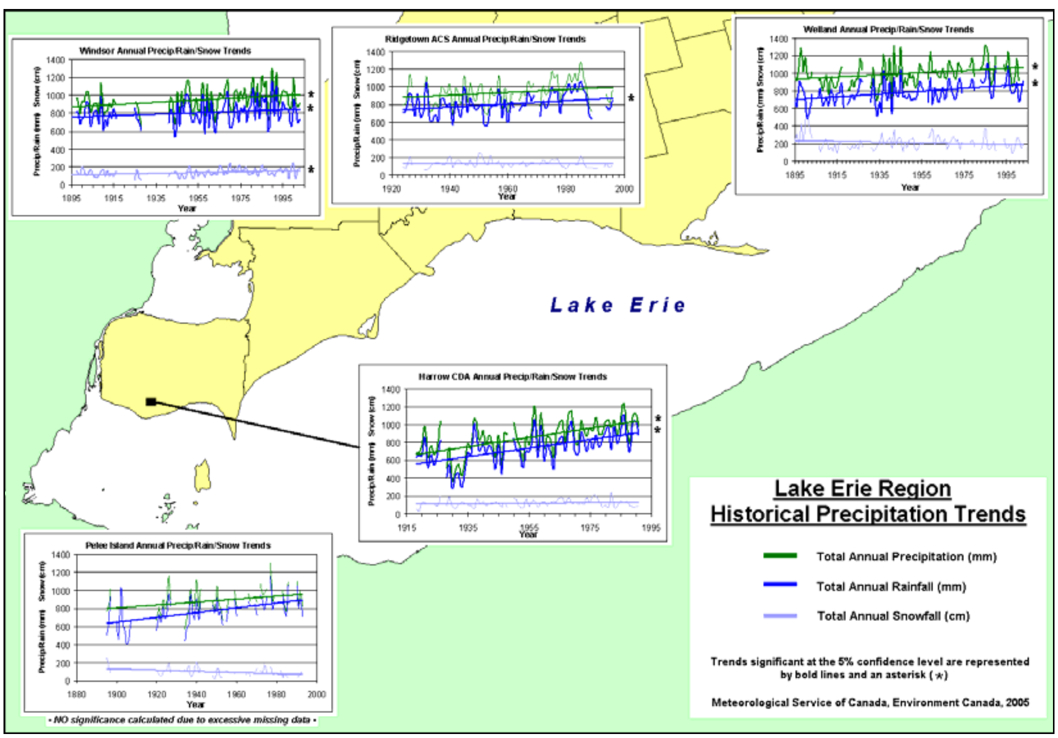


Figure 23: Lake Erie Historical Precipitation Trends (Environment Canada, 2005).

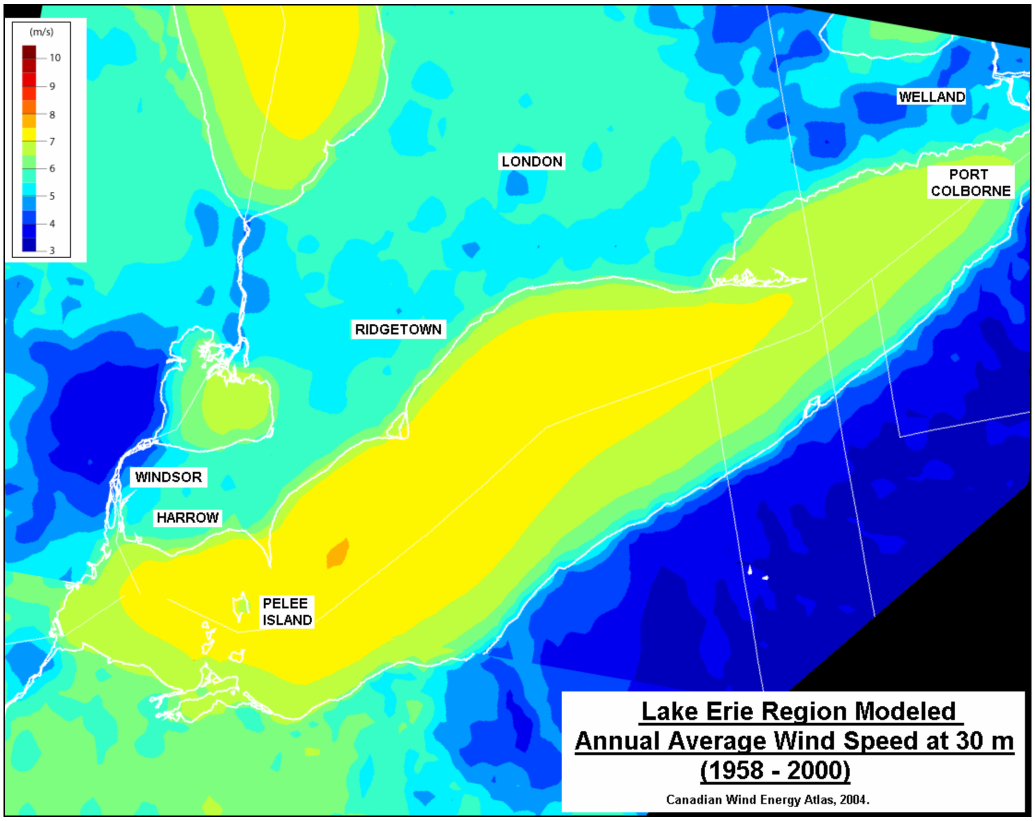


Figure 24: Lake Erie Modeled Annual Wind Speed (Canadian Wind Energy Atlas, 2004).

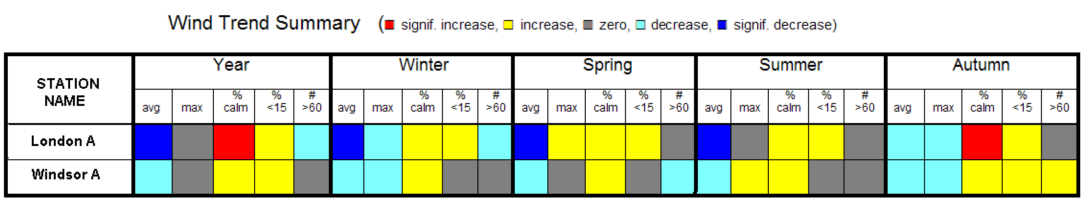


Figure 25: Wind Trend Summary 1974-2004.2006 (Environment Canada, 2005).

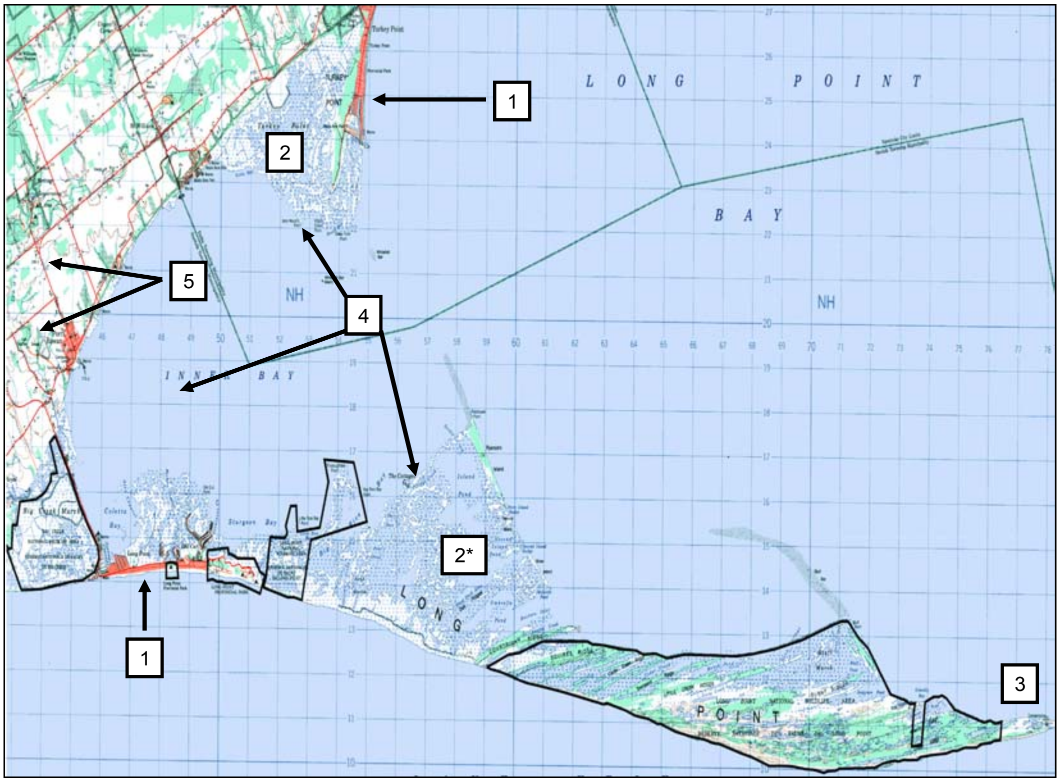


Figure 26: Long Point Study Area. Areas are denoted as follows; (1) Beaches; (2) Wetland; (3) Spit; (4) Fish nursery; (5) Community Water Treatment; * *Phragmites* present.


Figure 27a: Tundra Swans using fields in spring (S. Petrie).

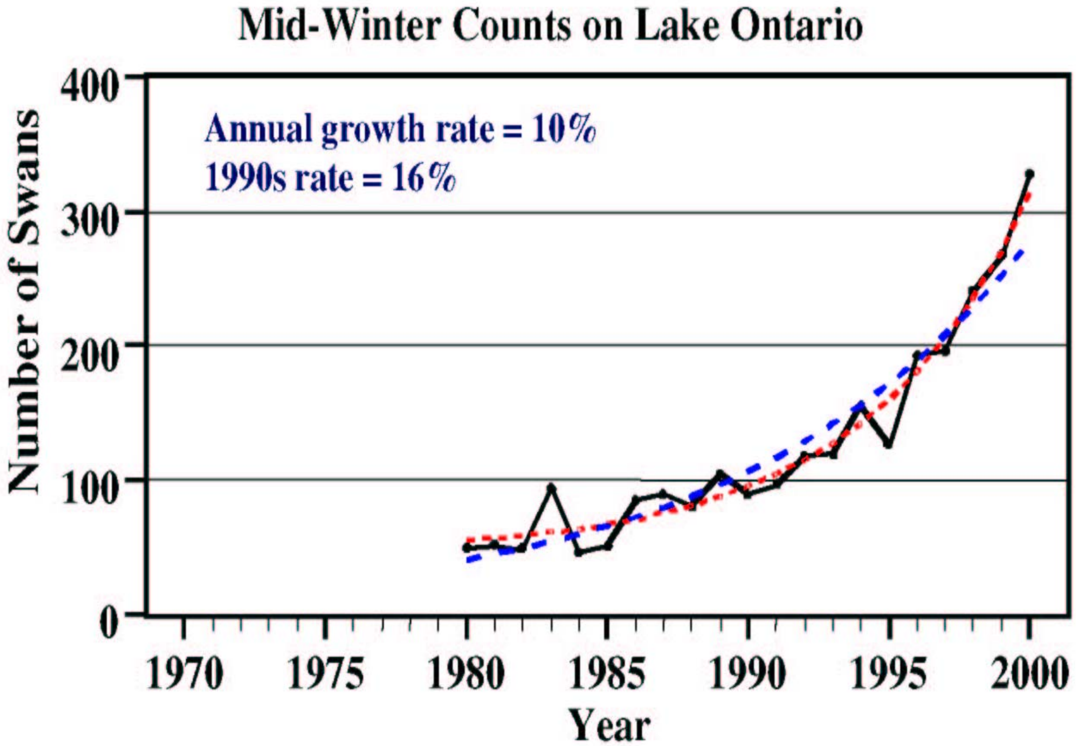


Figure 27b: The increase in the number of Mute Swans on Lake Ontario as depicted by mid-winter counts (S. Petrie).

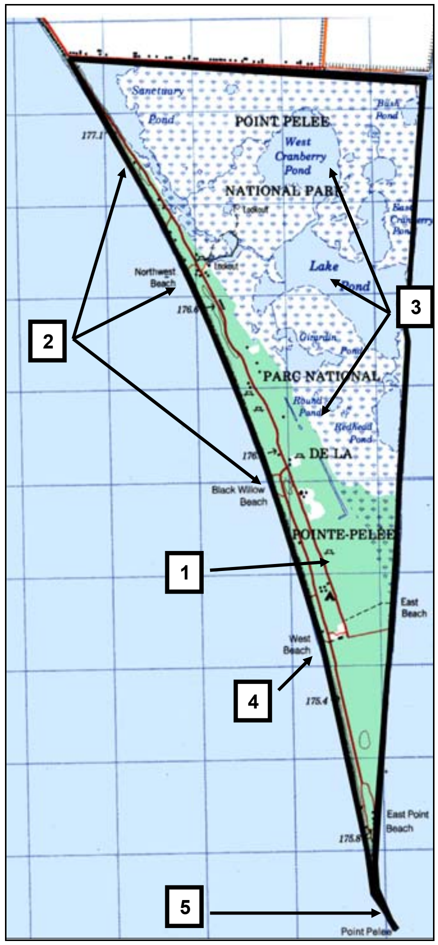


Figure 28: Point Pelee National Park. Areas denoted by; (1) Carolinian forest; (2) Beaches; (3) Wetlands; (4) Park facilities, roads and parking; (5) Spit dynamics.

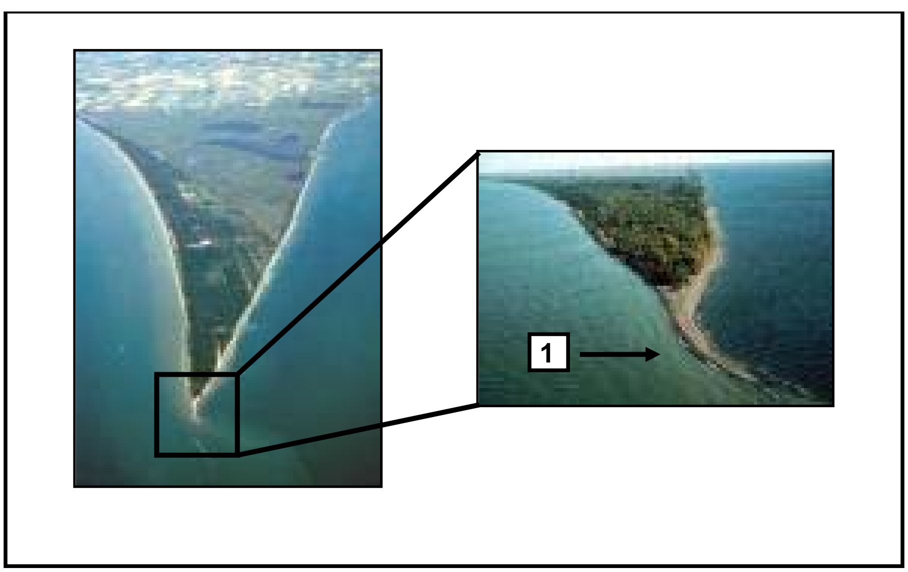


Figure 29: View of eroded Spit at Point Pelee National Park; (1) denotes eroded spit (Environment Canada).

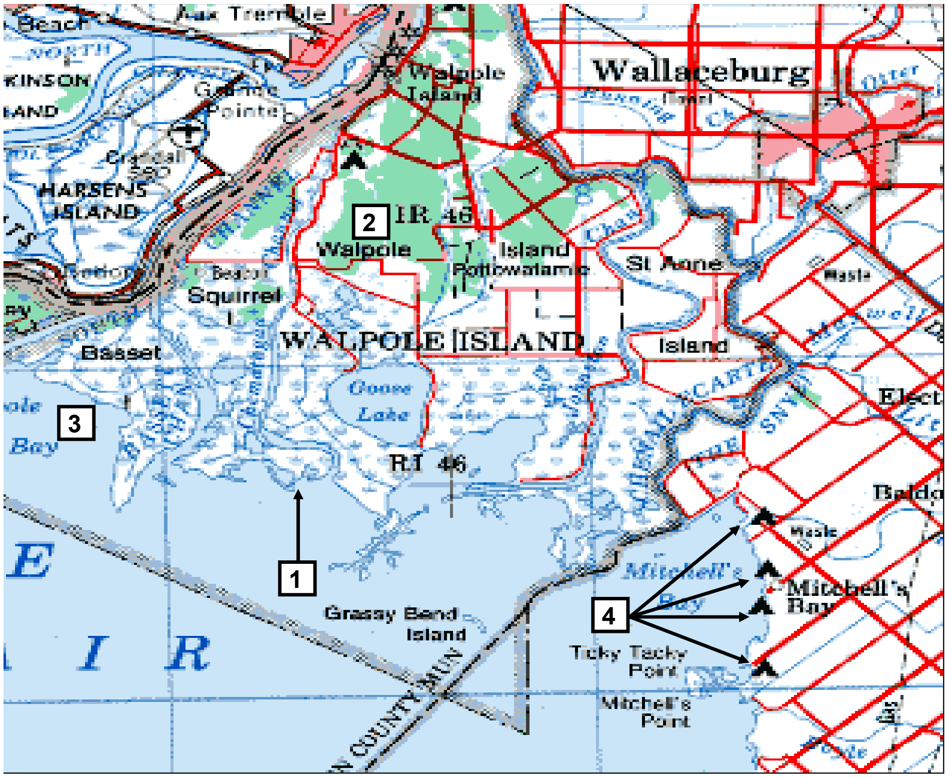


Figure 30: Walpole Island Lake St. Clair. Areas are denoted as follows; (1) Wetlands; (2) Agriculture; (3) Bathymetry; (4) Camping.

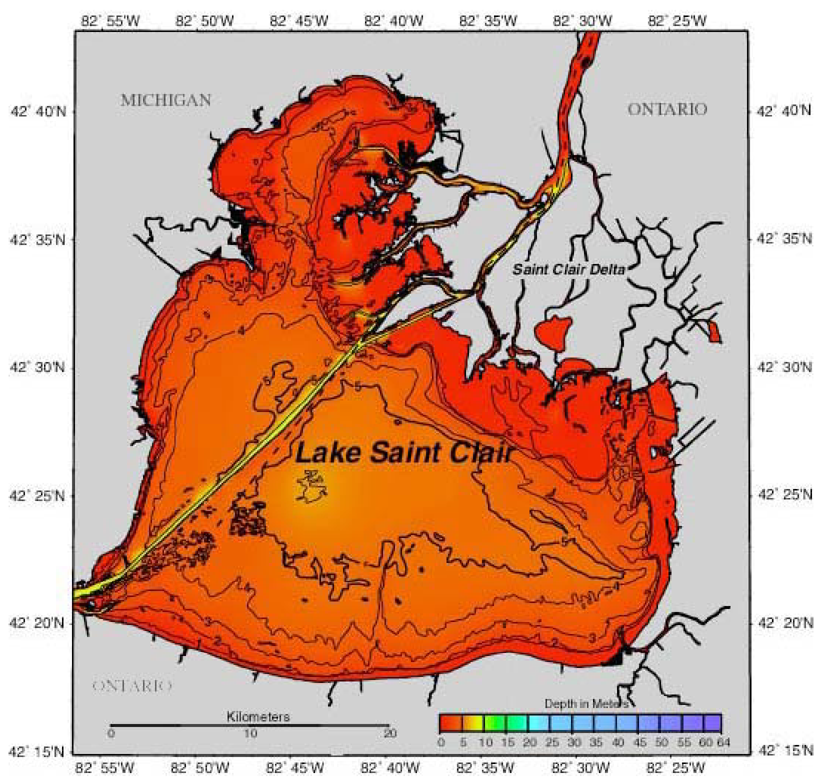


Figure 31: Bathymetry of Lake St. Clair (NOAA).

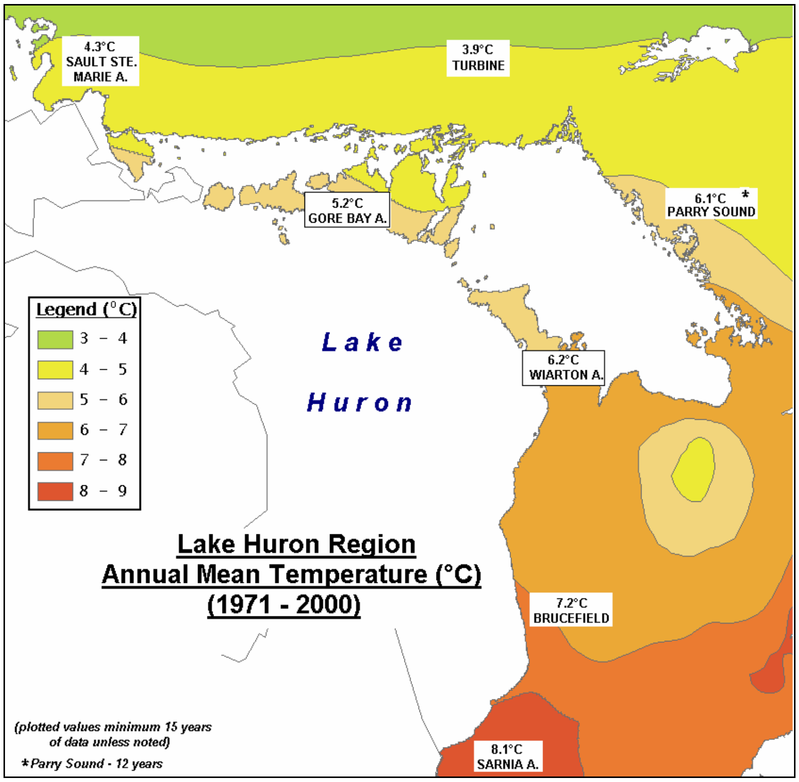


Figure 32. Lake Huron Annual Mean Temperature (Environment Canada, 2005).

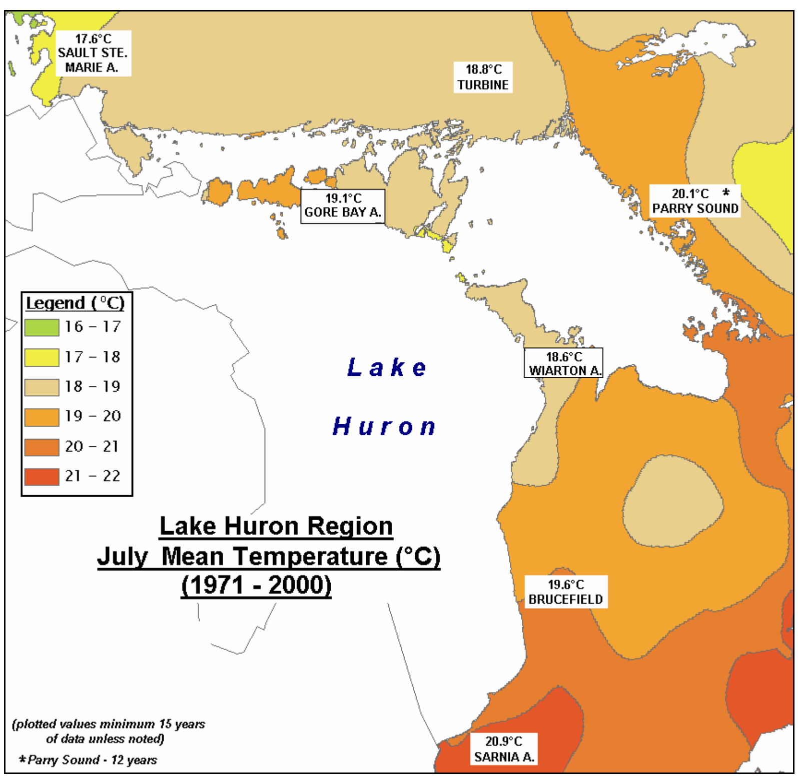


Figure 33: Lake Huron July Mean Temperature (Environment Canada, 2005).

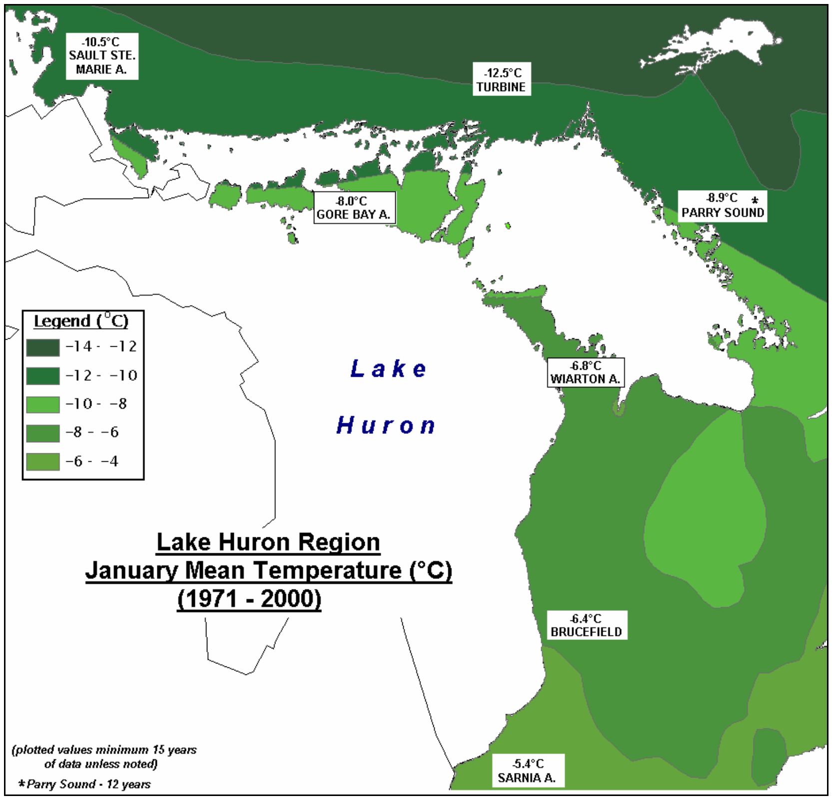


Figure 34: Lake Huron January Mean Temperature (Environment Canada, 2005).

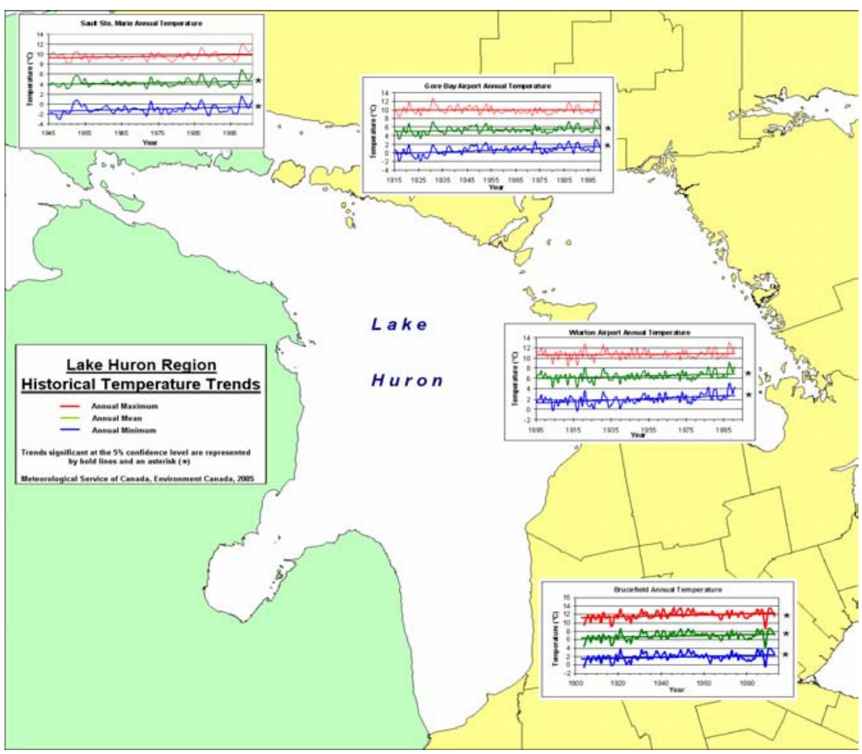


Figure 35: Lake Huron Annual Temperature Trends (Environment Canada, 2005a).

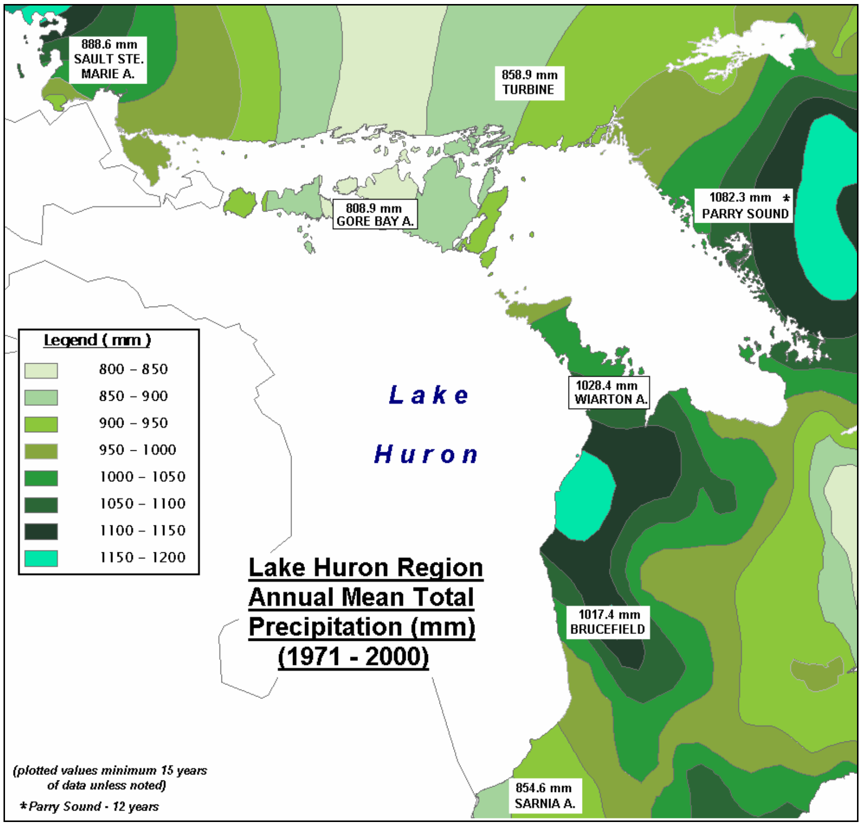


Figure 36: Lake Huron Annual Precipitation (Environment Canada, 2005).

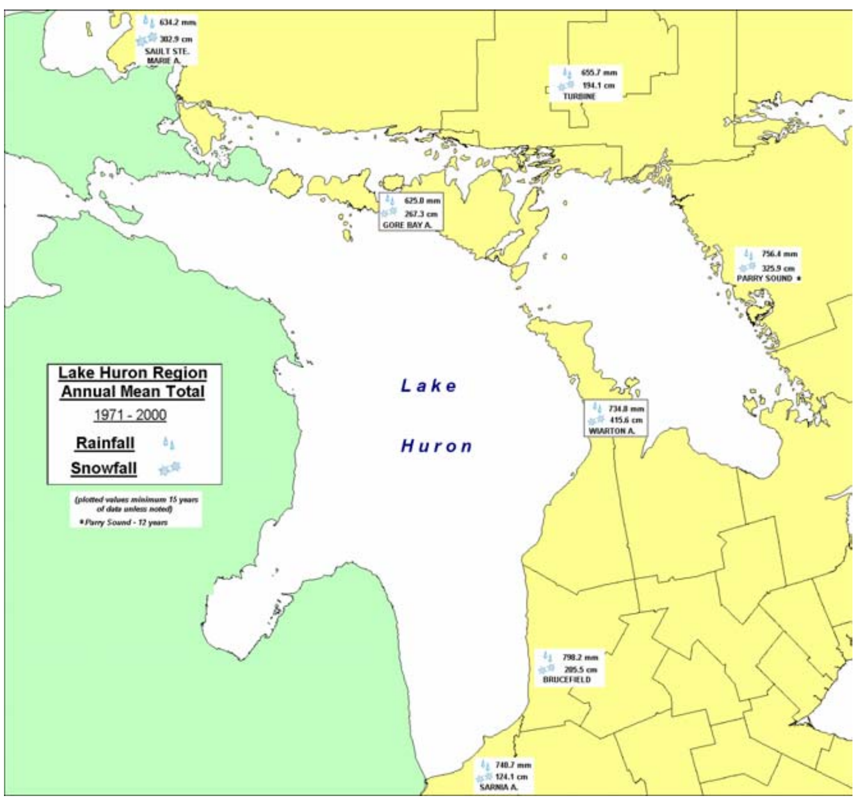


Figure 37: Lake Huron Annual Rainfall and Snowfall (Environment Canada, 2005).

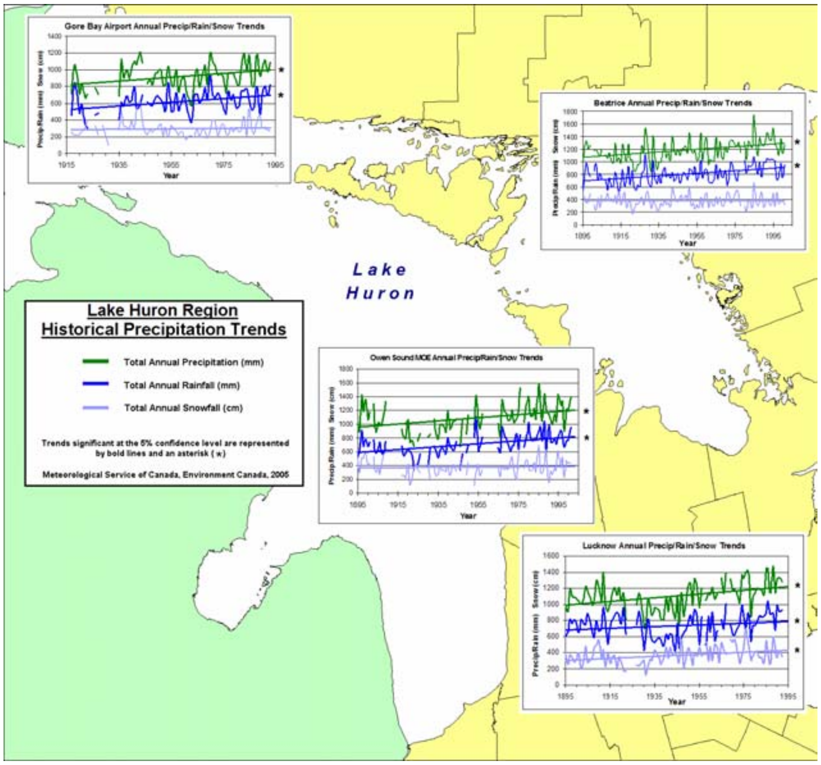


Figure 38: Lake Huron Historical Precipitation Trends (Environment Canada, 2005a).

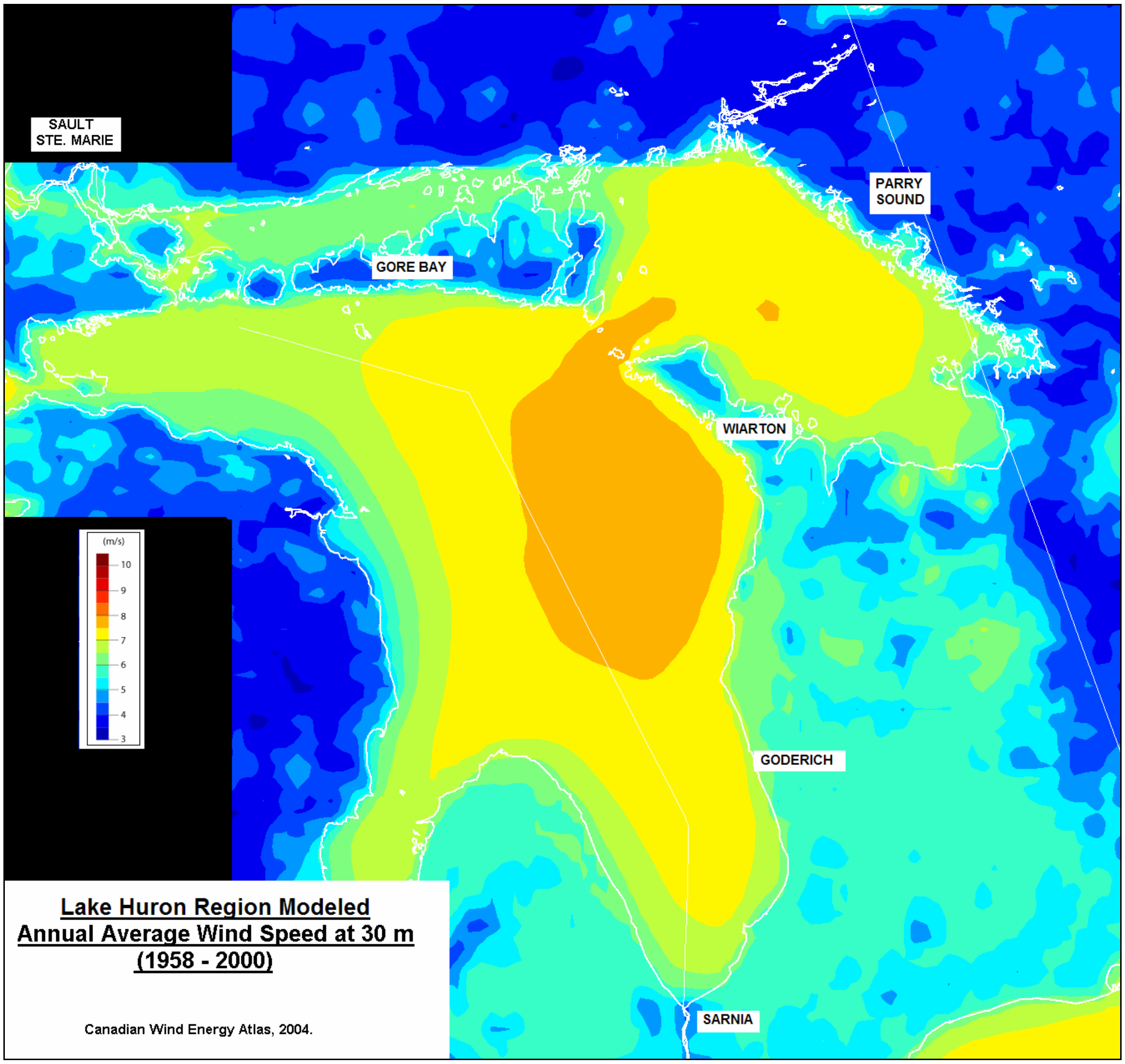


Figure 39: Lake Huron Modeled Annual Wind Speed (Canadian Wind Energy Atlas, 2004).

Wind Trend Summary (■ signif. increase, ■ increase, ■ zero, ■ decrease, ■ signif. decrease)

STATION NAME	Year					Winter					Spring					Summer					Autumn				
	avg	max	% calm	% <15	# >60	avg	max	% calm	% <15	# >60	avg	max	% calm	% <15	# >60	avg	max	% calm	% <15	# >60	avg	max	% calm	% <15	# >60
Gore Bay A	decrease	decrease	signif. decrease	increase	decrease	signif. decrease	decrease	decrease	increase	signif. decrease	decrease	decrease	signif. decrease	increase	zero	decrease	decrease	signif. decrease	increase	zero	decrease	decrease	signif. decrease	increase	zero
Wiarton A	signif. decrease	signif. decrease	zero	signif. increase	signif. decrease	decrease	signif. decrease	decrease	zero	signif. decrease	signif. decrease	decrease	zero	increase	decrease	signif. decrease	signif. decrease	increase	signif. increase	zero	decrease	signif. decrease	zero	zero	decrease

Figure 40: Lake Huron Wind Trend Summary 1974-2004 (Environment Canada, 2005).

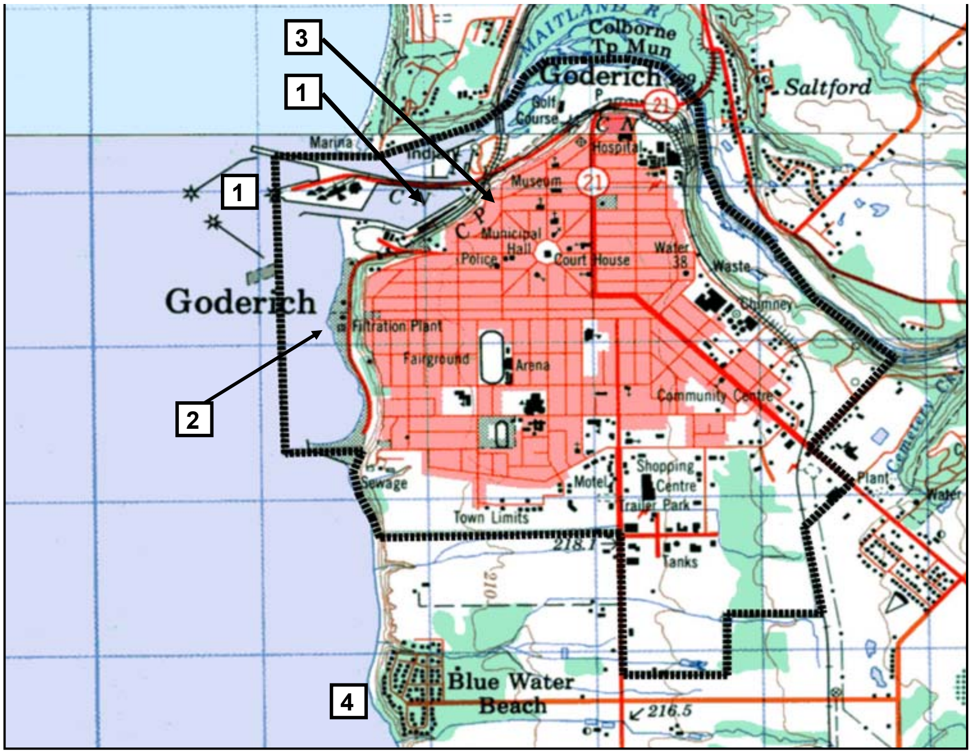


Figure 41: Goderich Harbour Study Area. Areas are denoted as follows; (1) Water depth; (2) Groynes; (3) Road salt use; (4) Erosion of Bluffs.

Figure 42: Goderich Harbour – Groynes Protecting Beach (M.Taylor).

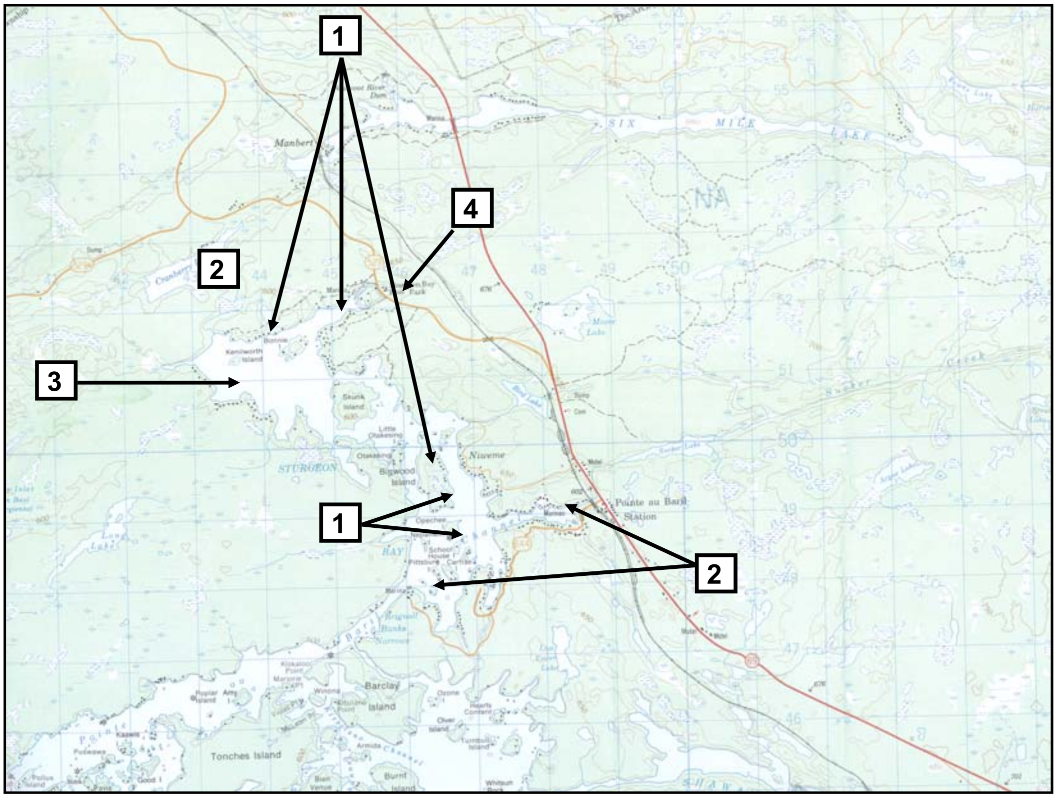


Figure 43a: Georgian Bay - Sturgeon Bay Study Area. Areas are denoted as follows; (1) Cottage development; (2) Marinas; (3) Shallow hypolimnion; (4) Provincial Park.

Figure 44a: Georgian Bay Wetland (M. Taylor).

Figure 44b: Blue-green algae and low water levels (K. Schiefer).

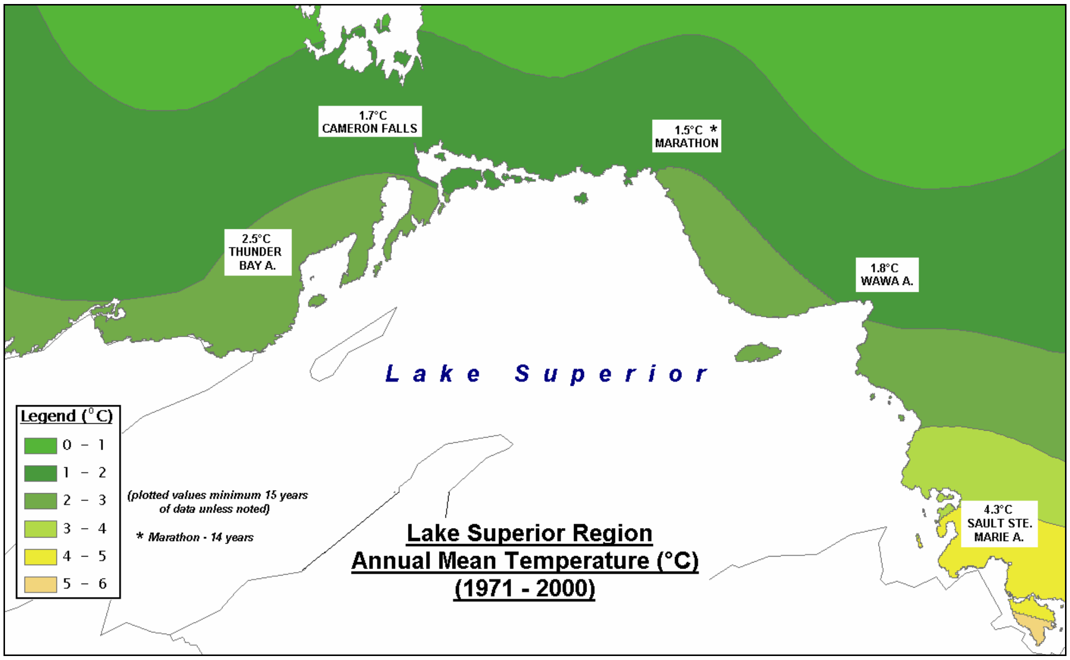


Figure 45: Lake Superior Annual Mean Temperature (Environment Canada, 2005).

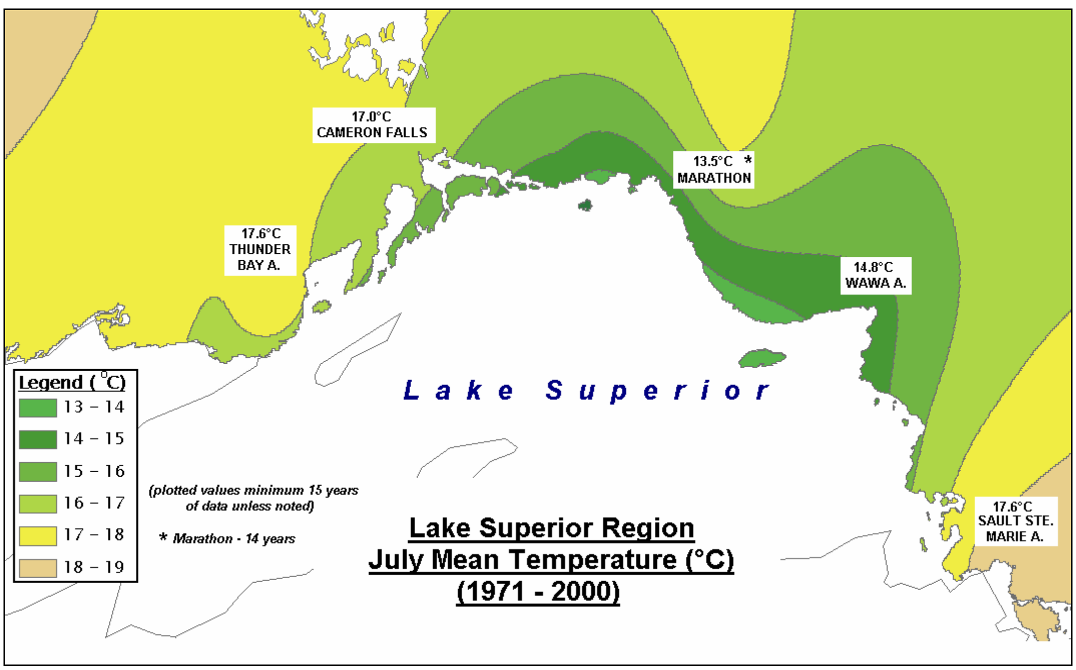


Figure 46: Lake Superior July Mean Temperature (Environment Canada, 2005).

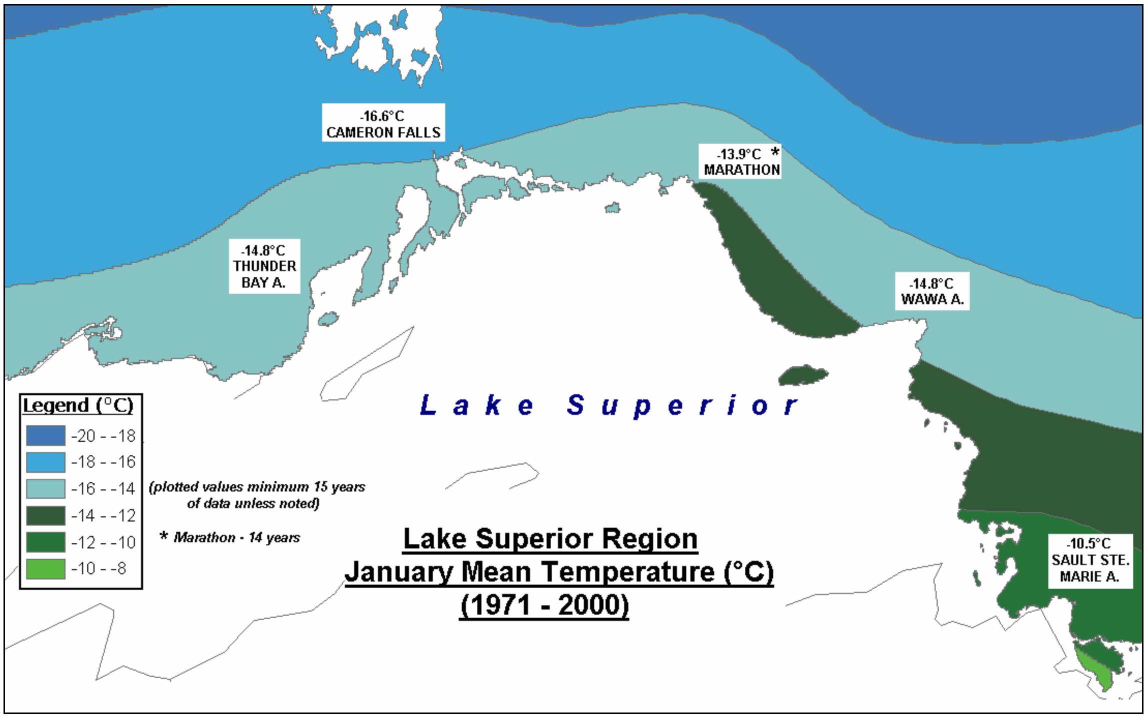


Figure 47: Lake Superior January Mean Temperature (Environment Canada, 2005).

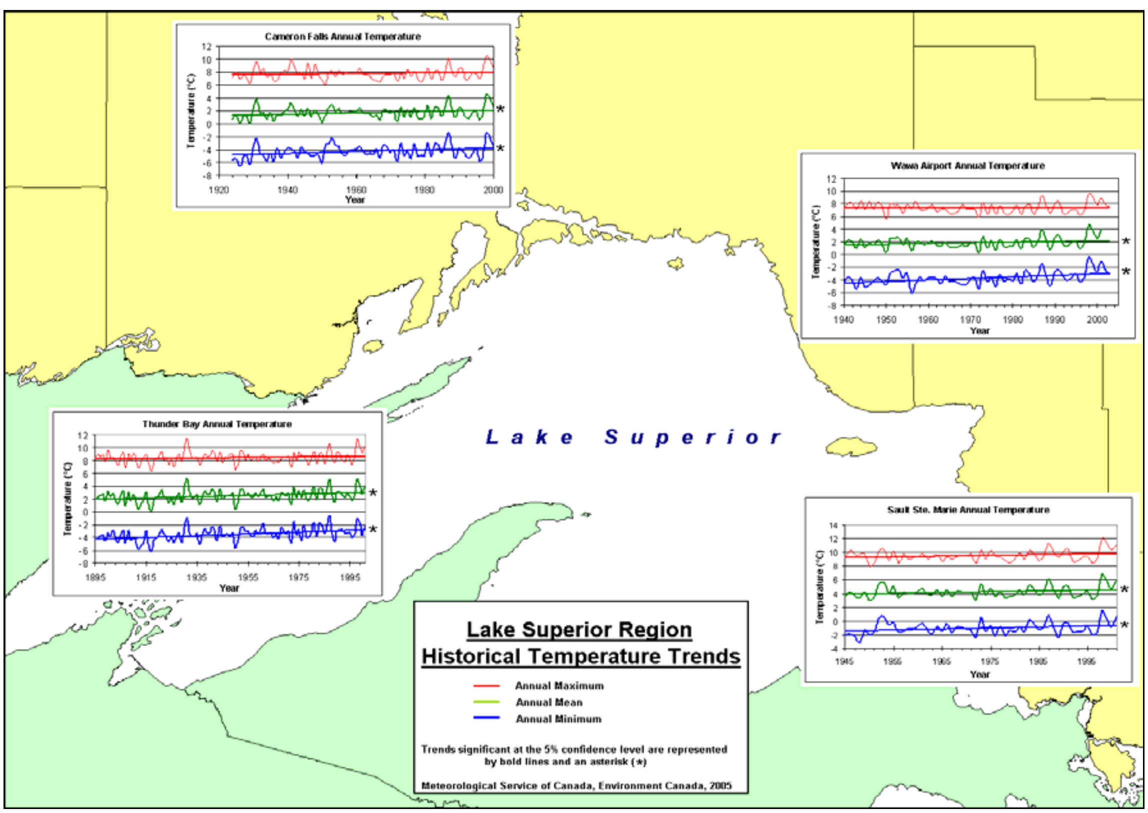


Figure 48: Lake Superior Historical Temperature Trends (Environment Canada, 2005a).

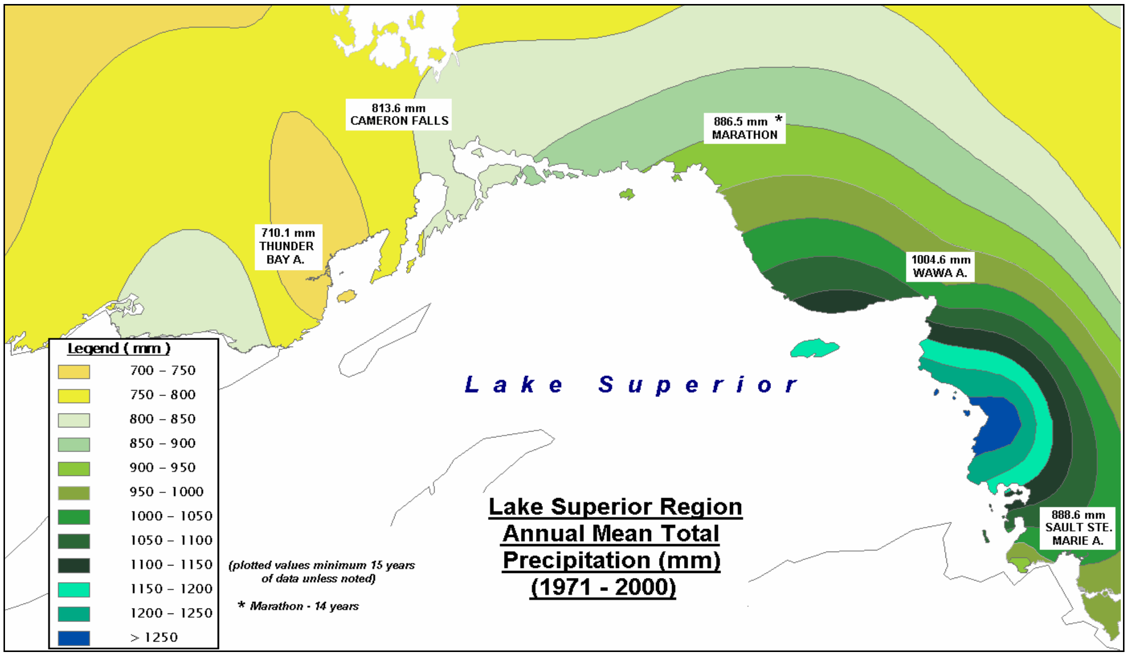


Figure 49: Lake Superior Annual Precipitation (Environment Canada, 2005).

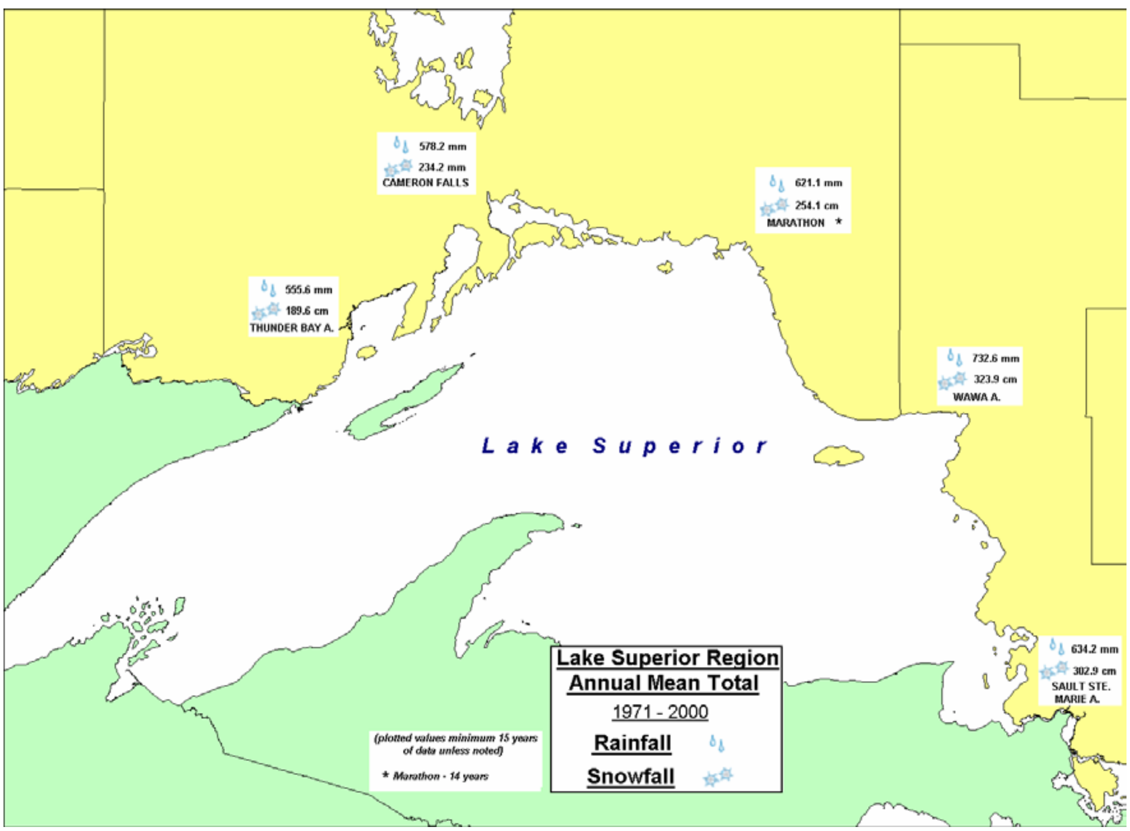


Figure 50: Lake Superior Annual Rainfall and Snowfall (Environment Canada, 2005).

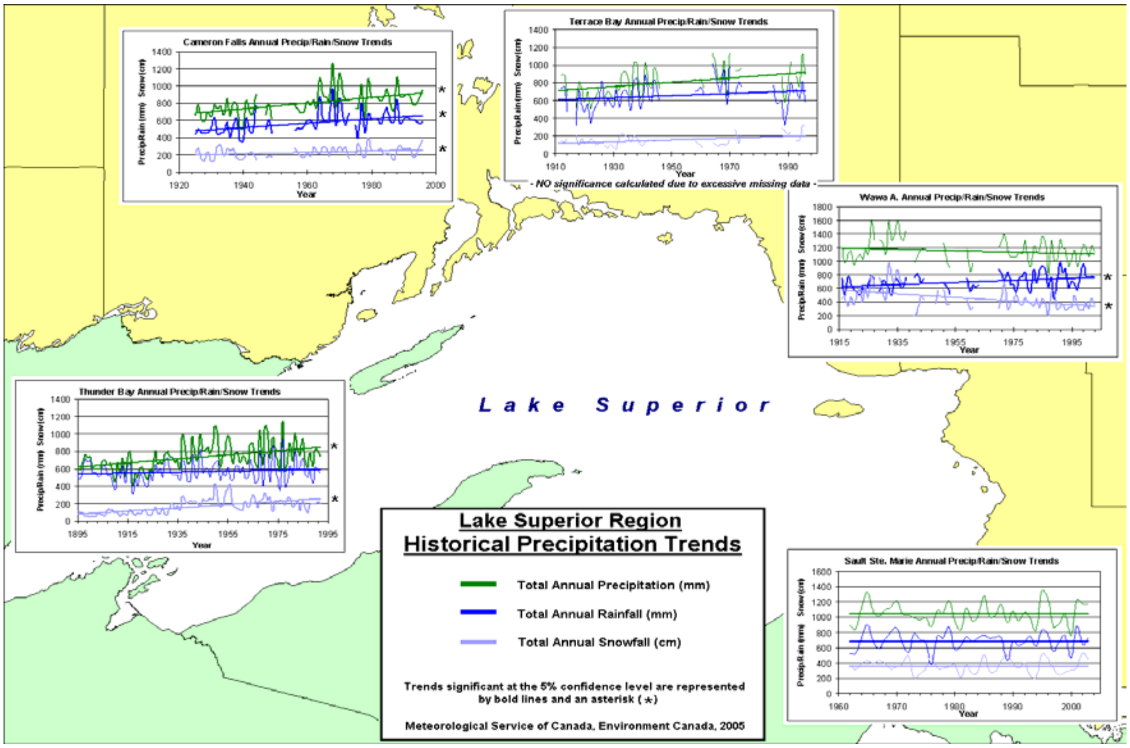


Figure 51: Lake Superior Historical Precipitation Trends (Environment Canada, 2005a).

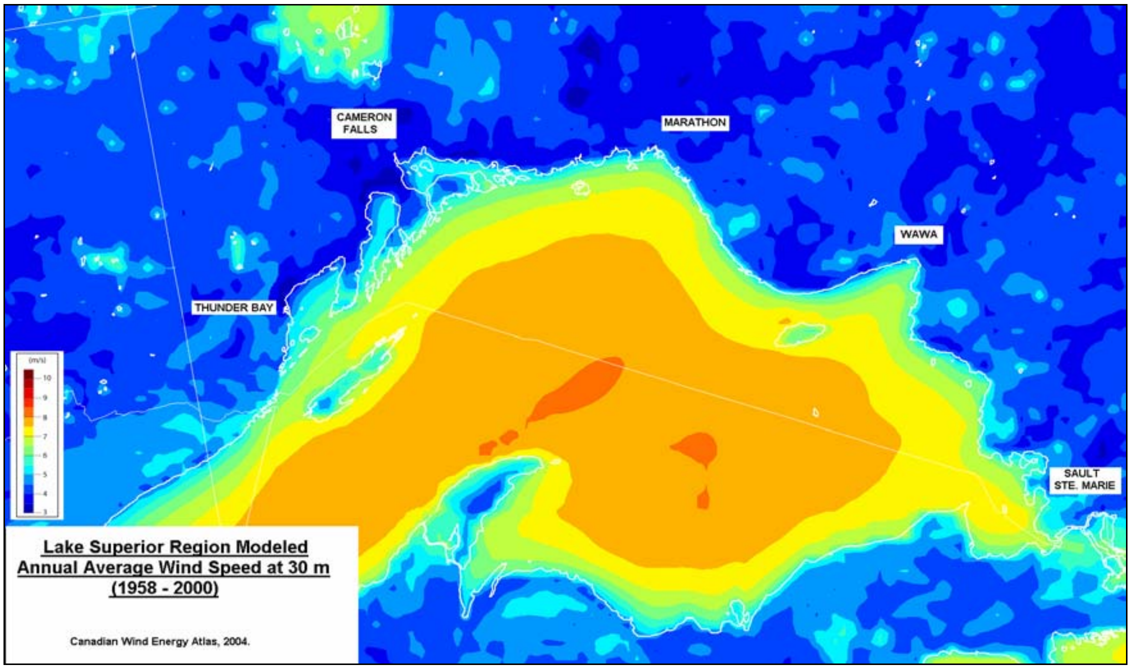


Figure 52: Lake Superior Modeled Annual Wind Speed (Canadian Wind Energy Atlas, 2004).

Wind Trend Summary (signif. increase, increase, zero, decrease, signif. decrease)

STATION NAME	Year					Winter					Spring					Summer					Autumn				
	avg	max	% calm	% <15	# >60	avg	max	% calm	% <15	# >60	avg	max	% calm	% <15	# >60	avg	max	% calm	% <15	# >60	avg	max	% calm	% <15	# >60
Sault Ste Marie A	signif. decrease	signif. decrease	signif. increase	signif. increase	signif. decrease	signif. decrease	signif. decrease	increase	signif. increase	signif. decrease	signif. decrease	signif. decrease	increase	signif. increase	decrease	signif. decrease	signif. decrease	increase	increase	zero	signif. decrease	signif. decrease	signif. increase	signif. increase	signif. decrease
Thunder Bay A	zero	signif. increase	signif. decrease	zero	signif. increase	decrease	zero	signif. decrease	zero	zero	zero	increase	decrease	zero	zero	zero	increase	decrease	zero	signif. increase	decrease	increase	decrease	decrease	zero

Figure 53: Lake Superior Wind Trend Summary 1974-2004 (Environment Canada, 2005).

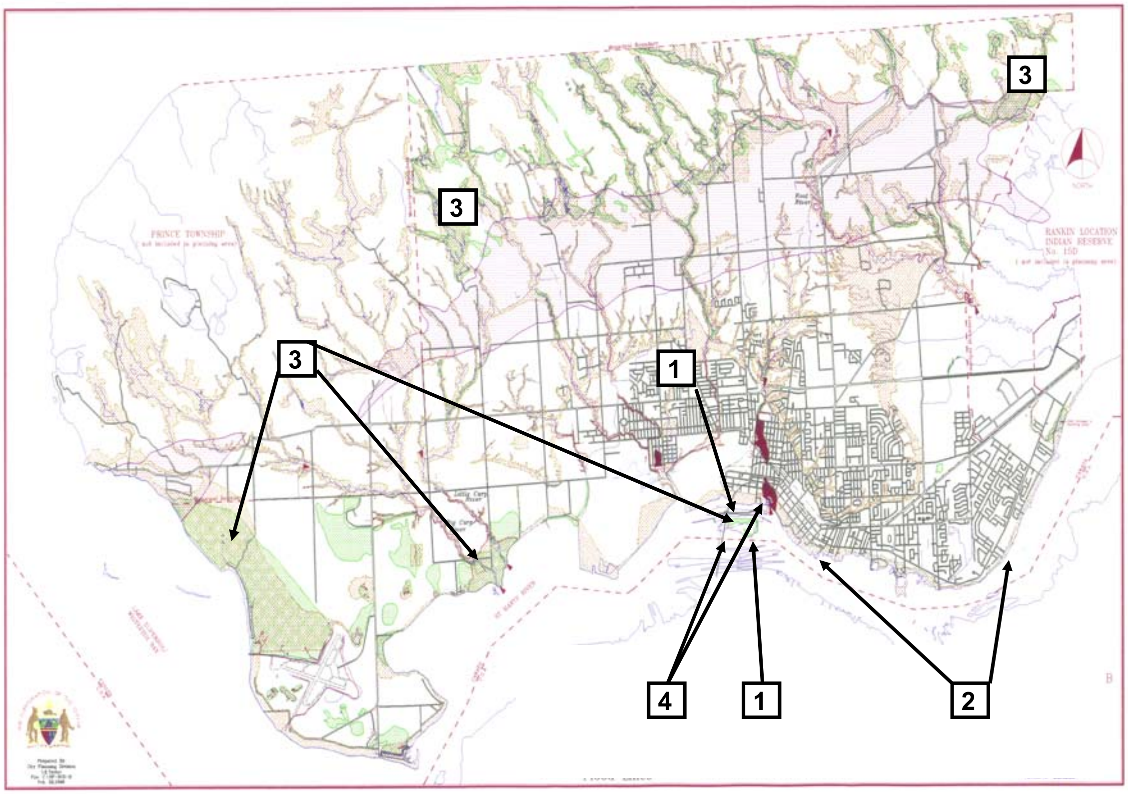


Figure 54: Sault Ste Marie Study Area. Areas denoted as follows; (1) Locks; (2) Waterfront; (3) Wetlands; (4) Power generating stations.

Figure 55: Shipping using Sault Locks (IJC 2006).

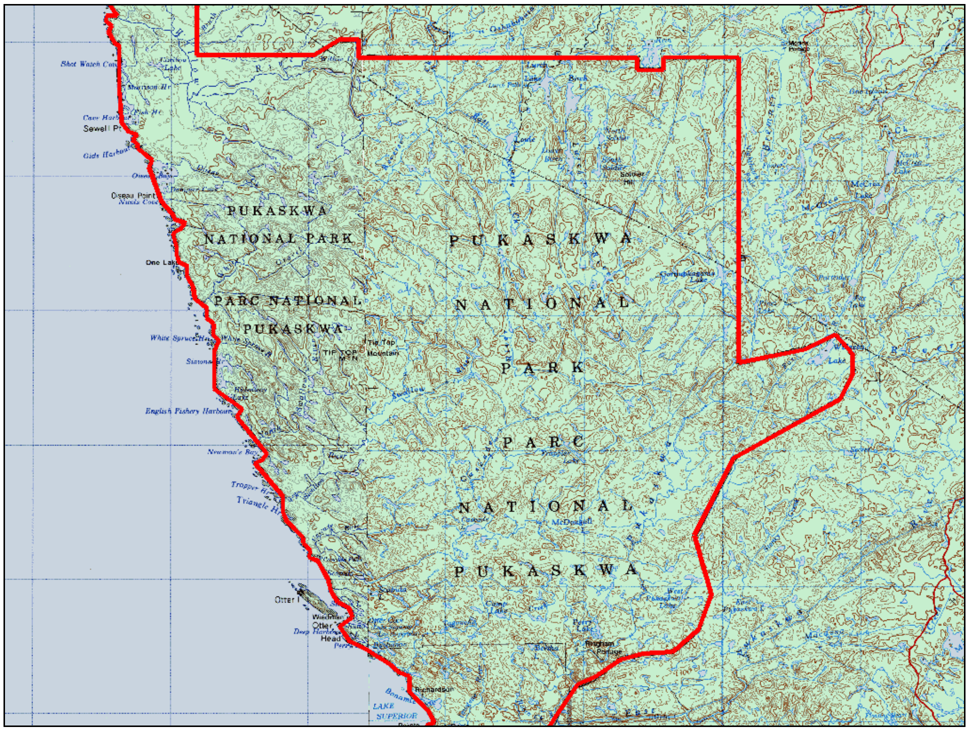


Figure 56: Pukaskwa National Park.

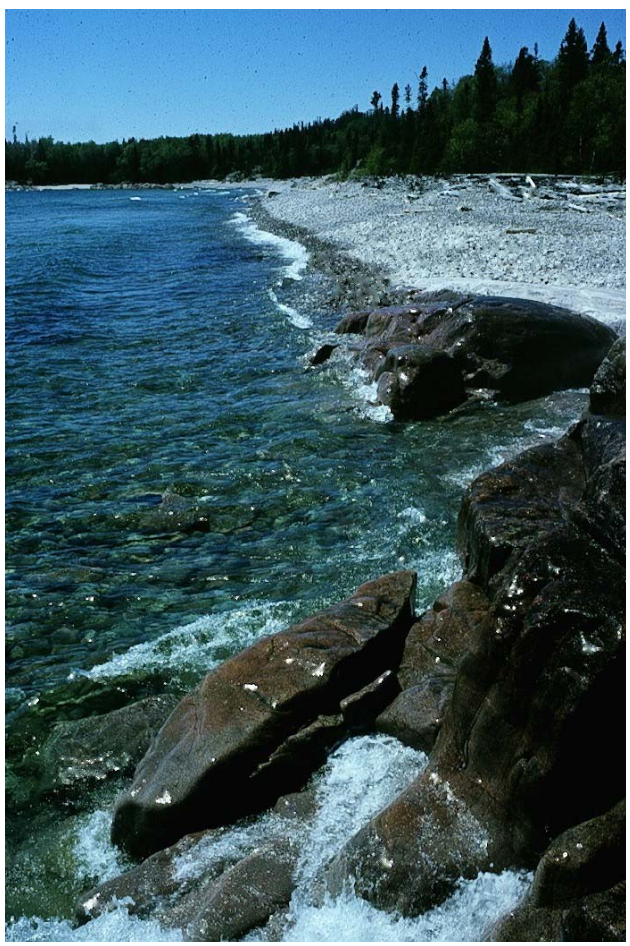


Figure 57: Stone Rings on Cobble Beach, Pukaskwa. Note steep cobble beach (J. Rivet).

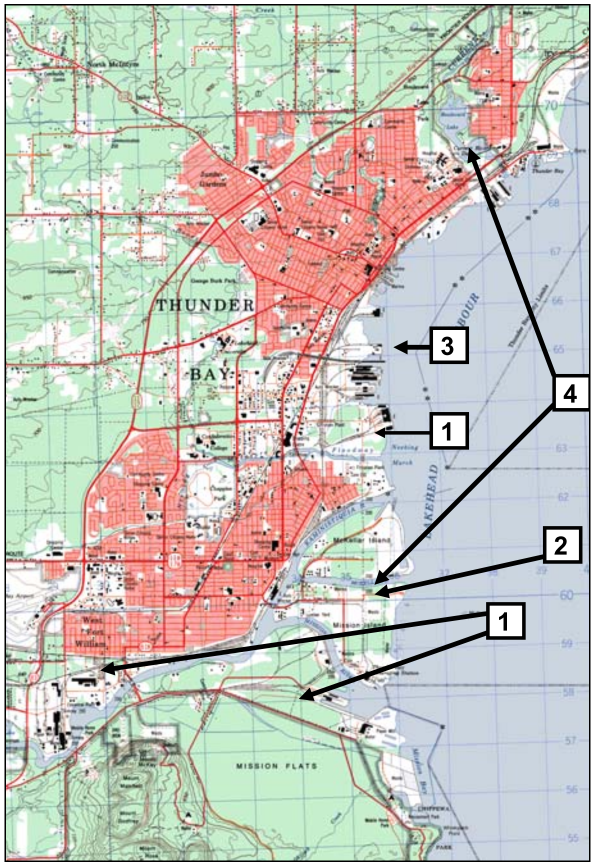


Figure 58: Thunder Bay Study Area. Areas denoted as follows; (1) Industrial Area; (2) Wetlands; (3) Shipping; (4) Fisheries.

Figure 59: Wetland Restoration Thunder Bay (North Shore RAP 1998).

APPENDIX A

COMMON AND SCIENTIFIC NAMES

APPENDIX A
SPECIES LIST - COMMON AND LATIN NAMES

PLANTS

Common Name	***Scientific Name***
American Beech	*Fagus grandifolia*
Ash	*Fraxinus spp.*
American Sweet Chestnut	*Castanea dentata*
Balsam Fir	*Abies balsamea*
Basswood	*Tilia americana*
Birch	*Betula spp.*
Black Ash	*Fraxinus nigra*
Black Oak	*Quercus velutina*
Black Berry	*Rubus idaeus*
Black Spruce	*Picea marinana*
Blue Ash	*Fraxinus quadrangulata*
Bur Oak	*Quercus macrocarpa*
Cattail	*Typha spp.*
Chestnut Oak	*Quercus montana*
Chinquapin Oak	*Quercus muehlenbergii*
Common Reed	*Phragmites communis*
Cucumber Magnolia	*Magnolia acuminata*
Englemann's cyperus	*Cyperus engelmanni*
Dune Grass	*Ammophila breviligulata*
Eastern Hemlock	*Tsuga canadensis*
Eastern White Cedar	*Thuja occidentalis*
Eastern White Pine	*Pinus strobus*
Encrusted Saxifrage	*Saxifrage spp.*
Franklin’s Lady Slipper	*Cypripedium passerinum*
Hackberry	*Celtis occidentalis*
Hickory	*Carya spp.*
Honey Locust	*Gleditsia tricanthos*
Hop Tree	*Ptelea trifoliata*
Jack Pine	*Pinus banksiana*
Manitoba Maple	*Acer negundo*
Nut Rush	*Scleria verticillata*
Oval Ladies’-tresses	*Spiranthes ovalis*
Panic Grass	*Panicum philadelphicum*
Pitcher’s Thistle	*Cirsium pitcheri*
Prickly Pear Cactus	*Opuntia humifusa*
Poplar	*Populus spp.*
Red Ash	*Fraxinus pennsylvanica*
Red Cedar	*Juniperus virginiana*
Red Oak	*Quercus rubra*
Red Mulberry	*Morus rubra*
Reed	*Scirpus spp.*
Sassafras	*Sassafras albidum*
Sea Holly	*Eryngium spp.*
Slender Bulrush	*Scirpus heterochaetus*
Small White Ladies’-slipper	*Cypripedium candidum*
Sugar Maple	*Acer saccharinum*

PLANTS (Cont'd)

Common Name	***Scientific Name***
Swamp White Oak	*Quercus bicolour*
Sycamore	*Platanus occidentalis*
Tamarack	*Larix laricina*
Tulip Tree	*Liriodendron tulipifera*
Water Celery	*Vallisneria americana*
Water Milfoil	*Myriophyllum spp.*
Water Smartwort	*Potamogeton pectinatus*
Waterweed	*Elodea canadensis*
White Birch	*Betula papyrifera*
White Elm	*Ulmus americana*
White Gentian	*Gentiana alba*
White Oak	*Quercus alba*
White Spruce	*Picea glauca*
Witchhazel	*Hammamaelis virginiana*
Yellow Birch	*Betula alleghaniensis*

MAMMALS

Common Name	***Scientific Name***
Beaver	*Castor canadensis*
Black Bear	*Ursus americanus*
Chipmunk	*Tamias striatus*
Coyote	*Canis latrans*
Eastern Cottontail	*Sylvilagus floridanus*
Eastern Mole	*Scalopus aquaticus*
Grey Squirrel	*Sciurus carolinensis*
Lynx	*Lynx canadensis*
Moose	*Alces alces*
Muskrat	*Ondatra zibethicus*
Red Squirrel	*Sciurus carolinensis*
Southern Flying Squirrel	*Glaucomys volans*
Raccoon	*Procyon lotor*
Red Fox	*Vulpes vulpes*
River Otter	*Lutra canadensis*
Snowshoe Hare	*Lepus americuanus*
Virginia Opossum	*Didephis virginiana*
White-tailed Deer	*Odocoileus virginiana*
Wolf	*Canis lupus*
Woodland Caribou	*Rangifer tarandus*

BIRDS

Common Name	***Scientific Name***
Bald Eagle	*Haliaeetus leucocephalus*
Black-crowned Night-heron	*Nycticorax nycticorax*
Brant Goose	*Branta bernicla*
Canada Goose	*Branta canadensis*
Canvasback	*Aythya valisneria*
Carolina Wren	*Thryothorus ludovicianus*
Caspian Tern	*Sterna caspia*
Common Merganser	*Mergus merganser*
Common Tern	*Sterna hirundo*
Double-crested Cormorant	*Phalacrocorax auritus*
Dowitcher	*Limnodromus spp.*
Dunlin	*Calidris alpina*
Greater Scaup	*Aythya marila*
Henslow's Sparrow	*Ammodramus henslowii*
Herring Gull	*Larus argentatus*
Killdeer	*Charadrius vociferus*
Lesser Scaup	*Aythya affinis*
Louisiana Waterthrush	*Seiurus motacilla*
Mute Swan	*Cygnus olor*
Prothonotary Warbler	*Protonotaria citrea*
Red-breasted Merganser	*M. serrator*
Redhead	*Aythya americana*
Ring-billed Gull	*Larus delawarensis*
Screech Owl	*Otis asio*
Spotted Sandpiper	*Actitis macularia*
Tundra Swan	*Cygnus buccinator*
Whimbrel	*Numenius phaopus*
Wood Duck	*Aix sponsa*
Yellow-breasted Chat	*Icterea virens*

AMPHIBIANS

Common Name	***Scientific Name***
American Toad	*Bufo americanus*
Blanding's Turtle	*Emydoidea blandingi*
Bullfrog	*Rana catesbeiana*
Fowler's Toad	Bufo woodhousei fowleri
Green Frog	*Rana clamitans*
Leopard Frog	*Rana pipiens*
Midland Painted Turtle	*Chrysemys picta*
Snapping Turtle	*Chelydra serpentina*
Spiny Softshell	*Trionyx spiniferus*
Spring Peeper	*Hyla crucifer*
Yellow-spotted Salamander	*Ambyostoma maculatum*

REPTILES

Common Name	***Scientific Name***
Blanding's Turtle	*Emydoidea blandingi*
Brown Snake	*Storeria dekayi*
Common Snapping Turtle	*Chelydra serpentina*
Eastern Garter Snake	*Thamnophis sirtalis*
Map Turtle	*Graptemys geographica*
Midland Painted Turtle	*Chrysemys picta*
Spiny Softshell	*Trionyx spiniferus*

FISH

Common Name	***Scientific Name***
Bullheads	*Ictalurus* spp.
Lake Chubsucker	*Erimyson sucetta*
Largemouth Bass	Micropterus salmoides
Northern Pike	*Esox lucius*
Pugnose Shiner	*Notropis anogenus*
Rainbow Smelt	Osmerus mordax
Smallmouth Bass	*Micropterus dolomieui*
Spotted Gar	*Lepisosteus oculatus*
Sunfish	*Lepomis* spp.
Yellow Bullhead	*Ictalurus natalis*
Yellow Perch	*Perca flavescens*
Walleye	*Stizostedion vitreum*
Warmouth	*Lepomis gulosus*,
White Perch	*Morone americana*

CRUSTACEA

Common Name	***Scientific Name***
Meadow Crayfish	*Cambarus diogenes*

INSECTS

Common Name	***Scientific Name***
Monarch Butterfly	*Danaus plexippus*

APPENDIX B

PROJECT WEBSITE

Year	Month	Unique Visitors	Pages Viewed	Countries of Origin	Cities of Interest
2005	January	2	13	Canada	
	February	18	156	Canada	
	March	6	32	Canada, Brazil	
	April	8	30	Canada, US	Santa Clara (CA), Rancho Santa Margarita (CA)
	May	10	28	Canada, US	
	June	37	243	Canada, US	San Francisco, Cambridge, Houston
	July	30	63	Canada, US, France	New York, Neuilly, Palo Alto
	August	21	95	Canada, US	Los Angeles
	September	21	81	Canada, US, Germany	Hamburg
	October	35	123	Canada, US	
	November	32	101	Canada, US	
	December	9	17	Canada, US, Germany, Finland	Kassel, Tampere
2006	January	10	23	Canada, US	
	February	10	41	Canada, US	LA, Phoenix, Grand Rapids
	March	14	29	Canada, US	Dufferin Peel School Board, Sydney
	April	10	22	Canada, US, Australia	Houston, LA, Halifax
	May	6	16	Canada, US	San Francisco, Newark
	June	9	14	Canada, US	
	July	5	12	Canada, US	
	averages	***15***	***59***		