# DOWNSCALING THE GREAT LAKES: TECHNIQUES FOR ADAPTIVE POLICY

# DOWNSCALING THE GREAT LAKES: TECHNIQUES FOR ADAPTIVE POLICY AND ECOSYSTEM IMPACT ASSESSMENTS TO IMPROVE RESILIENCY IN LIGHT OF CLIMATE CHANGE

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For my very supportive family. My mother for her extensive love and my father, the avid scientist, for passing on his curiosity and passion for knowledge to me.

## Declaration of Academic Achievement

The work of this thesis was that solely of Sommer Abdel-Fattah with editing and input both the supervisor, Gail Krantzberg and from all committee members. The papers are joint authored by Sommer Abdel-Fattah and Gail Krantzberg. Eleni Koukidis from Adaptation & Impacts Research Division (AIRD) at Environment Canada at the University of Toronto provided some input data from Environment Canada for the climate models as well as training in SDSM.

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## Preface

This thesis is the sole work of Sommer Abdel-Fattah, edited and reviewed throughout by Gail Krantzberg. Chapter Eight is the currently published as Chapter 15 in Great Lakes: Lessons in Participatory Government. Permission from Science Publishers for its publication in this thesis was authorized. Elsevier, to which all other works in this thesis have been submitted under different journals, permit journals to be published as part of a PhD dissertation.

# CHAPTER ONE: INTRODUCTION

The ecosystems and human economies of the Great Lakes region, profoundly shaped by human activities, are now further threatened by climate change (Millerd, 2007). An increase in annual and seasonal temperatures for the Great Lakes watershed is predicted. The greatest range in projected temperature increase is in the Spring (0.75 to 5.0°C) while Summer had the least (1.5 to 4.0°C) (Great Lakes Water Quality Board 2003). Changes in precipitation patterns and temperature changes will cause increased evaporation and evapotranspiration, and more coastal storms. These changes will affect many ecosystem components including water temperatures, water levels, soil moisture, seasonal flow and timing, soil moisture, ground water recharge, runoff vegetation type and animal habitats as well as other systems.

Most climate studies in the region have highlighted basin-wide changes or lake-wide changes. This study focuses on specific gridpoint locations in basin. The locations chosen were Areas of Concern as designated by the Great Lakes Water Quality (QLWQA) as these areas are already degraded. Degradation is qualified by beneficial use impairments as listed in Annex 2 of the GLWQA. It is reasonable to assume that already degraded areas will be more sensitive and at risk to climate change and thus would require forward planning and management. For this reason it was important to investigate local climate changes and the related impacts on beneficial uses already impaired. This research aimed to examine local changes in three Areas of Concern: Thunder Bay area of Concern, Cornwall and Toronto. The location of the AOCs and the associated beneficial use impairments will in part determine sensitivities to climate change impacts. Identifying common lake impairments will allow for targeted adaptation strategies since many of the beneficial use impairments are affected by climate change determinants that are common.

The research first sets out to predict the future climate for the AOC sites. This is done through statistical downscaled models to forecast future climate changes at these three locations. Downscaling relates the global scale atmospheric predictors to local scale predictands from meteorological weather stations. The relationships established using a downscaling technique were then applied to GCM output data to predict climate change and for regional hydrologic modelling (Wigley et al., 1990; Karl et al., 1990). This study applies downscaling techniques using the Statistical DownScaling Model and the Artificial Neural Network Model to generate the possible future values of local meteorological variables such as precipitation and temperature based on the Canadian Global Climate Model data and Hadley Climate Model data. Two different downscaling methods were chosen for accuracy because they relate the data in different ways (SDSM is a multiple linear regression model, and the Artificial Neural Network model uses non-linear regression). Two different GCMs were chosen to validate the different methods and account for any variance. These models were chosen based on their predominant use by other researchers in the field during the time the modeling was performed for this research in 2009. Forecasts were based on the Special Report on Emissions Scenarios

(SRES), a report by the Intergovernmental Panel on Climate Change (IPCC) that was published in 2000.

Results were compared to basin results in order to evaluate any correlations between local and regional results. It was then necessary to examine ecological impacts at the local level due to climate change by exploring the specific beneficial uses already impaired within the basin and how these may become exacerbated or newly impaired. Twelve of the 14 beneficial uses were identified as having a potential vulnerability to climate change. The two beneficial uses impairments' that were considered not directly affected by climate change are fish tumours or other deformities and bird or animal deformities or reproduction problems (IJC, 1991). Beneficial use impairments were then grouped by degradation drivers (such as runoff, and reduced water levels) to allow for a highlight of sensitivities at these locations and build adaptation strategies.

The next phase of this project aimed to validate some of the impact assessment of climate since this area has high uncertainty that cannot be well numerically established. For this reason the Delphi Method was employed. The Delphi involved a multi-round, interactive survey of experts in the field of climate change, policy and adaptation. One of the aims of using Delphi is to achieve greater consensus amongst surveyed experts. Empirically, consensus is determined by measuring the variance in responses of Delphi panelists over rounds, with a reduction in variance indicating that greater consensus has been achieved (Rowe and Wright, 1999). The survey consisted of three rounds, and each round provided respondents with results and feedback from others on the previous survey so they could reflect and if convinced alter their previous responses. It was suspected that through rounds there maybe some consensus on possible adaptations as experts assessed each other's opinions. Participants were asked to assess first the opinions of climate change and their impacts in the region and whether current policies adequately addressed issue, second whether certain adaptation strategies would be successful and thirdly the feasibility of these strategies for implementation. These answers provide a starting point for understanding current issues and scientific assessment of the problem and some adaptation strategies in order to plan for policy reformation and preventable measures for building resiliency in the Great Lakes against climate change.

The final phase of the work was to recommend policy revisions for the Great Lakes Water Quality review that had been underway from 2009-2012. Climate change will potentially exacerbate existing water quality problems in the Great Lakes-St. Lawrence River system because it will exacerbate existing chemical, physical, and biological stressors and create new problems on top of the current problems. Warmer water, increased nutrient and sediment loadings from intense storms, increased Winter evaporation, and the likelihood of more extreme fluctuations in water levels are all consistent with predicted climate change impacts. The Agreement must acknowledge the scope and scale of climate change impacts and the serious gaps in understanding and the need for strategies to mitigate the effects. Due to the fact that climate is constantly changing, restored beneficial uses need to be monitored at a higher frequency. Adaptation responses directed at these beneficial uses that are highly sensitive to projected effects of climate change, and generally widespread across Ontario's AOCs, should aid in achieving more resilient end points to sustain delisting activities.

It is important to present possible future scenarios and policy goals around social and environmental impacts to push for a policy that aims to better our future. Thus, a renewed Great Lakes Quality Agreement, or efforts towards its implementation need to include two important considerations:

- Options for consideration to ensure restored beneficial uses remain restored
- Potential adaptation responses to enhance the resilience of beneficial uses

This dissertation approaches the identification of policy options by proposing ecological, social or economic adjustments that can be made to reduce the magnitude of the threats to a particular conservation target and thus reduce the vulnerability of beneficial uses. This will allow for sequential consideration of the individual conservation targets for impaired beneficial uses and create a policy solution for including climate change in decision making in the Great Lakes. Adapting to the changes now, could reduce the potential impacts in the future.

Clearly, the changes expected with a changing climate cannot be ignored. With the imminent impacts of a changing climate it may be more appropriate to plan precautionary steps and adaptation strategies to reduce risk and minimize future environmental threat and associated costs. This research aims to contribute to this endeavour by presenting a novel framework that conceptualizes climate change as actions. The framework is intended to analyze climate change risks and identify possible mitigation and adaptation strategies. Thus to summarize, the objectives of this research were:

1. An evaluation of current climate change information and development of downscaled models (SDSM and ANN) for Areas of Concern.

2. An analysis of the predicted impacts of climate change on the status of beneficial uses in the Areas of Concern. This will include an integration of climate information with adaptation strategies for beneficial use resiliency.

3. Climate information validation and adaptation strategy assessment through The Delphi Survey Method to identify appropriate adaptive management responses and their feasibility to improve the resilience of beneficial uses to climate change.

4. Policy review and recommendations for renewal of the GLWQA. The purpose is to facilitate policy responses and improve the ability to delist Areas of Concern.

Primarily it was important to provide, real-world applicable technical techniques to assess the problem, as well as survey methods in order to build adaptation strategies. These four objectives provide a means to adapt management tools to address the threat of climate change to maintain the Great Lakes ecosystems including preserving the surrounding habitats as well as access to clean water and the beneficial uses the Great Lakes provide. Policy recommendations that result in ecosystem resilience to climate change will aim at long term delisting of impaired beneficial uses.

The organization of this manuscript sequentially guides the reader through the research process. The first chapter after the introduction is a review paper that provides background information regarding the state of climate change research in the Great Lakes region. Chapter three illustrates the largely technical aspects of the downscaled models. Chapter four closely relates as it translates the forecasted temperature and precipitation results from the technical material to what this means for the AOCs and beneficial uses. In this Chapter, only SDSM data is supplied due to the fact that it performed overall better than ANN. Since the computation was reduced by removing a model, it was possible to add an additional site (Toronto). Chapter five expands on this concept to build adaptation strategies for preserving beneficial use. Chapter six discusses the Delphi validation of the results of the findings of the previous two chapters. Chapter seven is a chapter providing policy solutions for including climate change in the Great Lakes Water Quality Agreement. Chapter seven summarizes the climate results of the thesis and is a published book chapter that relates the results of the research and suggests policy options for inclusion in the GLWQA. The thesis chapters were written so each chapter can stand alone as a single paper. As such, there is some overlap in the background information of some of the articles.

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# CHAPTER TWO

# A Review of the State of Climate Change in the Great Lakes

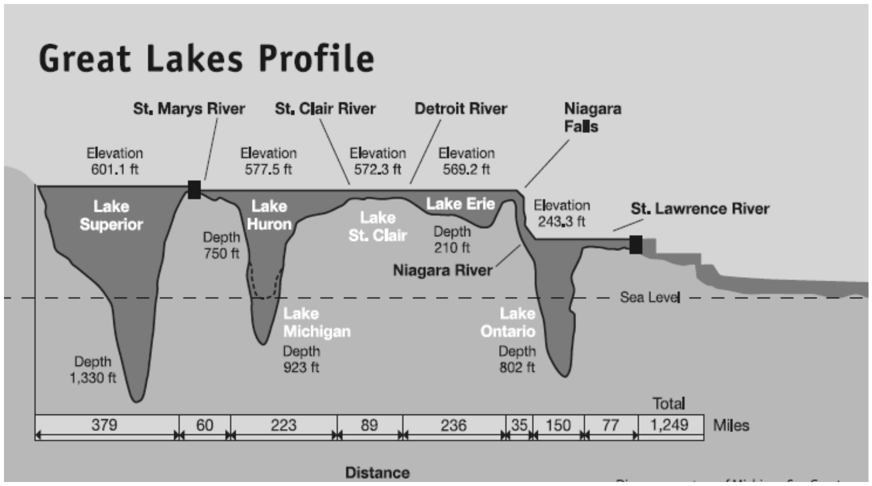
## 1.0 Introduction

The net effect of climate changes on water resources is complex. The variables of precipitation, evaporation and transpiration, soil moisture, runoff and basin supply interact in many ways that could significantly affect ecosystem structure and function in the Great Lakes. This research examines climate scenarios for the Great Lakes to provide a window into potential futures and possible impacts on ecosystems at local rather than basin-wide scales.

## 2.0 Study Area

The Great Lakes basin area is 770,000 $km^2$, about one-third of which is water surface. The basin extends 3,200 km from the western edge of Lake Superior to the St. Lawrence at Cornwall, Ontario on the St. Lawrence River (Figure 1).

Figure 1. Great Lakes Depth Profile (Michigan Sea Grant, 2012)




Lake Superior is largest and deepest Lake. Lakes Superior, Michigan, Huron, and Ontario are very deep (229—405 m) while Lakes Erie and St. Clair are very shallow (6—64 m). Lake Superior outflows and levels are regulated to balance Lakes Superior, Michigan, and Huron water levels (Croley and Lewis, 2006).

Lakes Michigan and Huron are hydraulically linked because of their connection through the deep Straits of Mackinac. The drop in water surface between Lakes Michigan-Huron and Lake Erie is only about 2 m (Croley and Lewis, 2006). This results in a large backwater effect between Lakes Erie, St. Clair, and Michigan-Huron. Thus, changes in Lakes St. Clair and Erie levels are transmitted upstream to Lake Michigan-Huron.

Lake Ontario upstream and downstream outflows and levels are controlled by the Moses-Saunders Power Dam between Massena, New York and Cornwall, Ontario. From Lake Ontario, the water flows through the St. Lawrence River to the Gulf of St. Lawrence and to the Atlantic Ocean (Croley and Lewis, 2006).

## 3.0 Regional Climate

The weather in the Great Lakes basin is affected by three factors: air masses from other regions, the location of the basin within a large continental landmass, and the moderating influence of the lakes themselves. The prevailing movement of air is from the west. The constantly changing weather of the region is the result of alternating flows of warm, humid air from the Gulf of Mexico and cold, dry air from the Arctic (US EPA, 2010).

In Summer, the northern region around Lake Superior receives cool, dry air masses from the Canadian northwest while the southern area receives tropical air masses originating in the Gulf of Mexico (US EPA, 2010). As the Gulf air crosses the lakes, the bottom layers remain cool while the top layers are warmed. Occasionally, the upper layer traps the cooler air below, which in turn traps moisture and airborne pollutants, and prevents them from rising and dispersing. This results in a temperature inversion causing humid days in areas in the midst of the basin, such as Michigan and Southern Ontario, and can also cause smog in industrial areas, which is difficult to predict using Global Climate Modelling (US EPA, 2010).

Parts of Southern Ontario, Michigan and western New York enjoy milder Winters than similar mid-continental areas at lower latitudes. In the Autumn, the rapid movement and occasional clash of warm and cold air masses through the region produce strong winds and signal more storms and precipitation. In Winter, the Great Lakes region is affected by two major air masses; warm humid, air from the Gulf of Mexico and cold, dry Arctic air. Arctic air from the northwest is very cold and dry when it enters the basin. When Arctic air enters the basin and reaches the land, the moisture condenses as snow, creating heavy snow falls on the lee side of the lakes in areas frequently referred to as snowbelts (US EPA, 2010). Ice frequently covers Lake Erie but seldom fully covers the other lakes. Spring in the Great Lakes region, like Autumn, is characterized by variable weather. Alternating air masses move through rapidly, resulting in frequent cloud cover and thunderstorms. The lakes are slower to warm than the land and tend to keep adjacent land areas cool, thus prolonging cool conditions sometimes well into April (US EPA, 2010).

## 4.0 Climate Change

The Intergovernmental Panel on Climate Change (IPCC) ( 2001) defines climate change as "statistically significant variations of the mean state of the climate or of its variability, typically persisting for decades or longer." Based on this definition, climate has changed over centuries, as far back as the glacial advancement and retreat cycles that have been observed since the last glacial period (Arnell, 2002). The IPCC (2007) has shown that the global mean annual temperature has already increased 0.6±0.2°C over the past 100 years. Scientists have shown with certainty that the concentrations of CO2, CH4, N2O, and CFCs have increased. As a consequence of these changes, many hydrological processes will be altered. The 'greenhouse effect' is a natural phenomenon. It is a process by which water vapour and carbon dioxide in the atmosphere absorb heat given off by the earth and radiate it back to the surface. Consequently the earth remains warm (16°C average world temperature rather than -18°C without the greenhouse effect). However, humans have increased the carbon dioxide present in the atmosphere since the industrial revolution from 280 parts per million to the present 350 ppm, and it is predicted that the concentration will reach twice its pre-industrial levels by the middle of the next century (Kling et al., 2003).

The state of the past climate has been inferred by examining indicators such as stratified sediment in streams, lakes, and swamps; pollen profiles; layered ice cores; and tree rings (Hecht, 1985). Climate change has been seen in the region through observed temperature increases in the northern hemisphere by more than 0.5°C, lengthened growing seasons, and precipitation increases by 5 to 10 percent since 1900 (Kling et al., 2003). Other indicators that the climate has warmed include documented losses of alpine glaciers, sea ice, and seasonal snow cover (Chao, 1999). There are many anthropogenic and natural factors that have influenced these patterns. Ice core studies indicate that atmospheric concentrations of carbon dioxide, which fluctuated around 280 parts per million by volume (ppmv) during the last 18,000 years, began to increase concurrently with industrialization that began approximately 200 years ago. By 1994, atmospheric concentrations of carbon dioxide had reached 358 ppmv, an increase of almost 30% over pre-industrial levels (Herfst, 1998). Industrialisation combined with urbanization and growing populations has resulted in loss of natural ecosystems further adding to the problem as net deforestation accounts for about 18% of current total CO2 emissions (Herfst, 1998).

It is suggested that slightly less than one-half of human-induced emissions of carbon dioxide, from the combustion of fossil fuel and changing patterns of land use practices, remain in the atmosphere. The remainder is believed to be taken up by natural sinks, primarily oceans and, to a lesser extent, vegetation.

Another influence is the direct negative radiative forcing (cooling) due to aerosols (primarily from fossil fuel burning); which is particularly significant regionally. This offsets or "masks" greenhouse gas warming (Ramanathan*et al*., 2001). Regionally it is most significant in Eastern North America, where acid rain is a serious problem due to sulphate emissions. This region has also shown less significant observed warming over the past few decades compared to warming of central and western Canada, partly due to this effect (Roderick and Farquar, 2002). As efforts continue to curb sulphate emissions this may unmask greenhouse warming in regions where sulphate aerosols have been historically high. There may also be substantial indirect effects of aerosols through induced cloudiness (Herfstf, 1998).On the other hand, increases in tropospheric (low level) ozone in urban and regional smog, especially in industrialized regions have had a positive (warming) radiative effect, adding about 20% of the direct greenhouse gas effects globally (Roderick and Farquar, 2002). Among the other greenhouse gases caused by human or anthropogenic activity are low-level ozone, methane, nitrous oxide, and chlorofluorocarbons (CFCs). These gases are found in lower concentrations than carbon dioxide, but are more effective in trapping heat. CFCs are some of the most heat absorbent of the greenhouse gases: one CFC molecule may have from 10 000 to 13 000 times the impact of a CO2 molecule (Environment Canada, 2010). Water vapour, a natural greenhouse gas and the most abundant one, will also increase with global warming, as warmer temperatures would cause more evaporation and increase the atmosphere's ability to hold moisture. An increase of the amount of cloud cover will further increases the albedo of the earth increasing the amount of reflected incoming solar radiation. Furthermore, precipitation magnitude and frequency would decrease due to increasing concentrations of aerosols as evaporation rates would decrease due to the increased cloud cover reflecting incoming solar radiation (Roderick and Farquar, 2002). Changes in radiation from variations in intensity of sunlight reaching the earth may be another factor, but, on a century time-scale, are estimated to be much smaller than those due to greenhouse gases. A pattern of climatic response to human activities is identifiable in the climatological record.

# 5.0 Future Forecasts

Climatologists using the General Circulation Model (GCM) have been able to determine the manner in which the increase of carbon dioxide emissions will affect the climate in the Great Lakes basin. Climate scenarios developed from GCMs produce changes in the mean values of climatic elements by applying 1XCO2 and 2XCO2 ratios to historic base-case climate. This allows for incorporation of the variability of base climate in future predictions; however, potential changes in variability patterns in future climate cannot be modelled due to the statistical nature (regression methods) of the modelling.

## 5.1 Basin-wide Forecasted Changes

There are many basin-wide changes that are expected to affect the entire Great Lakes region. An increase in annual and seasonal temperatures for the Great Lakes watershed is predicted. The greatest range in projected temperature increase is in the Spring (0.75 to 5.0°C) while Summer had the least (1.5 to 4.0°C), although this is still significant (Great Lakes Water Quality Board 2003). Summer daily temperatures are projected to gradually increase towards 2030 and then a more rapid increase could have daily average Summer temperatures 10°C higher than the 1960-1990 average by 2100 (Kling *et al.*, 2003). Numerous GCM experiments have determined that the daily temperature range, the difference between the daily high and daily low temperature, tends to decrease with increasing greenhouse gas (Stone and Weaver, 2002).

Overall, annual average precipitation is expected to increase. Winter and Spring modeling scenarios show consistent increases in precipitation in these seasons while Autumn scenarios show a precipitation decrease. Analyses of precipitation extremes in global climate models (GCMs) and regional climate models (RCMs) indicate more heavy precipitation events, fewer moderate events and more dry days or days with light precipitation between storms (Cubaschet al., 1995; Hennessy et al., 1997; Jones et al., 1997 in Trenberth, 1999; Trenberth, 1999). The distribution of precipitation throughout the year will be altered. Sharif and Burn (2006) estimate that only the months of January, March and October will have increased monthly precipitation while the other months may see a decrease in precipitation, including the months between April to September when water demand is the highest. Changes in precipitation, combined with temperature increases, will influence soil moisture, ground water recharge, and runoff in the Great Lakes watershed. Warmer air temperatures in Winter and early Spring affect the form of precipitation. It is expected that frequency of temperatures rising above the 0°C threshold will increase and precipitation that previously fell as snow may Fall as rain. As a result, more runoff may occur in Winter and less snow may accumulate and become more intermittent (Great Lakes Water Quality Board, 2003).

#### 5.2 Lake-wide Climate Change Scenarios

Changes in temperature and precipitation for each of the Great Lakes are dependent on the differences in the physical characteristics of the lakes and local climatic differences as predicted by Mortsch and Quinn (1996) (Figures 2(a) and 2(b) (based on CGCM1).

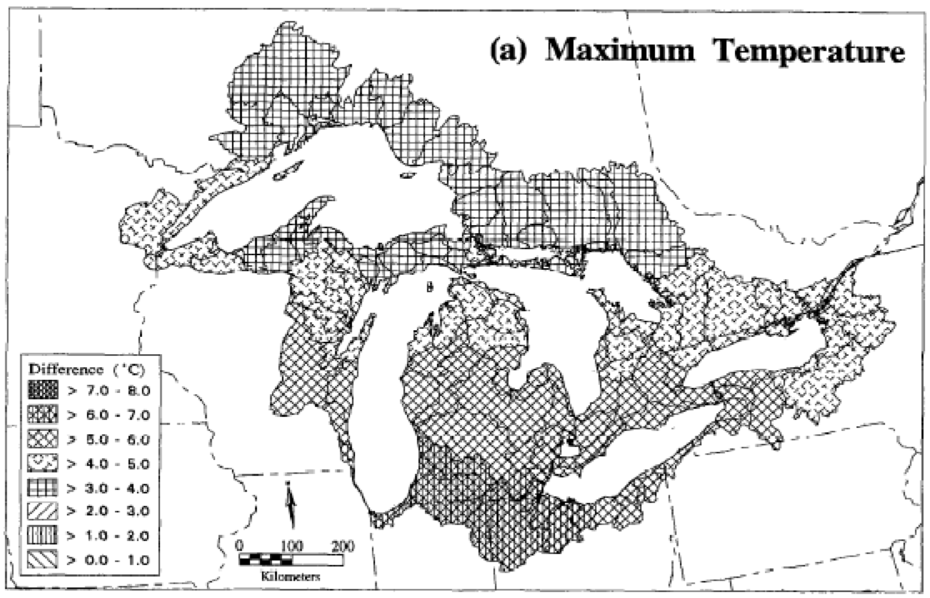



Figure 2 (a) Maximum air temperature differences, 2x CO2- 1x CO2 (°C)

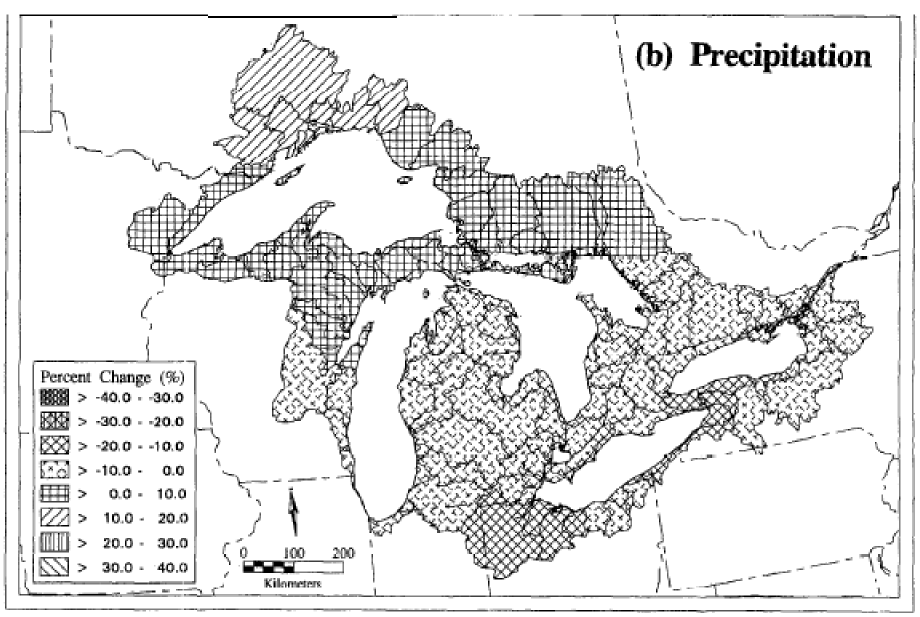



Figure 2(b) Precipitation differences, 2x CO2- 1x CO2 (mm)

A more recent study by Trumpickas et al. (2009) used climate modeling techniques to predict the surface water temperature of each of the Great Lakes. They also used different CO2 concentrations to categorize climate into two emissions scenarios called A2 and B2 developed by Intergovernmental Panel on Climate Change. The A2 and B2 scenarios assume relatively high and relatively low greenhouse gas emission levels for the period 2000 to 2100, respectively (Nakicenovic et al., 2000).
A2 is the more aggressive scenario, showing more dramatic increases in CO2 and thus larger temperature changes (Figure 3).

Figure 3. Predicted values of $T_{max}$, and predicted changes in Spring and Fall from normal under the IPCC A2 and B2 scenarios for lakes Superior, Huron, Erie, and Ontario. Edited from (Trumpickas et al., 2009).

| Lake | Time period | Scenario | $T_{max}$ (°C) | Δ $T_{max}$ from norms (°C) | $\Delta_{Spring}$ from norms | $\Delta_{Fall}$ from norms |
|---|---|---|---|---|---|---|
| Superior | 1971–2000 | Norm | 15.1 | | | |
| | 2011–2040 | A2 | 17.0 | + 2.0 | − 10.0 | + 15.0 |
| | 2011–2040 | B2 | 17.1 | + 2.1 | − 12.4 | + 16.6 |
| | 2041–2070 | A2 | 18.9 | + 3.9 | − 21.8 | + 29.6 |
| | 2041–2070 | B2 | 18.2 | + 3.2 | − 17.6 | + 24.5 |
| | 2071–2100 | A2 | 21.8 | + 6.7 | − 38.3 | + 51.2 |
| | 2071–2100 | B2 | 19.7 | + 4.6 | − 26.0 | + 36.1 |
| Huron | 1971–2000 | Norm | 19.7 | | | |
| | 2011–2040 | A2 | 21.0 | + 1.3 | − 8.1 | + 8.1 |
| | 2011–2040 | B2 | 20.9 | + 1.2 | − 9.8 | + 9.1 |
| | 2041–2070 | A2 | 21.9 | + 2.2 | − 19.8 | + 16.8 |
| | 2041–2070 | B2 | 21.6 | + 1.8 | − 16.5 | + 13.7 |
| | 2071–2100 | A2 | 23.6 | + 3.9 | − 35.2 | + 26.9 |
| | 2071–2100 | B2 | 22.3 | + 2.6 | − 24.1 | + 20.7 |
| Erie | 1971–2000 | Norm | 23.3 | | | |
| | 2011–2040 | A2 | 24.1 | + 0.9 | – 11.0 | + 6.5 |
| | 2011–2040 | B2 | 24.0 | + 0.8 | − 11.6 | + 6.6 |
| | 2041–2070 | A2 | 24.7 | + 1.5 | − 20.8 | + 14.8 |
| | 2041–2070 | B2 | 24.9 | + 1.6 | − 17.4 | + 12.4 |
| | 2071–2100 | A2 | 26.6 | + 3.3 | − 34.8 | + 26.2 |
| | 2071–2100 | B2 | 25.6 | + 2.4 | − 23.8 | + 17.7 |
| Ontario | 1971–2000 | Norm | 21.6 | | | |
| | 2011–2040 | A2 | 23.0 | + 1.4 | – 10.0 | + 6.9 |
| | 2011–2040 | B2 | 22.9 | + 1.3 | – 12.2 | + 7.0 |
| | 2041–2070 | A2 | 24.1 | + 2.5 | – 25.6 | + 18.2 |
| | 2041–2070 | B2 | 23.8 | + 2.2 | – 21.3 | + 14.8 |
| | 2071–2100 | A2 | 26.4 | + 4.8 | – 46.5 | + 30.7 |
| | 2071–2100 | B2 | 24.8 | + 3.2 | − 30.7 | + 23.7 |

$T_{max}$ is the twentieth highest temperature observed in a lake for a year.

#### 5.2.1 Lake Superior Future Climate Scenarios

In Lake Superior, the deepest coldest lake, average annual surface water temperatures could increase 5°C by 2100 (CGCM1 and HadCM2 scenarios), while Summer maximum surface water temperatures could be greater than 20°C (Lehman, 2003). Summer and Fall water levels could decrease while Spring and Winter levels would remain roughly the same. Bottom water temperatures also increase in scenarios but not as dramatically. Higher bottom water temperatures increase the metabolic rates of invertebrates and microbes and accelerate dissolved oxygen use (Lehman, 2003) and bioturbation rates.

#### 5.2.2 Lake Michigan Future Climate Scenarios

Temperatures are expected to rise by 3-5.5°C Winter and a 4-7°C rise in Summer temperatures by the end of the century (Kling et al, 2003).Although average annual precipitation is not expected to stay stable, an overall drier climate is expected due to increased evaporation resulting from greater temperatures. Thus Michigan may see drier soils and more droughts. Seasonally, Winter precipitation is expected to increase by 5-25% while Summer precipitation is expected to remain the same. Extreme heat will be more common, and the frequency of heavy rainstorms will increase and could be 50-100% higher than today. The growing season could be 8-10 weeks longer and declines in ice cover on the Great Lakes and inland lakes that have been recorded over the past 100-150 years, are expected to continue through 2100 (Kling et al., 2003).

#### 5.2.3 Lake Huron Future Climate Scenarios

Overall, Lake Huron water levels have declined due to a combination of lower precipitation, higher air temperatures, and increased evaporation over the past eight years. Although Summer precipitation levels are above average, water levels continue to decline, and are currently approaching a record low. As cold, dry air masses pass over warmer Lake Huron waters in the Fall and Winter, the potential exists for lake levels to plummet to their lowest point in 36 years (Schwartz, 2001). Studies have indicated that Lake Huron water levels are projected to decline by as much as 1 m by 2050 (Mortsch et al., 2000). There was however, a trend in Michigan-Huron of higher peaks in Winter comparatively, since 1965, to more runoff in Winter and less in the Spring.

#### 5.2.4 Lake Erie Future Climate Scenarios

McBean and Motiee (2008) estimate that annual average air temperature in the Lake Erie basin will only slightly increase (0.80°C increase by 2050). However, this small increase masks the intra-annual changes, as seasonal temperatures and diurnal temperatures are expected to fluctuate more dramatically (Cunderlik and Simonovic, 2004; Jyrkama and Sykes, 2007). Temperature increases and increased evaporation will largely impact lake water levels decrease and increase exposed shorelines as has already been seen in the recent past.

#### 5.2.5 Lake Ontario Future Climate Scenarios

Temperatures in Lake Ontario are expected to increase by +1.3°C by 2040. Fall and Spring temperatures are expected to be highly variable and increase more dramatically than any other Great Lake (Trumpickas et al. 2009). As with the other Great Lakes precipitation is expected to increase in intensity although the type of precipitation will change to more frequent rain than any other type of precipitation. The maximum ice cover extent demonstrates the influence of a lake's thermal capacity and is less sensitive to warming on Lake Erie than on Lake Superior (Lofgren *et al.*, 2002).

Projected annual average water level reductions in Lakes Ontario, Erie, St. Clair, and Michigan-Huron ranged from 15 to 118 cm for the year 2050 across all scenarios. The recent series of unusually warm years is already to blame for a drop of 1.07m in water levels for Lakes Huron, Michigan and Erie since 1997 (Sousounis and Glick, 2007). Increased evaporation was the likely culprit for the decline in water levels; other Great Lakes have locks or gates that can control water levels, but Huron and Michigan do not. As a result, water levels are vulnerable to climate change.

## 6.0 Conclusion

The state of climate change modeling is constantly evolving. Recent studies have presented information that may challenge the current predictions, including those presented in this paper. More recent studies from the NOAA Great Lakes Environmental Research Laboratory report on a new method for estimating evapotranspiration. Previous models used air temperature as an indicator of energy input, however evaporation is also influenced by energy input from the sun, and also by greenhouse gases which bump up the mercury by slowing down heat's escape from the earth and atmosphere. Thus both incoming and outgoing energy need to be considered in climate modelling. The results yield different evaporation values indicating less water will be lost than previously predicted (Lofgren, Hunter and Wilbarger, 2011). New models will need to be developed in the Great Lakes region and evaluated against current climate information to reduce the knowledge and uncertainty gap regarding climate change impacts in the basin.

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# CHAPTER THREE

# DownScaling the Great Lakes: Climate Change Forecasts

## Abstract

Established climate models for the Great Lakes Region have been of great interest to scientists concerned with the potential ecosystem changes and related risks. Past climate change studies have been performed on a basin-wide scale using Global Climate models. Through downscaling methods, the element of local sites can be assessed and compared to identify if there will be significant differences between local sites within the basin. In this study, two downscaling techniques were applied and tested for accuracy; the Statistical DownScaling Model (SDSM) and Artificial Neural Networks (ANN). Downscaled precipitation and temperature scenarios were generated to investigate local climatic changes within the Great Lakes Basin; with Thunder Bay and Cornwall as study sites. From these comparisons, we have identified statistically significant differences between the two sites thus illustrating that within the basin regional modeling through downscaled scenarios is more relevant when evaluating the Great Lakes basin. Thus using GCM output directly could lead to misleading results for specific locations.

The results identified differences between local predictions and GCM-scale scenarios. Local scenarios will reduce some uncertainty and aid in site specific management planning for resiliency in light of climate change.

**Keywords:** Great Lakes, Climate Change, Downscaling, SDSM, ANN

# 1. Introduction

## 1.1 Background and Context

Much of Ontario's southern border is defined by four of the five Great Lakes. More than 60 million people live in the Great Lakes states and Ontario, half within the Great Lakes drainage basin itself (Kling et al., 2003). The important shipping industries and human economies of the region have confounded greenhouse gas emissions resulting in expedited climate change (Millerd, 2007). Evidence for climate change can be seen in the basin through the temperature increases in the northern hemisphere between 0.5°C-3°C, lengthened growing seasons, and precipitation increases of 5 to 10 percent since 1900 (Kling et al., 2003). As global greenhouse gas emissions continue to rise, the increased warming will lead to mounting stress on the socioeconomic and ecological well-being of the Great Lakes may be compromised.

General circulation models (GCMs) have been used to predict future climate in the Great Lakes region. GCMs simulate the present climate and project future climate with forcing by greenhouse gases and aerosols. The model divides the atmosphere and ocean into a horizontal grid with a horizontal resolution of 2 to 48 latitude and longitude, with 10 to 20 layers in the vertical. In general, most GCMs simulate global and continental scale processes in detail and provide a reasonably accurate representation of the average global climate. An issue with the use of GCM output for local applications is that the coarse spatial resolution of the predicted output does not account for regional heterogeneity that may affect local climate (i.e., effects of local topography and convective processes) (Salathé Jr., 2005; Varis et al., 2004; Mearns et al., 2003). Moreover, GCMs were not designed for climate change impact studies and do not provide a direct estimation of hydrological responses to climate change. Therefore, to assess the hydrological impacts of climate change impact, hydrological models in addition to GCM output. One technique to combine climate modeling with hydrology, is downscaling which can be used to convert GCM outputs into local meteorological variables required for reliable hydrological modeling, in addition to providing more locally representative scenarios of future climate variables.

Statistical downscaling methods and stochastic weather generators are less costly, and thus more common, to implement as compared to techniques that require limited-area models or regional climate models for providing local climate scenarios (Coulibaly and Dibike, 2005). Individual downscaling schemes differ according to the choice of mathematical transfer function, predictor variables and statistical fitting procedure (Wilby et al., 2002). Downscaling methods are capable of generating observed sequences of weather variables using complex random number generators to create and output that resembles daily weather data through a statistical analysis. For downscaling, the parameters of the weather generator are conditioned upon the time-averaged climate-change information from GCMs (Khan et al., 2006). The resulting weather generator models are then used to simulate daily series of the representative observed data (Wilks and Wilby, 1999).

This study applies downscaling techniques using the Statistical DownScaling Model and the Artificial Neural Network Model to generate possible future values of local meteorological variables such as precipitation and temperature based on Canadian GCM data (CGCM2) and Hadley Climate Model (HADCM3) output in the Thunder Bay Ontario watershed and the Cornwall, Ontario watershed.

## 2. Study Area and Data

### Thunder Bay

Thunder Bay is in the northerly area of Lake Superior. The Thunder Bay Area watershed extends approximately 28 km along the shoreline of Lake Superior and up to nine kilometres offshore from the City of Thunder Bay. The Thunder Bay watershed is drained by the Kaministiquia River system and a number of smaller rivers and creeks (Environment Canada, 2009). The Thunder Bay Airport hydro-meteorological data provides the most robust data for Thunder Bay. The data was taken from Environment Canada according to the paramaters in Table 1.

Table 1. Environment Canada Hydro-meteorological data for Thunder Bay

| AOC Site | Station Name | Station Number | Latitude (North) | Longitude (West) | Longitude (East) | Elevation (m) | Data Range |
|---|---|---|---|---|---|---|---|
| Thunder Bay | Thunder Bay A | 6048261 | 45°1' | 89°20' | 270°40' | 199 | 1961-2000 |

## Cornwall, St. Lawrence River

Cornwall on the St. Lawrence River is approximately 80 kilometres in length and stretches from the Moses-Saunders power dam to the eastern outlet of Lake St. Francis. The St. Lawrence River is smooth flowing except by the Long Sault Rapids just west of Cornwall. The data provided was monthly data as well as annual data from 1930-1990. Hydro-meteorological data was taken from Environment Canada according to the criteria provided in Table 2.

Table 2. Environment Canada Hydro-meteorological data for Cornwall

| AOC Site | Station Name | Station Number | Latitude (North) | Longitude (West) | Longitude (East) | Elevation (m) | Data Range |
|---|---|---|---|---|---|---|---|
| St. Lawrence | Cornwall | 6101874 | 45°1' | 74°45' | 285°15' | 64 | 1961-2000 |

For each location 40 years of precipitation and temperature records representing the current climate (1961-2000) were identified for the downscaling experiments. Observed daily data of large scale predictor variables representing the current climate condition were derived from a reanalysis data set of the National Centers for Environmental Predication (NCEP). Climate variables corresponding to future climate scenarios were extracted from the Canadian Global Climate Model (CGCM2) output for each site. These variables include a number of surface and atmospheric factors for the time period 1961-2100. During modeling these variables were selected based on correlations analysis to the local modeled site. If the variable was identified as having a significance of 0.5 or greater it was included in the model parameters.

## 3. Statistical DownScaling

Downscaling relates the global scale atmospheric predictors to local scale predictands from meteorological weather stations. The relationships established using a downscaling technique could then be applied to GCM output data to predict climate change and for regional hydrologic modelling (Wigley et al., 1990; Karl et al., 1990). Individual downscaling schemes differ according to the choice of mathematical transfer function, predictor variables and statistical fitting procedure (Wilby et al., 2002).

The following three implicit assumptions are made during downscaling methods for assessing local climate change, (von Storch et al., 2000): (1) the predictors are variables of relevance and are realistically modeled by the GCM; (2) the predictors employed fully represent the climate change signal; and (3) the relationship established with the baseline is assumed to be valid under climate change scenario (which may not be provable (Khan et al., 2006; Dibike and Coulibaly, 2004)).

Down-scaling was performed using the Statistical DownScaling Model (SDSM), a multiple linear regression model, and the Artificial Neural Network model that uses non-linear regression to predict climate data. It does this by using weighting as it moves forward in time.

## 3.1 Statistical Downscaling Method (SDSM)

SDSM has been identified as one of the leading statistical downscaling techniques (Wilby et al., 2002; Dibike and Coulibaly, 2005) and is currently recommended by the Canadian Climate Change Scenarios Network (CCCSN) as an appropriate downscaling tool. To produce accurate daily predictions of future climate variables at the regional scale, the statistical DownScaling Model (SDSM) identifies relationships between large scale predictors and local-scale predictands, using a multiple linear regression model. In this study, separate downscaled precipitation and temperature scenarios were generated using the SDSM with the calibrations and validations derived from NCEP reanalyses.

## 3.2 Artificial neural network (ANN)

The second model in this study is the Artificial Neural Network (ANN) developed by Coulibaly et al., 2005. This model is a non-linear regression type which similarly relates a few selected large-scale atmospheric predictors and basin scale meteorological predictands (Khan et al., 2006). In this algorithm, network weights are moved along a gradient through a recurrent network model as it was modelled through time. In developing this relationship, a time lagged feed forward network is used in which inputs are supplied through a tap delay line and the network is trained using a back-propagation type algorithm (Khan et al., 2006).

In both cases, a range of possible options representing high, medium and low emissions trajectories for future scenario assessment based on the Special Report on Emission Scenarios (SRES) was used. The Report uses Green House Gases other than CO2 contents to predict the future by developing a range of possible outcomes. The SRES scenarios are divided into four general categories based on economic, technological and population (IPCC, 2001; Mortsch *et al*., 2005) with the A2 scenario being the most aggressive, industrial and polluting and B2 is progressive with improvements in green technology and more environmentally sustainable practices.

## 4. Methods

In this study, separate downscaled precipitation and temperature scenarios were generated using the SDSM with the calibrations and validations derived from Canadian General Circulation Model (CGCM2) and Hadley (HADCM3) models for Thunder Bay and Cornwall under A2 and B2 scenarios.

The sequential steps of the research are (1) quality control and data transformation (2) screening of potential downscaling predictor variables (3) model calibration (4) generation of ensembles of present weather data using *observed* predictor variables (5) statistical analysis of observed data and climate change scenarios (6) graphing model output, and finally (7) generation of ensembles of future weather data using GCM–derived predictor variables.

The first step is to check the raw data for missing values, outliers and errors. The screening of predictor variables involved choosing large-scale relevant predictors through correlation analysis, partial correlation analysis and scatter plots and also considering physical sensitivity between selected predictors and predictand for the site in question. Calibration of the SDSM model (using the years 1961-1990) is performed through bias correction and variance inflation factor to force the model to replicate the observed data and adjust the mean and variance (Khan *et al*., 2006). Variance inflation attempts to force the estimates of the local processes to align better with the observations. Use of stochastic random variarable also enables the SDSM model to generate multiple ensembles of downscaled weather variables. Using ANN, the model is trained differently. The artificial networks are trained with all the predictor variables (twenty-two) as inputs. A sensitivity analysis (about the mean) is then performed to determine the most relevant predictors and these are used to re-train the network. This is performed separately for each variable (precipitation, maximum temperature and minimum temperature) as well as for each type of output (CGCM2 and HADCM3). This is repeated until an acceptable validation is achieved in which simulated data closely aligns with observed data. Several training experiments are conducted with different combinations of input time lags, and number of neurons in the hidden layer until the optimum network is obtained. The generation of future local-scale climate scenarios relied on the identification of past relationships between local occurrences and the global-scale atmospheric state using NCEP reanalysis data (Wilby *et al*., 2002, Dibike and Coulibaly, 2004, Diaz-Nieto and Wilby, 2005, Khan *et al*., 2006). Using SDSM, Precipitation is modeled as an unconditional process in which local amounts are correlated with the occurrence of wet-days, which is correlated with regional-scale atmospheric predictors (Khan *et al*., 2006). A wet-day is any in which more than 0.3mm of precipitation falls. Unlike SDSM, precipitation is downscaled with ANN as an unconditional process establishing a direct link between large-scale predictors and local scale predictand (Khan *et al*., 2006). Temperatures are modeled as unconditional process in SDSM; a direct link is assumed between the large-scale predictors and the local scale predictand (Wilby *et al*., 2002; Coulibaly, 2008; Diaz-Nieto and Wilby, 2005). The SDSM model is structured monthly; twelve regression equations are derived for each month of the year using different parameters. Data was extracted for three distinct periods; the 2020s (covering a 30 year period between 2010 and 2039), the 2050s (2040-2069) and the 2080s (2070-2099).

Once generation of scenarios was complete a statistical analysis of observed data and climate change scenarios was performed through graphing model output and examining residual results. Once the performance of the model was deemed adequate generation of ensembles of future weather data was performed and assessed.

# 4. Results

## 4.1 Calibration

Screening predictor variables through exploratory analysis including linear correlation, and distribution graphing between the predictors and the predictand variables is the basis of good modeling. The exploratory analysis plots are constructed to determine the normality and presence of outliers for the observed daily precipitation (PREC), maximum temperature (TMAX) and minimum temperature (TMIN) for each month for the time period from 1961-1990. The strength of individual predictors may vary from month to month. The NCEP reanalysis data is used to investigate the variance between predictand-predictor pairs.

Due to the nature of daily PREC, and the majority of days that experience no rainfall, correlation can be very low shown or severely skewed as compared to that of temperature. Autocorrelation function (ACF) plots were created for the daily PREC, TMAX and TMIN for each month and indicate that significant serial correlation was present at the 95% confidence level, and diminish as the number of lag days progressed. Based on these tests, non-parametric analyses were most appropriate for this study due to violation of the assumption of normality (PREC) and serial independence (TMAX and TMIN) required for parametric testing. The most appropriate predictors are chosen based on the correlation analysis over 12 months by examining if they are physically sensible at the local site. Table 3 shows the variables chosen for each site for each model. The complete list of abbreviations translated to variables is available in Appendix A.

Table 3. Predictor Variables for SDSM and ANN, Thunder Bay and Cornwall

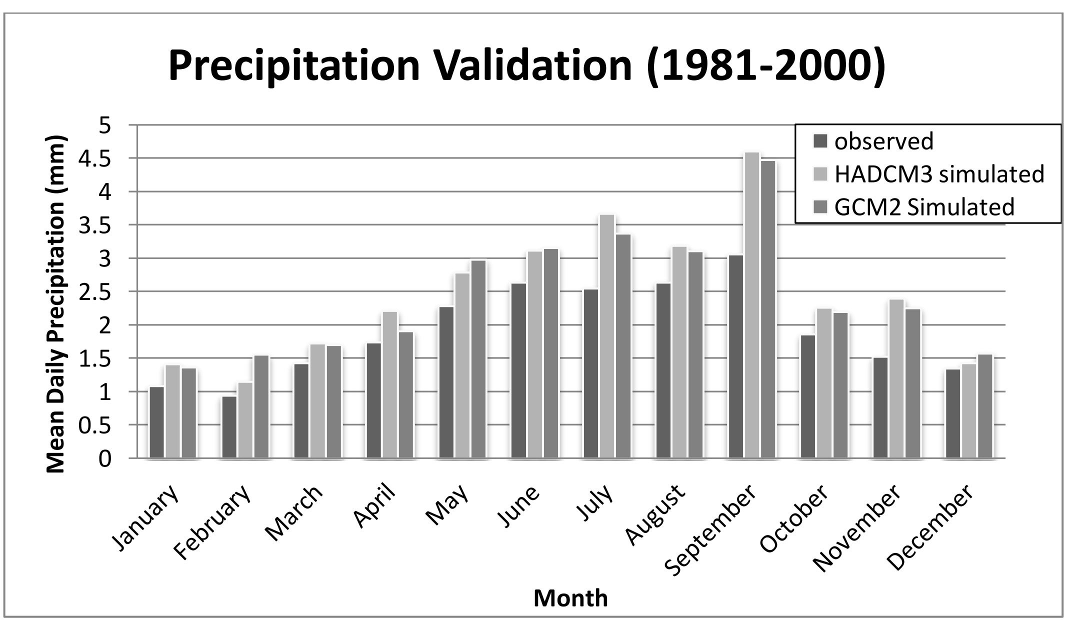
| SDSM | PREC | | TMAX | | TMIN | |
|---|---|---|---|---|---|---|
| | Thunder Bay | Cornwall | Thunder Bay | Cornwall | Thunder Bay | Cornwall |
| CGCM2 | p5zh | mslp | shum | shum | s850 | shum |
| | p8zh | p__v | temp | temp | shum | temp |
| | s500 | p_zh | | | temp | |
| | p5_v | p5_v | | | temp lag-1 | |
| | p8_v | p8zh | | | | |
| | | s500 | | | | |
| HADCM3 | mslp | mslp | p500 | temp | shum | shum |
| | p8_u | p__v | p8_z | | temp | temp |
| | p8_z | p5_v | shum | | | |
| | | p8_v | temp | | | |
| | | r500 | | | | |
| **ANN** | **PREC** | | **TMAX** | | **TMIN** | |
| CGCM2 | p_th | P8_f | shum | mslp | mslp | Mslp |
| | S580 | P8_th | temp | tmep | temo | P5_z |
| | s500 | P_v | P850 | tlag | | P500 |
| | | P_z | | | | Shum |
| | | S500 | | | | Temp |
| | | S580 | | | | tlag |
| | | Tlag | | | | |
| | | rhum | | | | |
| HADCM3 | mslp | P500 | temp | Mslp | mslp | Mslp |
| | P5_th | P_v | mslp | P5_z | temp | P5_f |
| | p8_th | shum | tlag | P5_th | tlag | P_z |
| | tlag | | rhum | P8_th | | P_th |
| | | | | P_th | | Shum |
| | | | | P_z | | Tlag |
| | | | | Rhumna | | temp |
| | | | | temp | | |

#### 4.1.2 SDSM Calibration and Validation Results

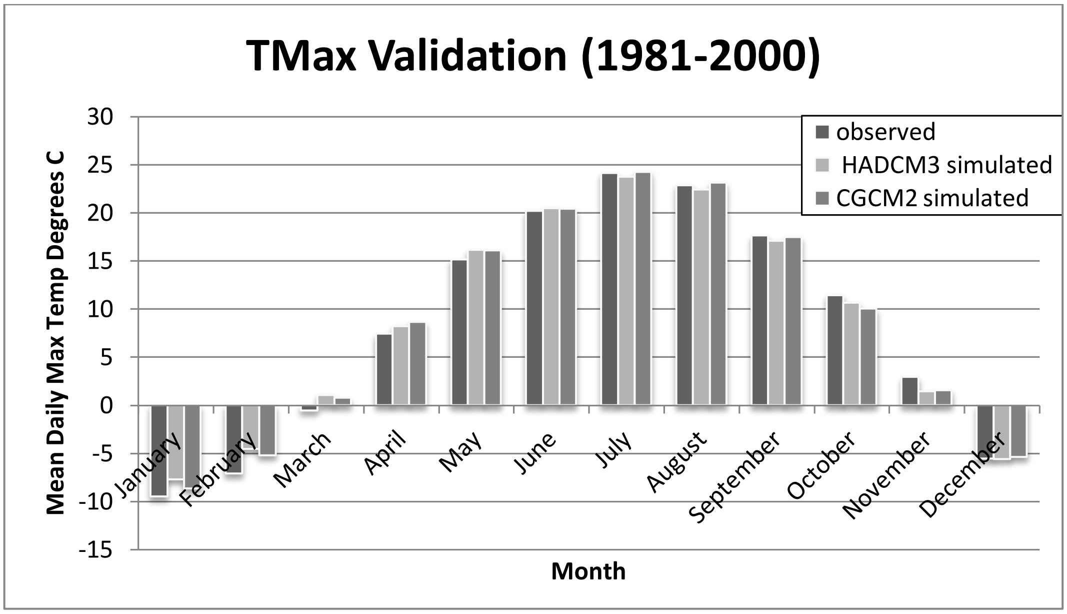
Calibration and validation involves comparing modeled data to actual observed data from the weather stations. As a standard, the first thirty years (1961-1990) of the forty years of current data (1960-2000) are used to calibrate the regression models and the last 20 years (1981-2000) are used to validate those models. For best performance, the modeled data during calibration and validation should have minimal deviation from the real data. For precipitation there is often variance between observed and predicted data due to the variability of daily precipitation. Figure 1 illustrates the validation performance of the downscaling model for the Thunder Bay site using SDSM.

Figure 1. Validation Results for Thunder Bay

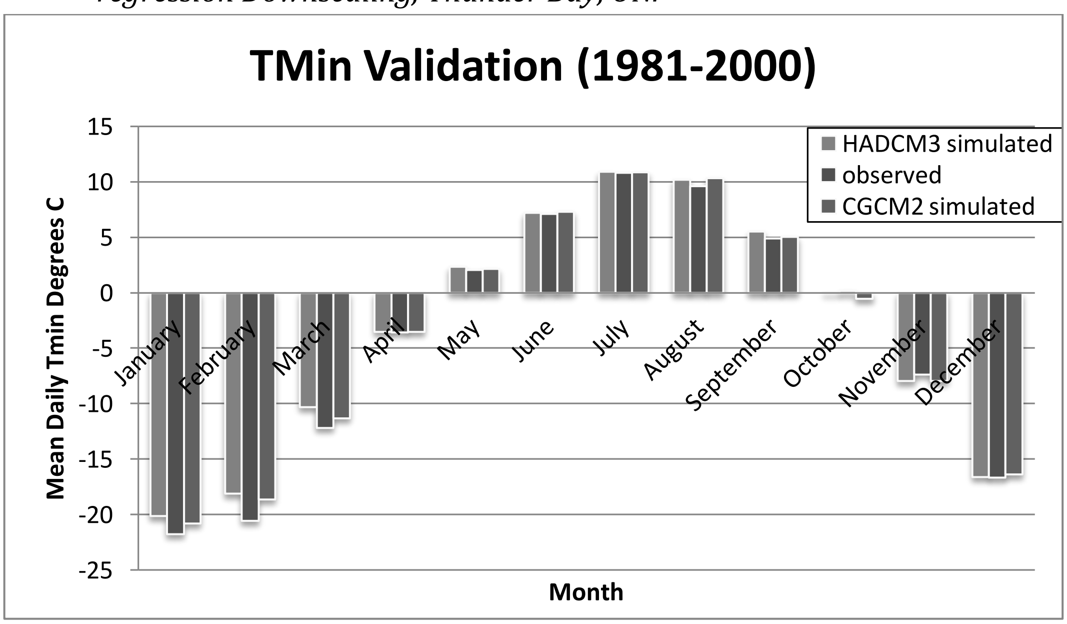
a) *Precipitation CGCM2 and HADCM3 Validation results of SDSM regression Downscaling, Thunder Bay, ON.*



*b) Maximum Temperature CGCM2 and HADCM3 Validation results of SDSM regression Downscaling, Thunder Bay, ON.*



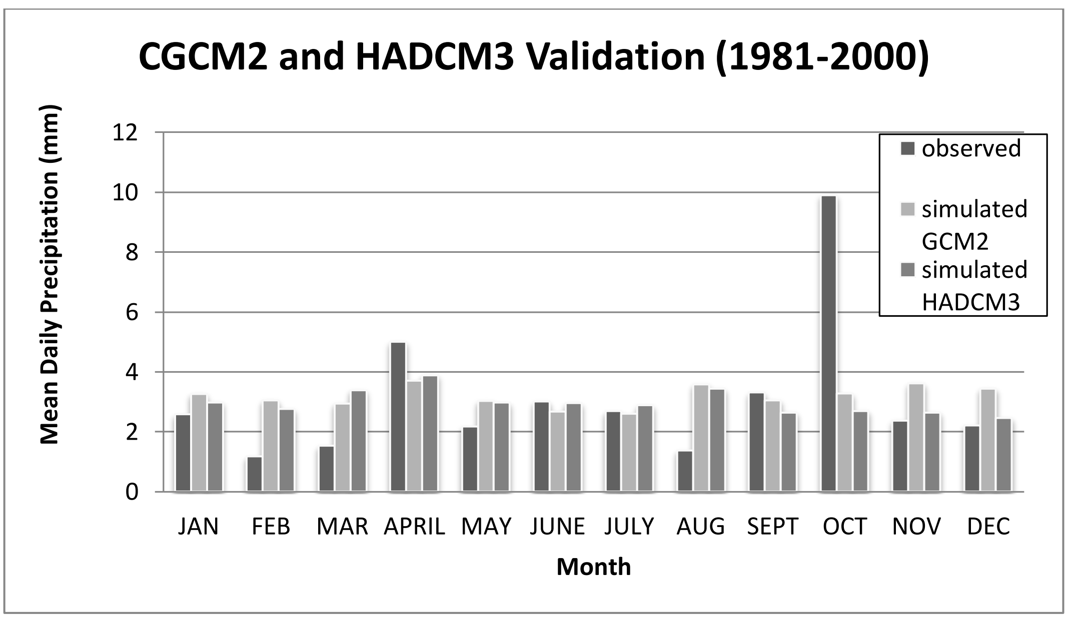

*c) Minimum Temperature CGCM2 and HADCM3 Validation results of SDSM regression Downscaling, Thunder Bay, ON.*



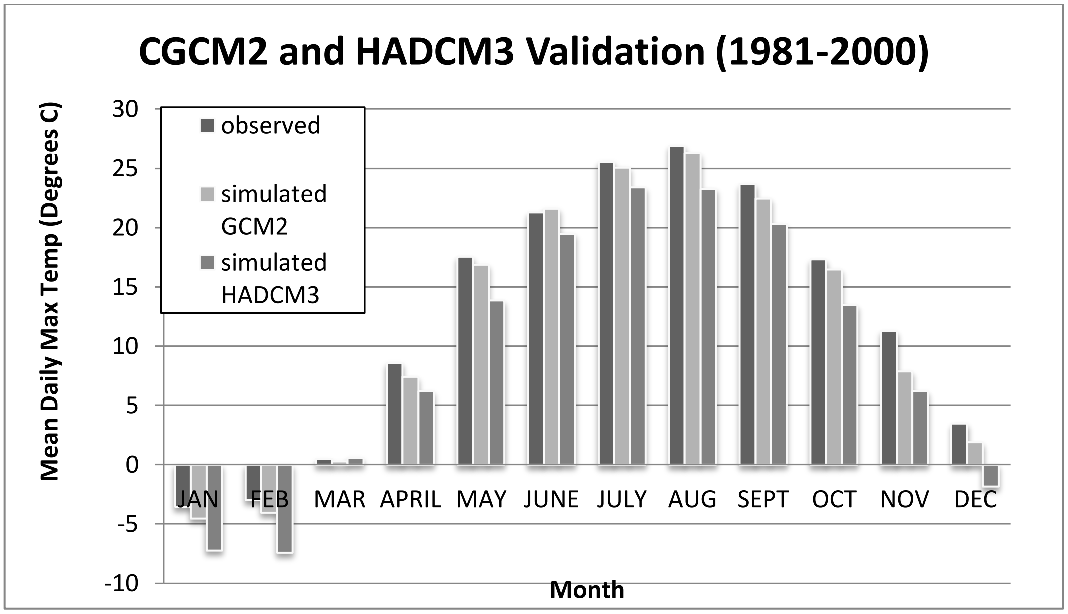
The results show agreement between the observed and simulated data for maximum temperature and minimum temperature and precipitation trends. Cornwall calibration and validation results also showed very low residuals values indicating that simulated and observed data were close and the model performed well during these tests. Figure 2 illustrates validation results for the Cornwall site.

Figure 2. GCM2 and HADCM3 Validation results of SDSM, Cornwall, ON.

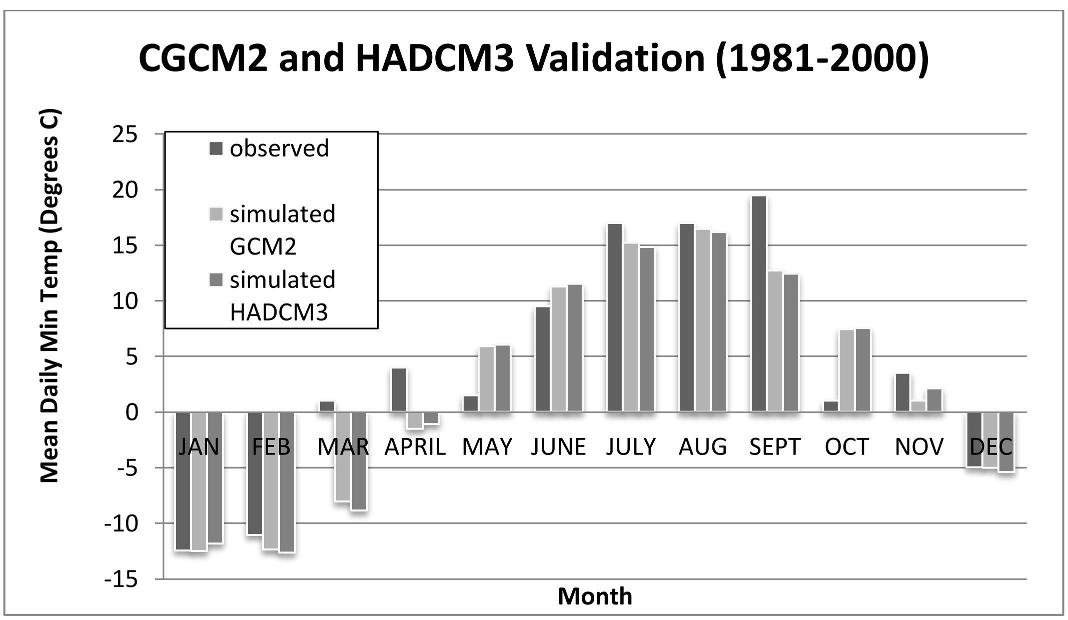
*a) Precipitation*



*b) Maximum Temperature (Tmax)*




*c) Minimum Temperature (Tmin)*



The CGCM2 model had lower error and was better at creating a statistical representation of actual minimum temperature, maximum temperature and precipitation for than the HADCM3 model overall. The graphs show the performance of the models during the validation periods express a good agreement between the observed simulation outputs of the downscaling model. However, it is clear that the simulated downscaled data from CGM2 typically overestimates the values compared to the observed, which is particularly evident for precipitation. The downscaled Hadley output are largely underestimated overall in the monthly averages.

Based on the performance of the calibration and validation, the predictors chosen for each site appear appropriate and future predicted data is examined for each of the four time periods (present, 2020s, 2040s and 2080s) though the downscaling techniques.

#### 4.1.3 ANN Calibration and Validation Results

Calibration was performed using the sensitivity about the mean in the Artificial Neural Network program. The predictors that had the highest sensitivity correlation about the mean were chosen as significant and to be used in the developed model. In most cases, where available, all predictors over 0.5 sensitivity were used in the models generated as variables.

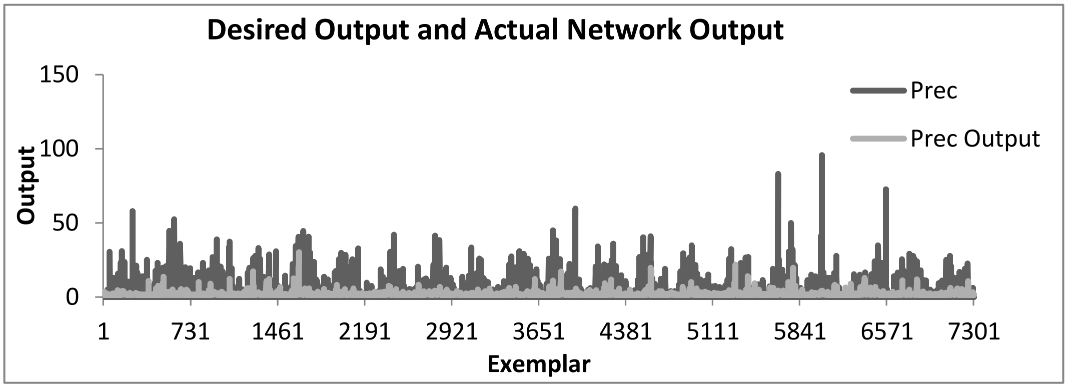
To further evaluate the accuracy of the three different data sets during validation, a residual analysis was performed. Residual analysis is a simplified statistical analysis to show how close two data sets are by using their differences. If the model fit to the data were correct, the residuals would approximate the errors that make the relationship between the explanatory variables and the response variable. Therefore, if the difference appears to behave randomly it suggests that the model fits the data well. Small residual values indicate the modeled data was close to the observed.

The CGCM2 model had slightly lower error and was better at creating a statistical representation of actual minimum temperature, maximum temperature and precipitation than the HADCM3 model. However, precipitation largely was not as well simulated in comparison to maximum and minimum temperature.

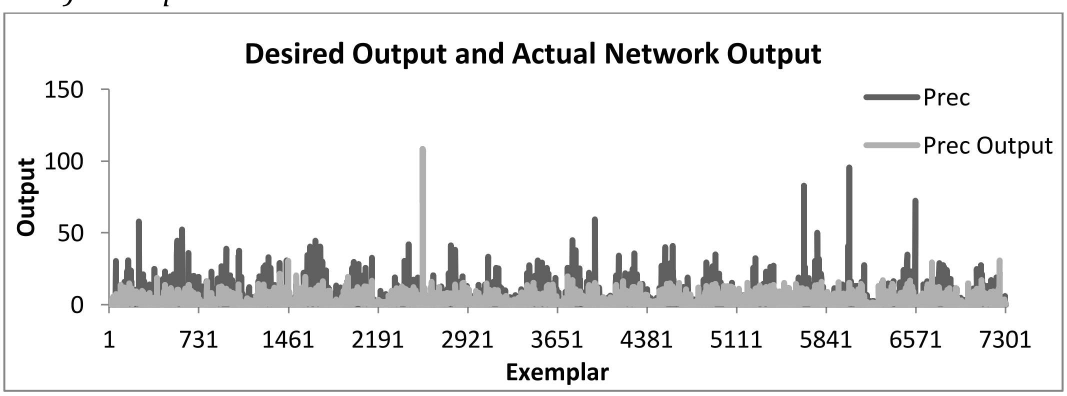
The desired output related to the observed output are closely overlapping and thus illustrate the model was able to simulate observed data. The model was best at predicting maximum temperature and minimum temperature. Validation results for Thunder Bay are shown in (Figure 3). Validation results for Cornwall also showed close relation between observed and simulated values. The two lines of desired and actual output are totally overlapping through most of the simulation.

Figure 3. ANN Validation Results for Thunder Bay

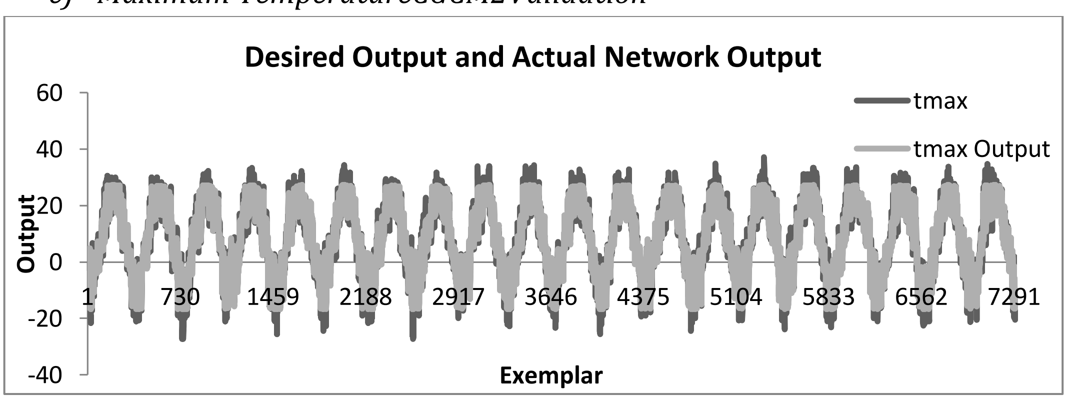
*a) Precipitation GCM2 Validation*



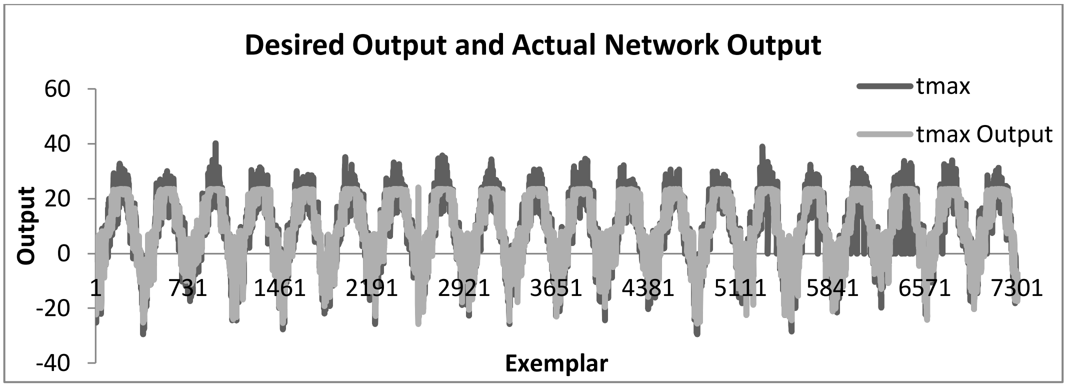

*b) Precipitation HADCM3 Validation*



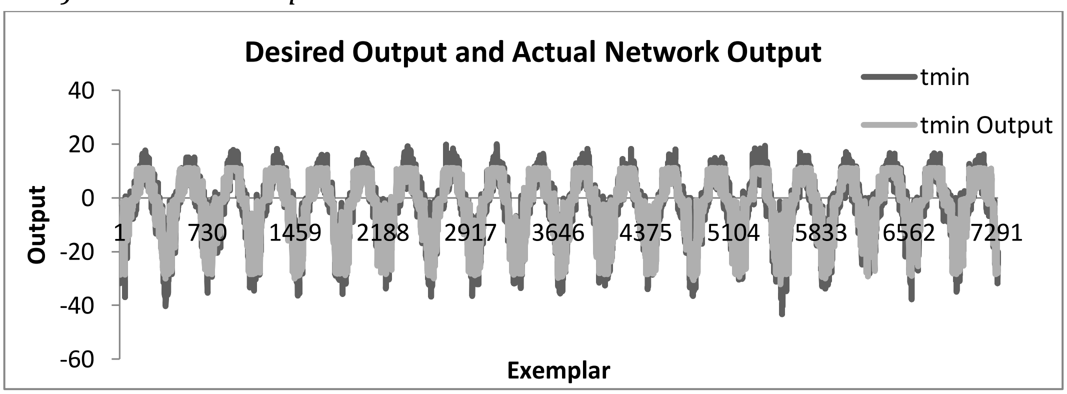

*c) Maximum TemperatureCGCM2Validation*



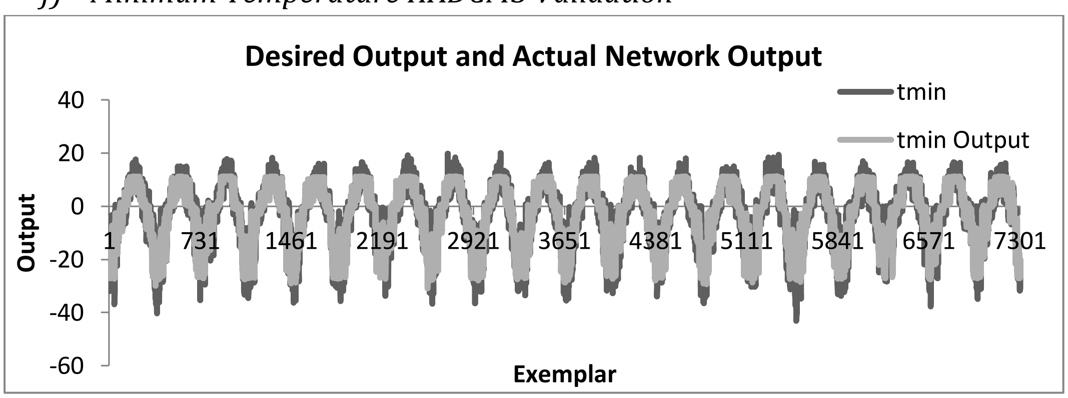
*d) Maximum Temperature HADCM3 Validation*




*e) Minimum Temperature CGCM2 Validation*




*f) Minimum Temperature HADCM3 Validation*



## 4.2 Downscaling Results

### 4.2.1 SDSM Downscaled results for Thunder Bay and Cornwall

Once the downscaling models have been setup and validated, the next step is to use these models to downscale the future climate change scenario simulated by GCM. Since precipitation often has lower validation performance the best possible model is used. Precipitation and temperature downscaling are done for each of the four periods.

There is an increasing trend both in the mean daily precipitation and precipitation variability especially in Spring and Summer and late Fall with a slight decrease during the Summer. The plots also show a consistent increasing trend both in the Tmax and Tmin values for most months of the year (Except for the HADCM3, which could be attributed to predictor variables). Between the current period and the 2080s period, Tmax on average increases with slightly more in Winter and Spring than in either Summer and Autumn. In the same period, average increase in Tmin values is slightly larger increase in Summer and Autumn. Overall, a decreasing variability trend for Winter while the variability in Summer and Autumn remains more or less the same. It is evident that the Hadley model produced more variance in the simulated results.

For Cornwall, the monthly statistics of downscaling results for daily precipitation as well as daily maximum and minimum temperature for the different periods show an increasing trend both in the mean daily precipitation. The plots also show a consistent increasing trend both in the Tmax and Tmin values for most months of the year. Temperature increases are largest in the Spring and Winter, particularly a large increase in temperature during the month of December. Between the current and the 2080s period, there is on average an increase in TMAX with a slightly larger increase in Winter and Spring than in Summer and Autumn. In the same period, there is an average increase in TMIN values with a slightly larger increase in the Summer and Autumn. Overall the variability is decreasing in the Winter while remaining stable in the Summer and Autumn. Again it is evident that the HADCM3 output produced more variance in the simulated results as seen in Appendix A. A summary of Downscaled results for SDSM are shown in Figures 4 and 5.

Figure 4. CGCM Downscaled Results for Thunder Bay

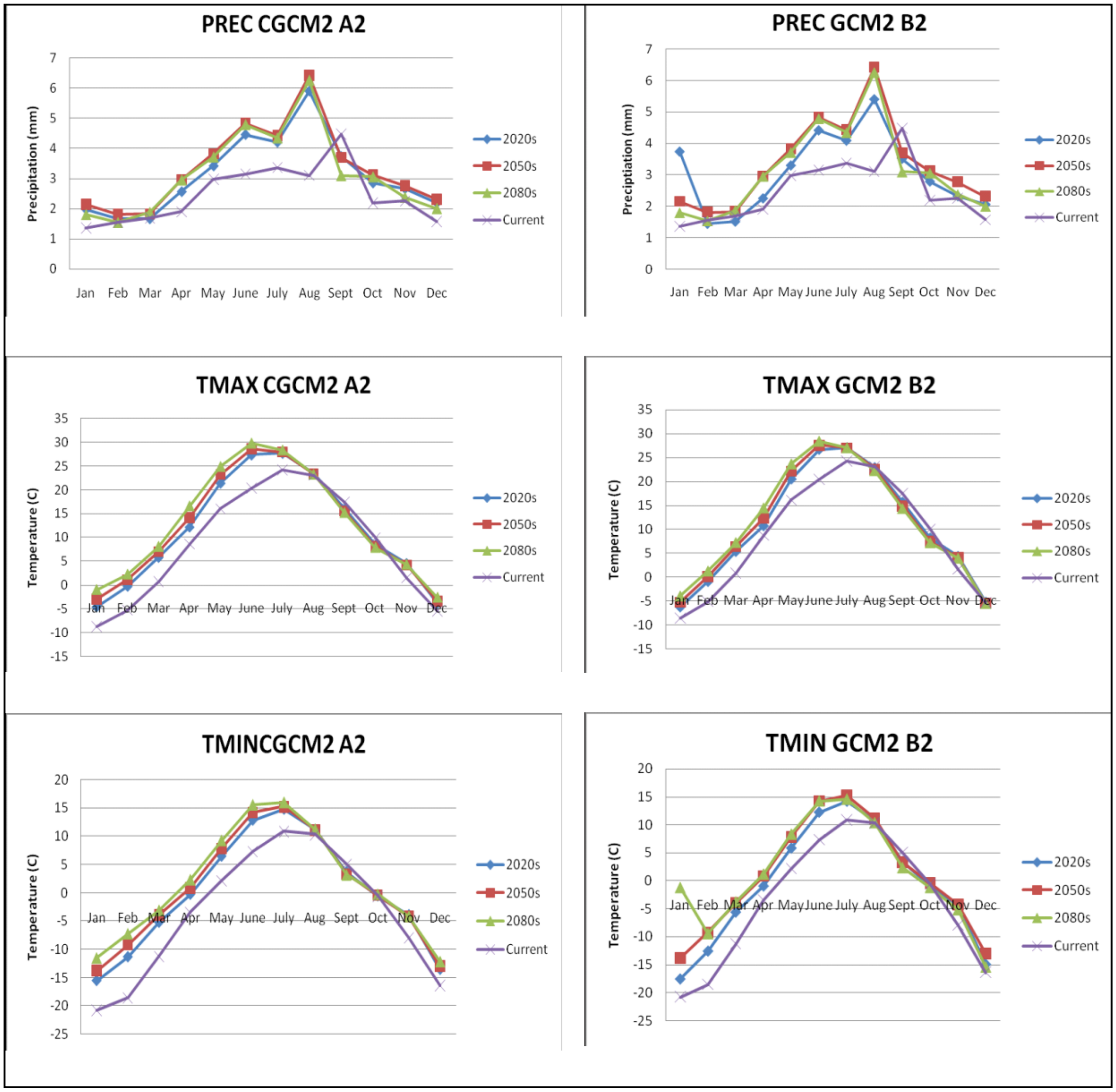
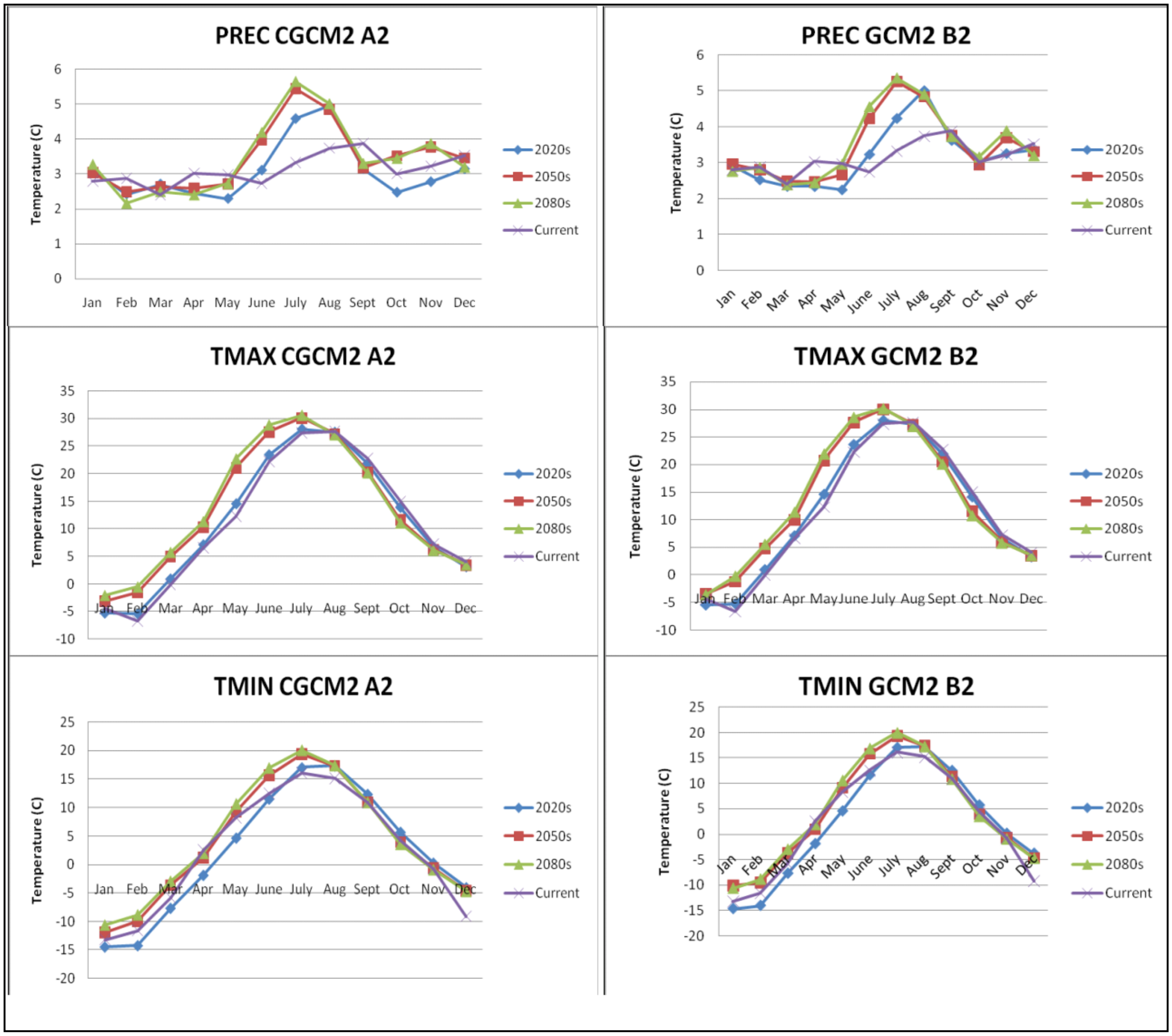


Figure 5. CGCM2 Downscaled Results for Cornwall

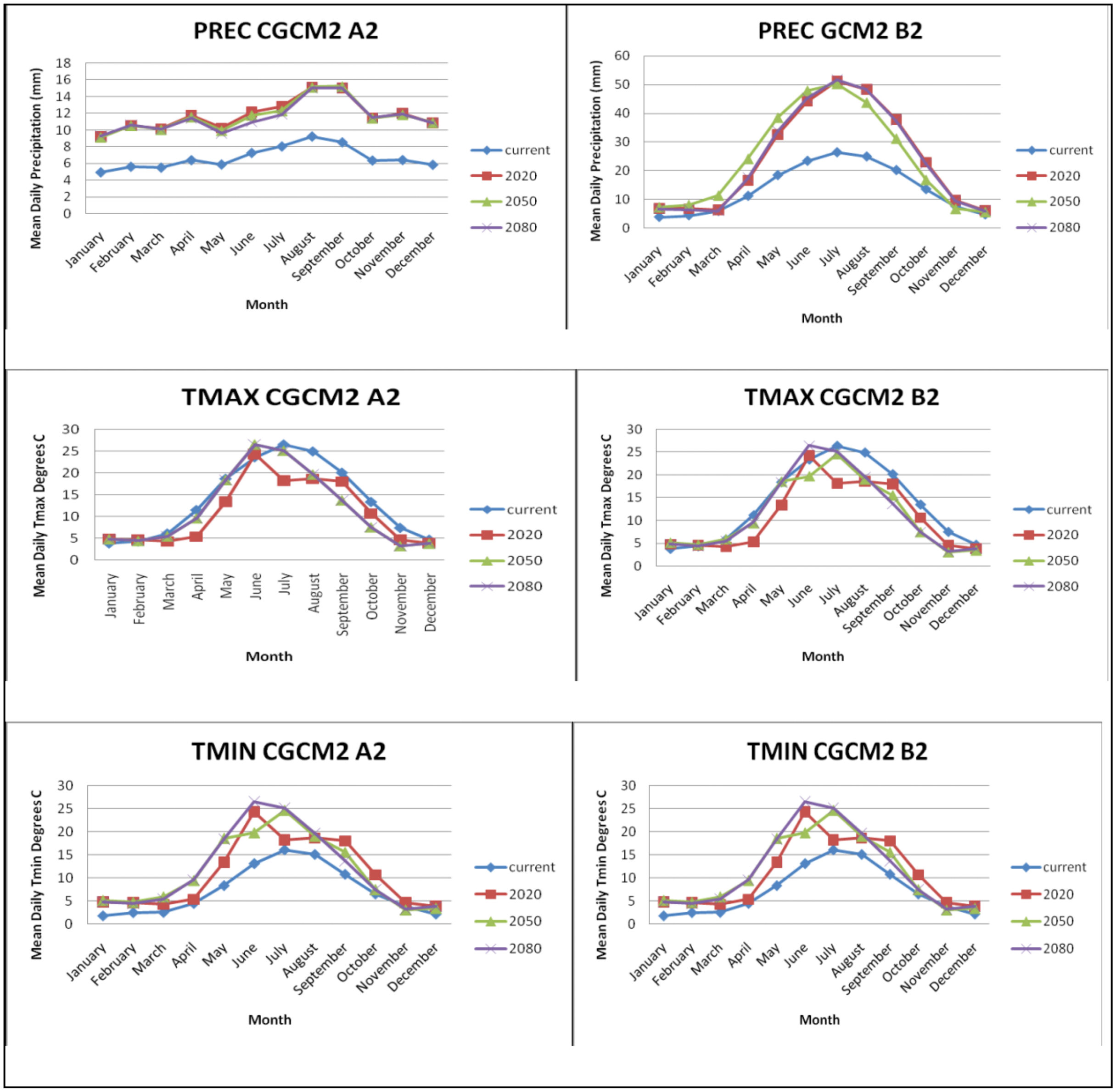



#### 4.2.2 ANN Downscaled results for Thunder Bay and Cornwall

For Thunder Bay, the monthly statistics of downscaling results for daily precipitation show a small increase in precipitation. A larger increase in precipitation is expected in the Spring months. There is also an increase in daily maximum and minimum temperature. High increases in maximum temperature are seen for the Summer period and increasing through the future. Minimum Temperature will increase in the Summer as well as in the Winter months, as expected by regional climate models. Mean daily minimum temperature seems to have high variability especially in Spring and Summer and late Fall. The results show a consistent increasing trend in variability of both Tmax and Tmin values for most months of the year. Between the current and the 2080s, Tmax increases on average are slightly larger in mid-Summer and Autumn. In the same period, there is an average increase in Tmin is slightly larger in Spring and Winter. Overall, the downscaled output indicates a decreasing variability trend for Winter while the variability in Summer and Autumn remains higher. It is evident that the Hadley model produced more variance in the simulated results. This will be discussed in the conclusions.

For Cornwall, the monthly statistics of ANN downscaling results for daily precipitation show a small increase in precipitation in the CGCM2 model. A larger increase in precipitation is seen in the Spring months. Daily maximum and minimum temperature are increasing. Higher increases in maximum temperature are expected for the Summer period and increasing through the future. TMIN will increase both in the Summer as well as in the Winter months. Figure represents expected changes modeled through ANN.

Figure 6. CGCM2 Downscaled Results for Cornwall



# 5.0 Efficiency and Errors

## 5.1 Residuals

The residuals of the validations show that minimum temperature appears to have the most constant trend and smaller peaks indicating smaller variances from observed data; demonstrating that minimum temperature had the best model performance.

## 5.2 Root Mean Squared Error

The mean square error is used to quantify the difference between an estimated value and the true value of the quantity being estimated. It measures the average of the square of the error (the amount the estimated value differs from the real value i.e. the variance). Taking the square root of the mean error yields the root squared error (RMSE) which has the same units as the quantity being estimated for an unbiased estimate. The RMSE is the square root of the variance, and gives the standard error. In this case, Model-2 (ANN) had a higher RMSE value, and therefore a higher standard error. This indicated that this model was slightly less accurate than model 1, as the values were farther away from the observed than they were in model 1.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{m=1}^{n} (X_p - X_o)^2}{n}},$$

where $X_P$ is simulated data, $X_o$ is observed data and $n$ is the number of data.

## 5.3 Relative Error

Relative Error is a simple calculation summing the predicted minus the observed, divided by the mean of the observed. This simply means that we are calculating how far away the difference between the observed and the predicted is from the mean of the true value. If the Relative error is greater than zero, we can assume that the value was over-estimated (higher than the mean). If the Relative Error is lower than zero, we can assume that many of the values were lower than the mean, and thus under-estimated.

## 5.4 Nash Efficiency Index

The Nash–Sutcliffe efficiency index is widely used in the water resources sector to assess the performance of a hydrologic model. Thus it was also used in this project in order to evaluate the selected model's performance. It is a quantitative assessment of the degree to which the modeled behaviour of a system matches with the observations to provide an evaluation of the model's predictive abilities. It is defined as:

$$E = 1 - \frac{\sum_{t=1}^{T} \left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T} \left(Q_o^t - \overline{Q_o}\right)^2}$$

Where $Q_o$ is observed discharge, and $Q_m$ is modeled discharge. $Q_{ot}$ is observed discharge at time t

The closer the values are to 1, the better the model performance is considered. Nash efficiencies can range from -∞ to 1. An efficiency of 1 corresponds to a perfect match of modeled discharge to the observed data. An efficiency of 0 indicated that the model predictions are as accurate as the mean of the observed data. An efficiency of less than zero occurs when the observed mean is a better predictor than the model and residual variance is greater than the data variance. Essentially, the closer E is to 1, the better the model. Table 4 identifies the results of accuracy and model efficiency tests.

Table 4.0 Summary of Tests

| Test | SDSM | ANN |
|---|---|---|
| Precipitation | | |
| RMSE | 4.341409 | 6.4741 |
| NASH | 0.355688 | -12.9861 |
| RE | 2.744208 | 6.269228 |
| Tmin | | |
| RMSE | 14.42265 | 14.20279 |
| NASH | -0.26197 | -12.5617 |
| RE | -4.15833 | -4.40261 |
| Tmax | | |
| RMSE | 3.20325 | 13.58102 |
| NASH | 0.935254 | -12.4654 |
| RE | 0.040827 | -0.47854 |

Based on these analyses, the SDSM model performed relatively better than the Neural Network model.

There are several limitations of statistical downscaling. GCMs cannot provide specific data regarding intense storm events, natural disasters, particularly at the local level. Precipitation in itself, is far more difficult to accurately predict because it is an unconditional process and thus precipitation results will in general be far more uncertain than temperature. Therefore, in climate change impact studies, hydrological models are required in addition to GCM output to estimate hydrologic processes such as streamflow.

First these techniques rely on the ability of the modeller to choose the most significant and relative predictant variables. Also these models have difficulty downscaling precipitation, even in validation it is difficult to fit precipitation data. SDSM is able to consider precipitation as a condition process, but ANN cannot do this and thus the results for precipitation were largely better with SDSM. ANN did perform will in generating a high r value in the validation period, but projected very small changes in the future overall.

## 6.0 Conclusion

The aim of this research was to evaluate the changes in precipitation and temperature using for downscaling daily precipitation and temperature time-series from GCM and Hadley output.

The (1981–2000), the 2020s (2010–2039), the 2050s (2040–2069) and the 2080s (2070–2099) were downscaled using two different procedures of calibrated regression models. A consistent increasing trend was found in both in the Tmax and Tmin values for all months of the year for both Thunder Bay and Cornwall. Between the current and 2080s period, there is on average an increase in with slightly larger increase in Winter and Spring than in Summer and Autumn. In the same period, there is an average increase in Tmin with slightly more increase in Winter and Spring than in Summer and Autumn.

There was a general increasing trend in the variability of Tmax values while the Tmin values show a decreasing variability trend for Winter and Spring while the variability in Summer remains more or less the same. Overall there was an average increase of 2-4°C for temperature in the next 30 years.

Validation of each downscaling procedure indicates that the CGCM2 model is more reliable than HADCM3 validation results. This is likely due to the difference in resolution. CGCM2 output has a resolution of 3.75° latitude x 3.75° longitude while the HadCM3 output has a resolution of 2.50° latitude x 3.75° longitude. With the smaller resolution of HadCM3, one would expect better results, but there may be some error caused by the fact that lake effect is not considered in the models. Also, GCMs lack the ability to simulate extreme events. Natural variability comprises some uncertainty, particularly as was the case with precipitation.

Of the two GHG scenarios, the A2 scenario is the more aggressive scenario based on increased emissions, thus the trends are more pronounced than the B2 scenarios as seen in the graphs of future scenario results. The results obtained for specific catchments are only examples of how the uncertainty in regional modelling and climate change impact study can be assessed. They are in no way an assessment of the quality of any of the modelling techniques.

The difference between the performance of the downscaling models (SDSM and ANN) lies in the selection of the predictants and in the statistical relationships (linear regression and non-linear regression respectively). Given the results, the linear regression seems to be more suitable for downscaling the Great Lakes basin, however, the impact of the chosen predictants must also be considered. Downscaling uncertainty can be significant: statistical methods compensate for modelling errors in the current climate, but the assumptions they are based upon may not remain true in the future. Dynamical models cater for changes in the atmospheric processes producing precipitation, but retaining potential bias in the model.

The significance of the results is that the two Great Lakes Basin sites show different climate change outcomes. This corresponds to different changes in ecosystem impacts throughout the basin. The Great Lakes cannot be treated as a single entity and thus adaptation planning must be specific and based on local change through downscaling local basin sites.

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# Appendix A

| PREDICTORS (Atmospheric Variables) | |
|---|---|
| mslp | Mean Sea Level Pressure |
| p__f | Surface Airflow Strength |
| p__u | Surface Zonal Velocity |
| p__v | Surface Meridional Velocity |
| p__z | Surface Vorticity |
| p_th | Surface Wind Direction |
| p_zh | Surface Divergence |
| p5_f | 500hPa Airflow Strength |
| p5_u | 500hPa Zonal Velocity |
| p5_v | 500hPa Meridional Velocity |
| p5_z | 500hPa Vorticity |
| p500 | 500hPa Geopotential |
| p5th | 500hPa Wind Direction |
| p5zh | 500hPa Divergence |
| p8_f | 850hPa Airflow Strength |
| p8_u | 850hPa Zonal Velocity |
| p8_v | 850hPa Meridional Velocity |
| p8_z | 850hPa Vorticity |
| p850 | 850hPa Geopotential |
| p8th | 850hPa Wind Direction |
| p8zh | 850hPa Divergence |
| rhum or shum | Near Surface Relative or Specific Humidity |
| r500 or s500 | Relative or Specific Humidity at 500hPa |
| r850 or s850 | Relative or Specific Humidity at 850hPa |
| temp | Mean Temperature at 2m |
| tlag (temp lag1) | Mean Temperature at 2m Lagged By One Day |

# CHAPTER FOUR

# Climate Impacts on Beneficial Use Impairments for Areas of Concern

## Abstract

Great Lakes researchers and scientists have been interested in the impacts of climate change in the Great Lakes region for decades. However, how these changes will impact already degraded regions, such as the Areas of Concern as designated by the Great Lakes Water Quality Agreement has been largely ignored. This research undertakes to examine local changes in three Areas of Concern: Thunder Bay area of Concern, Cornwall and Toronto. The research first develops statistical downscaled models to forecast future climate changes at these three locations then examines how specific beneficial use impairments will be impacted in order to highlight sensitivities.

**Key Words:** Climate Change, Downscaling, Areas of Concern, Beneficial Uses

## 1.0 Introduction

In order to identify locational sensitivities to climate change within the Great Lakes, we have highlighted chosen sites from geographic areas in the Great Lakes that were designated as Areas of Concern (AOCs) to model temperature and precipitation forecasts. These areas are described by Annex 2 of the Canada-US Great Lakes Water Quality Agreement (GLWQA) as "a geographic area that fails to meet the general or specific objectives of the Agreement where such failure has caused or is likely to cause impairment of beneficial use or of the area's ability to support aquatic life".

The location of the AOCs (Figure 1) and the associated beneficial use impairments will in part determine sensitivities to climate change impacts. Identifying common lake impairments will allow for targeted adaptation strategies. Many Canadian AOCs are geographically clustered and thus it is reasonable to group them in order to highlight main issues and strategically prioritize interventions that address climate change threats. It is reasonable to assume that already environmentally degraded regions will be more vulnerable to change and become further stressed. We combine knowledge about which impairments are common in certain Lakes as well as the climatic changes predicted for that particular region, to uncover adaptation strategies that minimize further risk, further damage, and improve resilience.

Figure 1: Map of Areas of Concern (Environment Canada, 2008)
(Note that since the production of Figure 1; an additional Canadian Area of Concern has been delisted; Wheatley Harbour).


The specific Areas of Concern used in our research are Thunder Bay, to reflect the geography and climate of the Upper Great Lakes, and the Toronto region and St. Lawrence River at Cornwall, to represent the Lower Great Lakes and river system.

Through identifying sensitivities in specified AOCs, remedial action plans (RAPs) can be developed that include efforts to address climatically stressed beneficial uses. Annex 2 of the GLWQA identifies Impairments of beneficial use(s) to mean a change in the chemical, physical or biological integrity of the Great Lakes System sufficient to cause any of the following: (i) restrictions on fish and wildlife consumption; (ii) tainting of fish and wildlife flavour; (iii) degradation of fish wildlife populations; (iv) fish tumors or other deformities; (v) bird or animal deformities or reproduction problems; (vi) degradation of benthos; (vii) restrictions on dredging activities; (viii) eutrophication or undesirable algae; (ix) restrictions on drinking water consumption, or taste and odour problems; (x) beach closings; degradation of aesthetics; (xii) added costs to agriculture or industry; (xiii) degradation of phytoplankton and zooplankton populations; and (xiv) loss of fish and wildlife habitat.

RAPs are required by Annex 2 of GLWQA to: "classify Areas of Concern by their stage of restoration progressing from the definition of the problems and causes, through the selection of remedial measures, to the implementation of remedial programs, the monitoring of recovery, and, when identified beneficial uses are no longer impaired and the area restored, the removal of its designation as an Area of Concern". While substantial effort has been in place to develop initiatives to restore these degraded areas, 24 years of working towards restoration could be in jeopardy in the face of climate change.

The main purpose of this research is to develop quantitative values of expected change and examine how these changes will affect beneficial uses. An understanding of why different areas will be impacted differently is also presented.

## 2.0 Methods

Future climate scenarios have been derived from Global Climate Model (GCM) outputs using downscaling techniques. Downscaling works by relating the global scale atmospheric predictors to local scale predictands from meteorological weather stations (Wigley et al., 1990; Karl et al., 1990). This study applies statistical downscaling techniques using the Statistical DownScaling Method (SDSM), a multiple linear regression technique, to generate the possible future values of local meteorological variables such as precipitation and temperature for Thunder Bay, and St. Lawrence River at Cornwall and Toronto Areas of Concern. Two different global climate models (GCMs), the Hadley Model (HADCM3) and the Canadian General Circulation Model (CGCM2) were used to provide future precipitation and temperature data for the period 2000- 2100. The GCM uses estimated GHG and aerosol concentrations to initialize to produce future predicted climate scenarios based on the rate of population growth, economic growth, technological development, use of fossil fuels and the establishment of social conservation policies (IPCC, 2000). A range of possible options representing high, medium and low emissions trajectories for future scenario assessment is seen in Table 1 (IPCC, 2001; Mortsch *et al*., 2005). Forecast results were used to relate how climate changes will impact the regional systems and their related beneficial uses.

***Table 1. Special Report on Emission Scenarios (SRES) storylines (IPCC, 2000).***

| Scenario | Variables |
|---|---|
| A1 | • Rapid economic growth<br>• Population peaks in 2050 and then declines<br>• Rapid technological growth<br>• Sub-divided into 3 scenarios based on technology<br>o A1F1 -- fossil fuel intensive<br>o A1T -- non-fossil fuel intensive<br>o A1B -- balance across all sources<br>• High emissions scenario |
| A2 | • Heterogeneous world, with regional diversity<br>• Self-reliance and preservation of local identity<br>• Continuously increasing global population<br>• Per capita economic growth and technological change are regionally fragmented and slower<br>• High-medium emissions scenario |
| B1 | • Population peaks 2050 and then declines<br>• Rapid changes in economic structures toward a service and information economy<br>• Reductions in material intensity<br>• Emphasis is global solutions to economic, social and environmental sustainability<br>• Low emissions scenario |
| B2 | • Continuously increasing global population although lower than A2 scenario<br>• Intermediate levels of economic development<br>• Less rapid and more diverse technological change that in B1 and A2 scenarios<br>• Emphasis on local solutions to economic, social and environmental sustainability<br>• Environmental protection and social equity at local and regional levels<br>• Low-Medium emissions scenario |

For the study sites, forty years (1961–2000) of precipitation and temperature hydro-meteorological data was taken from Environment Canada. For Thunder Bay, daily data was taken from Thunder Bay Airport (station # 6048261). For St. Lawrence data was taken from Cornwall, ON (station # 6101874). Toronto data was taken from Metro Toronto Harbour (station # 6158350).

The (1981–2000), the 2020s (2010–2039), the 2050s (2040–2069) and the 2080s (2070–2099) scenarios were simulated using the calibrated regression models (SDSM and ANN). The averages were compiled for each CGCM2 and HADCM3 for the A2 and B2 Scenarios.

## *3.0 Model Results*

The AOCs temperature and precipitation predicted by this study were similar to those predicted by Trumpickas et al. (2009). It is evident that larger average temperature changes (increases from normal) are expected with increasing latitude. Due to the fact that Lake Superior is the most northerly lake and expected to experience the most climatic change, it is understandable that values predicted for Thunder Bay (upper north region of Superior) have even higher changes than the overall average change over the entire Lake Superior average change. Not surprisingly, Thunder Bay exhibits the highest change of the three AOCs studied, as expected since Lake Superior also experiences the highest change from norm of the Great Lakes (Table 2).

Table 2. AOC GCM2 SDSM Forecasted Average Change from Present

| | | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Average Change |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thunder Bay | PREC | 2020s | 1.50 | 0.01 | 0.11 | 0.51 | 0.38 | 1.29 | 0.78 | 2.55 | 0.85 | 0.63 | 0.24 | 0.56 | 0.8 |
| | | 2050s | 0.79 | 0.26 | 0.13 | 1.06 | 0.84 | 1.68 | 1.06 | 3.31 | 0.78 | 0.93 | 0.52 | 0.74 | 1.0 |
| | | 2080s | 0.44 | 0.01 | 0.18 | 1.05 | 0.74 | 1.64 | 0.98 | 3.15 | 1.38 | 0.87 | 0.13 | 0.43 | 0.9 |
| | TMAX | 2020s | 3.25 | 4.60 | 4.80 | 2.78 | 4.86 | 6.60 | 3.11 | 0.03 | 1.63 | 1.68 | 2.90 | 0.86 | 3.1 |
| | | 2050s | 12.74 | 4.54 | 5.94 | 4.56 | 6.63 | 7.71 | 3.24 | 0.22 | 2.26 | 2.19 | 2.61 | 9.79 | 5.2 |
| | | 2080s | 11.14 | 3.44 | 6.89 | 6.87 | 8.22 | 8.74 | 3.46 | 0.36 | 2.72 | 2.50 | 2.55 | 9.44 | 5.5 |
| | TMIN | 2020s | 4.23 | 6.63 | 5.86 | 2.87 | 3.98 | 5.20 | 3.60 | 0.62 | 1.47 | 0.22 | 3.77 | 2.11 | 3.4 |
| | | 2050s | 6.99 | 9.41 | 7.36 | 4.34 | 5.68 | 6.88 | 4.37 | 0.79 | 1.71 | 0.13 | 3.71 | 3.37 | 4.6 |
| | | 2080s | 14.48 | 10.31 | 7.89 | 5.28 | 6.64 | 7.57 | 4.40 | 0.48 | 2.27 | 0.15 | 3.31 | 2.63 | 5.5 |
| Cornwall | PREC | 2020s | 0.23 | 0.41 | 0.12 | 0.63 | 0.71 | 0.43 | 1.09 | 1.24 | 0.50 | 0.27 | 0.20 | 0.28 | 0.5 |
| | | 2050s | 0.20 | 0.23 | 0.16 | 0.50 | 0.29 | 1.37 | 2.03 | 1.10 | 0.41 | 0.22 | 0.51 | 0.15 | 0.6 |
| | | 2080s | 0.22 | 0.37 | 0.04 | 0.61 | 0.14 | 1.64 | 2.18 | 1.22 | 0.37 | 0.30 | 0.66 | 0.34 | 0.7 |
| | TMAX | 2020s | 0.94 | 1.32 | 1.00 | 0.52 | 2.24 | 1.26 | 0.62 | 0.27 | 0.94 | 1.04 | 0.59 | 0.89 | 1.0 |
| | | 2050s | 1.18 | 5.28 | 4.97 | 3.63 | 8.59 | 5.33 | 2.69 | 0.45 | 2.38 | 3.44 | 1.13 | 0.61 | 3.3 |
| | | 2080s | 1.61 | 6.28 | 5.72 | 4.77 | 9.99 | 6.45 | 2.97 | 0.69 | 2.71 | 4.11 | 1.33 | 0.57 | 3.9 |
| | TMIN | 2020s | 1.35 | 2.57 | 1.92 | 4.42 | 3.65 | 0.90 | 0.92 | 2.11 | 1.52 | 1.37 | 0.93 | 5.24 | 2.2 |
| | | 2050s | 2.17 | 1.83 | 2.13 | 1.47 | 0.93 | 3.25 | 3.27 | 2.17 | 0.25 | 0.40 | 0.06 | 4.49 | 1.9 |
| | | 2080s | 2.56 | 2.69 | 2.79 | 0.61 | 2.33 | 4.40 | 3.89 | 2.14 | 0.03 | 0.83 | 0.22 | 4.41 | 2.2 |
| Toronto | PREC | 2020s | 6.99 | 9.41 | 7.36 | 4.34 | 5.68 | 6.88 | 4.37 | 0.79 | 1.71 | 0.13 | 3.71 | 3.37 | 4.6 |
| | | 2050s | 14.48 | 10.31 | 7.89 | 5.28 | 6.64 | 7.57 | 4.40 | 0.48 | 2.27 | 0.15 | 3.31 | 2.63 | 5.5 |
| | | 2080s | 0.23 | 0.41 | 0.12 | 0.63 | 0.71 | 0.43 | 1.09 | 1.24 | 0.50 | 0.27 | 0.20 | 0.28 | 0.5 |
| | TMAX | 2020s | 0.20 | 0.23 | 0.16 | 0.50 | 0.29 | 1.37 | 2.03 | 1.10 | 0.41 | 0.22 | 0.51 | 0.15 | 0.6 |
| | | 2050s | 0.22 | 0.37 | 0.04 | 0.61 | 0.14 | 1.64 | 2.18 | 1.22 | 0.37 | 0.30 | 0.66 | 0.34 | 0.7 |
| | | 2080s | 0.94 | 1.32 | 1.00 | 0.52 | 2.24 | 1.26 | 0.62 | 0.27 | 0.94 | 1.04 | 0.59 | 0.89 | 1.0 |
| | TMIN | 2020s | 1.18 | 5.28 | 4.97 | 3.63 | 8.59 | 5.33 | 2.69 | 0.45 | 2.38 | 3.44 | 1.13 | 0.61 | 3.3 |
| | | 2050s | 1.61 | 6.28 | 5.72 | 4.77 | 9.99 | 6.45 | 2.97 | 0.69 | 2.71 | 4.11 | 1.33 | 0.57 | 3.9 |
| | | 2080s | 1.35 | 2.57 | 1.92 | 4.42 | 3.65 | 0.90 | 0.92 | 2.11 | 1.52 | 1.37 | 0.93 | 5.24 | 2.2 |

There is a consistent increasing trend both in the maximum temperature (Tmax) and minimum temperature (Tmin) values for all months of the year for all three AOC sites. Between the current period and the 2080s period, there is an increase in Tmax with slightly larger increase in Winter and Spring than in Summer and Autumn in all cases. In the same period, there is an average increase in Tmin with slightly more increase in Winter and Spring than in Summer and Autumn. There is a general increasing trend in the variability of Tmax values while the Tmin values show a decreasing variability trend for Winter and Spring while the variability in Summer remains more or less the same. The precipitation data is more difficult to predict as it does not easily fit to a statistical model. As such, the confidence in precipitation results is not as high as it is with temperature.

There are however, some errors in the data. The coarse spatial resolution of the predicted data produced by GCMs (i.e. 3.75ºx 3.75º for Canadian GCM2) and HadCM2 (resolution of 2.50° latitude x 3.75° longitude), simply does not account for regional heterogeneity that may affect regional climate (i.e. lake effects, and convective atmospheric processes) (Wilby et al., 1999; Murphy, 1999; Mearns, 2003). The Great Lakes play an important role in the climatology of the surrounding areas due to energy fluxes between the lakes and the atmosphere. Also, GCMs lack the ability to simulate extreme precipitation events because these events are usually dependent on regional processes. Thus, GCMs should only be used as a starting point for research at a local or regional scale (Wilby et al., 2000).

With this empirical evidence that climate change is occurring in the Great Lakes region, specifically at the AOCs it is useful to examine the beneficial use impairments at these sites and how the forecasted changes will have an impact.

## *4.0 Beneficial Use Impairments under Climate Change*

Although management interventions have aided in restoring some beneficial uses as well as delisting AOCs, it is important to understand what impacts the ongoing climatic changes will have on beneficial use impairments. Table 3 describes the beneficial use impairments in each of the AOCs studied.

Table 3. Beneficial Use Sensitivities by location (Impairments Labeled by Letter as seen in Legend)

| AOC | Beneficial Use Impairments |
|---|---|
| Thunder Bay | A,B,C,D,F,G,J,K,M,N |
| St. Lawrence River | A,C,F,G,I,J,N |
| Toronto | A,C,F,G,H,J,K,N |

| | Beneficial Uses | | |
|---|---|---|---|
| A | Restrictions on Fish and Wildlife Consumption | G | Restrictions on Dredging Activities |
| B | Tainting of Fish and Wildlife Flavour | J | Beach Closings |
| C | Degraded Fish and Wildlife Populations | K | Degradation of Aesthetics |
| D | Fish Tumors or Other Deformities | L | Added Costs to Agriculture or Industry |
| E | Bird or Animal Deformities or Reproductive Problems | M | Degradation of Phytoplankton and Zooplankton Populations |
| F | Degradation of Benthos | N | Loss of Fish and Wildlife Habitat |

Delisted beneficial use impairments were not included in the above table. Furthermore, two beneficial uses impairments' that were considered not directly affected by climate change are fish tumours or other deformities and bird or animal deformities or reproduction problems (IJC, 1991). Beneficial use improvements as well as delisted AOCs could be compromised by the changing climate. Understanding how these impairments will continue to be affected by a changing climate is important in identifying sensitivities and adaptation responses. For brevity, only common impairments among the AOCs were presented in this paper.

**4.1 Restrictions on Fish and Wildlife Consumption**

- Many RAP practitioners have adopted a delisting criteria that contaminant levels in fish and wildlife populations will not exceed current standards, objectives or guidelines, and that there are no public health advisories due to local sources (IJC, 1991).

Climate change projections predict a corresponding change in the type and quantity of fish available. Climate change will alter growth rates, mortality rates, reproductive capacity and distribution of fish which may cause a shift in contaminant uptake leading to greater restriction on fish consumption (Brander, 2006).

Restrictions on fish consumption are usually based on levels of polychlorinated biphenyls (PCBs) or mercury which approach or exceed the Ontario Guide to Eating Sportfish (Ontario Ministry of the Environment, 2011) guidelines.

A study by Bruhn and McLachlan (2002) explored the impact of seasonal fluctuations in forcing factors such as atmospheric concentration, temperature, and biological productivity on the concentration of PCBs in surface water. A clear seasonal variability in dissolved PCB concentrations was observed with higher levels in Summer than in Winter and Spring. This was attributed to changes in atmospheric concentrations and water temperature showing the PCB levels in the atmosphere and surface water to be close to a partitioning equilibrium. A seasonal pattern was observed which was consistent with kinetic limitations on partitioning into particles caused by plankton growth. This suggests that PCB concentrations will increase with warming temperatures and may increase fish contamination (Bruhn and McLachlan, 2002).

Excessive levels of dioxin and chlordane also result in fish consumption advisories. Given the projected trend in warming of the waters of the region, and increased incidences of anoxia, it is realistic to project enhanced mercury methylation would increase bioavailability and hence, incidences of consumption advisories based on mercury. In freshwater aquatic ecosystems, warm, shallow, organic-rich lake sediments are often important zones of net methylation. These warm shallow regions are expected to expand with the increasing temperatures and erratic precipitation events expected with climate change. Flooding, another anticipated event with extreme weather events caused by climate change, also increases the production of MeHg due to increased rates of decomposition of terrestrial organic matter, which stimulates development of poor oxygen conditions and activity of Hg-methylating bacteria. Soil drying and rewetting cycles also strongly affect Hg methylation. Changes in water levels in lakes and wetlands can significantly affect MeHg levels in fish.

#### 4.2 Degraded Fish and Wildlife Populations

- While delisting targets for fish and wildlife populations are complex and very diverse across AOCs, in general, fish and wildlife will be considered impaired "when fish and wildlife management programs have identified degraded fish or wildlife populations due to a cause within the watershed" (IJC, 1991). In addition, some AOCs use fish or wildlife bioassays with appropriate quality assurance controls to confirm presence or absence of toxicity from the water column or sediment.

Climate change effects on fish and wildlife populations are expected to be abrupt giving little time for natural adaptation and will significantly depend on species and genetic diversity (Cherry, 1998). Although Great Lakes are expected to stay cold, nearshore and wetland regions will experience more dramatic temperatures increases and exceed fish and wildlife tolerance limits. Water temperature increases in epilimnetic habitats would alter yearling growth and prey consumption. This extent of this change would be dependent on the species optimal thermal state (Hill and Magnuson, 1990). For example, reptile populations could increase with warming temperature, resulting in large increases in reptilians farther north than currently (Currie, 2001). In Canada, with the migration northward of new species, there could be increase mixing of subspecies due to decreased populations size, which could lead to a decrease in biodiversity (Kerr et al., 1997: 268). Similarly, populations of plants and animals may experience the effect of climate change directly through shifts in their growth rates and indirectly through interaction with other species (Fleming et al., 1997).

Some nearshore, wetland inhabitants and cold water fish species, such as trout and salmon, are expected to decline with rising temperatures. A predicted warming of 2.5ºC over the next 70 years would decrease the habitat of brook, rainbow, cutthroat and brown trout by one-fourth, possibly even down to one-third (Dempsey et al., 2008). There would also be a shift away from cold-water fisheries such as walleye and trout, and even some warm-water species such as smallmouth bass (Sousounis and Glick, 2007). Large-mouth bass, striped bass, and Chinook salmon (Brandt et al., 2002) and carp that can tolerate warmer temperatures and as such may expand and increase in number (Poff et al., 2002). Warmer water temperatures would lead to an increase in warmer water species and other aquatic life that is tolerant to warmer temperatures. Fish that migrate to seek an optimum temperature zone and feeding can face severe pre-spawning mortality, even with small temperature increases (Hofmann et al., 1998). Most species may experience a time lag before their transition into the new habitat resulting in what may appear as a short term range diminishment (Peters, 1990).

Increases in water temperature by 2-4°C can also cause decreased growth and reproductive success of some types of fish, as seen in female rainbow trout in California (Van Winkle et al., 1997). Cherry (1998) found that some species will experience extreme shifts in range boundaries and as such will lose some their genetic variation. Some smaller, localized species may undergo severe population reductions or even extinction. A species' ability to respond to climatic changes is dependent on the timing and magnitude of warming, as well as their own genetic capacity to withstand seasonal changes (Chen *et al.*, 1996). Species populations with greater genetic variability will be more adapted to inhabit a wider range of environmental conditions relative to species with lower genetic variability (Hogg *et al.*, 1998). These changes in population dynamics will ultimately affect the ecosystem dynamics including the food web, and habitat causing increased stress to population based impairments in existing and new regions.

Lowered water levels and increased water temperatures will also impact the physical health of a species. Lower water levels lead to poorer conditions for wildlife diversity (Mortsch, 1998). For example, drought and lower water levels may result in increased ultraviolet radiation damage to frogs and other aquatic organisms, especially in clear, shallow water bodies (Kling et al., 2003).

Sharp increases in temperature and changes in the timing and severity of flood pulses are likely to reduce safe breeding sites, especially for amphibians, migratory shorebirds, and waterfowl, and may cause some northern migratory species such as Canada geese to Winter further north. Based on the sensitivity of the species and their ability to adapt to climatic changes, some species may become sparse, or migrate out of Canada.

Severe storm events will also have an impact on fish and wildlife populations. Runoff including sewage, stormwater runoff, wind-blown dust, roof runoff, and road surface materials will increase under climate change projections bringing contaminants into the lake that may be harmful to fish and wildlife.

Though few, there are some positive results from climatic changes (increased temperature and precipitation) including faster growth and maturation rates for fish, less Winter mortality due to less severe cold or anoxia, and expanded habitats with increased ice retreat. This could offset some negative factors such as increased Summer anoxia, heightened demands for food due to faster metabolisms, negative changes in lake thermal structure, and decreased habitats for cold-water species (Regier et al., 1996). There could be an overall increase in fish production, however, there would be a change in community composition as a result of thermal tolerance.

These changes could affect local ecosystems causing different species to compete for resources or habitats or disrupt predator-prey relationships. These changes could threaten fish and wildlife populations causing further stress in areas where this beneficial use is already impaired or become impaired in new regions.

#### 4.3 Degradation of Benthos

- When the benthic macro-invertebrate community structure significantly diverges from reference sites of comparable physical and chemical characteristics this beneficial use is classified as impaired. In addition, when toxicity (as defined by relevant, field-validated, bioassays with appropriate quality assurance/quality controls) of sediment associated contaminants at a site is significantly higher than controls the impairment can be confirmed (IJC, 1991).

Water quality changes caused by climate change affect benthos, with shallow water fauna more sensitive to water quality than those in deep water (Kilgour et al., 2000). Since an increase in air temperature enhances water column mixing, re-suspension of bottom sediment could disrupt benthic communities (Atkinson et al., 1999).

Rising surface temperatures may amplify the negative consequences of eutrophication, as well as hypoxia (Kennedy, 1990) and their subsequent pressures on benthic communities. Many species of chironomids and tubificid oligochaetes are tolerant to low dissolved oxygen, such that these become the dominant in lakes with hypoxic hypolimnia. In cases of prolonged anoxia, the common variety of benthic organisms might disappear entirely (Mackie, 2004). Increasing contamination and toxicity of sediment caused by increasing runoff will affect sensitive benthic organisms such as Hyallela and Diasporea (Mackie, 2004).

#### 4.4 Restrictions on Dredging Activities

- Impairment occurs when contaminants in sediment in navigational channels exceed standards, criteria, or guidelines such that there are restrictions on dredging or disposal activities and added costs for environmental dredging and containment (IJC, 1991).

With increased runoff caused by more intense storm events, it is expected that more contaminants will enter the sediment eventually resulting in restrictions on dredging activities. Further, decreasing water levels could result in an increase in the need for navigational dredging.

#### 4.5 Beach Closings

- When waters, which are commonly used for total-body contact or partial-body contact recreation, exceed standards, objectives, or guidelines, beneficial use of swimming is impaired (IJC, 1991).

The intensity of precipitation that is expected with climate change will have an impact on beach closings. Severe storm events will result in sewage overflows which will contribute to increased bacteria in surface waters posing as a health risk to swimmers. Furthermore, pollution problems may also be exacerbated on some beaches with low water levels, resulting in more beach closures (Gabriel et al., 1993). Severe storms may also cause erosion and make some near-land regions unusable. Lower lake levels will impact beaches, with the amount of new exposure being a function of water depth, lakebed composition and slope, and water level decline (Wall, 1998). Larger beach surfaces could increase recreation space, however, lower projected water levels may be below those desired by recreational users. Furthermore, exposed mud flats could reduce shoreline aesthetics, and there is the potential that exposed lakebeds could include toxic sediment (Mortsch, 2000). Changes in the timing and duration, height and elevation of annual and seasonal water levels may also lead to beach closings due to high tides or flooding that would cause swimming to be hazardous.

Clearly, with a changing climate, intense rain events, declining water levels and severe storms will cause beach closures hugely impacting the recreational use of the Great Lakes.

#### 4.6 Loss of Fish and Wildlife Habitat

- When fish and wildlife management goals have not been met as a result of loss of fish and wildlife habitat due to a perturbation in the physical, chemical, or biological integrity in the AOC, this beneficial use is considered impaired (IJC, 1991).

The warmer temperatures predicted for the next decades would increase the rate of evaporation. Lower lake levels declines could cause wetland areas to disappear or appear in new places. Decreased water levels negatively impact the shoreline wetlands surrounding the Great Lakes, resulting in loss of diversity and areal extent (Mortsch, 1998) which could impact important spawning and nursery sites for fish (Edsall et al., 1997). Changes in the population and species can also impact and accelerate changes in vegetation (Hobbs, 1996). Increases in temperature, and changes in precipitation can have an impact on vegetation biodiversity of wetlands (Thompson et al., 1998). Elevated $CO_2$ levels, increased temperatures, increased drought severity and frequency as a result of climate change are three driving factors which affect plant physiological processes.

Climate sensitivities such as changes in timing, duration, height and elevation of annual and seasonal water levels can alter the natural succession of plants (Wilcox et al., 1995, Mortch 1998, Bedford, 1992). Phenology, the study of periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate, predicts shortened growing seasons due delayed bud burst in the Spring and earlier buds in the Fall sounds backwards.  Earlier Springs and later Winters, means longer growing seasons. It is also expected that there will be increased growth rates, increased root growth and greater allocation to stemwood volume (Great Lakes Water Quality Board, 2003). This influences the availability of habitat and as a consequence, the species, diversity and number of wildlife a wetland can support (Mortsch, 1998).

Changes in temperature can also bring with it disturbance hazards such as forest fires and insect outbreaks. Increased temperatures may be favourable to breeding and migration of some insects as well as increased disease. Under climate change, intense spruce budworm outbreak could reduce the renewal capacity of host tree populations and cause local extinctions in the Canadian boreal forest (Fleming et al., 1997). Forest fires caused by extreme heat and dryness could also wipe out forest and destroy wildlife habitat. For AOCs concerned with interior forest wildlife, this is a consideration regarding remedial and preventative measures.

Increased temperature can cause droughts. In the case of drought, photosynthesis and photorespiration is reduced during and for a period following drought relief. The plants are also more susceptible to other stresses such as acid precipitation, ozone, insects and disease (Great Lakes Water Quality Board, 2003) during this time. If the period of drought is prolonged over time connecting channels may dry up, and some rivers may lose their fish populations due to the disappearing habitat and corresponding migratory pathways. Temperature changes are also expected to change the timing and duration of ice break up. Changes in ice break-up intensity can alter channel morphology, affecting riparian vegetation (Prowse et al., 2002).

Clearly, Great Lakes water levels in the lakes, rivers, and wetlands could lower significantly, altering the landscape in the region and diminishing healthy wildlife habitats. These changes could markedly reduce viable habitat for wildlife and fish and they be forced to retreat to new regions or risk death.

#### 4.7 Eutrophication or Undesirable Algae

- When there are persistent water quality problems (*e.g.* dissolved oxygen depletion of bottom waters, nuisance algal blooms or accumulation, decreased water clarity, attributed to cultural eutrophication beneficial use of the Great Lakes is considered impaired (IJC, 1991).

Warmer water enhances productivity, particularly in the growth of undesirable species such as blue-green blooms (Poff et al., 2002). As noted previously, extreme precipitation can result in sewage overflows and bypasses, increasing nutrient loads and therefore, eutrophication.

It is clear that climate change will influence and affect our ability to maintain the beneficial uses of the Great Lakes and prevent further impairment. In order to protect the Great Lakes from this threat, sensitivities must be highlighted.

Degradation of benthos, restrictions on dredging activities, and loss of fish and wildlife habitat and Restrictions on fish and wildlife consumption are most common impairments throughout the Canadian AOCs. Fish tumours and bird or animal deformities or reproduction programs and not considered to be directly impacted by climate change. These types of abnormalities are largely caused by chemical contamination. There is almost overwhelming epidemiological evidence, that some of the cases of cancers reported in Great Lakes fishes are caused by carcinogenic chemicals (Baumann et al. 1990). Bird or animal deformities are largely due to toxicity from water column or sediment contaminants. Temperature and precipitation will impact all impaired beneficial uses as these are the major climate drivers. Evaporation and shortened seasons impact fish and wildlife populations and fish and wildlife habitat; those ecosystems dependent on seasonal changes, seasonal vegetation or reproductive timelines. Since evaporation is largely related to reduced water levels, those beneficial uses depending on a stable water table or are effectively near shore impairments will be affected most by evaporation.

## 5.0 Discussion

It is reasonable to assume that different sites and areas of the lake will experience different impacts to beneficial uses and at different intensities due to how the physical characteristics of the lakes interface with climatic changes. A management framework for restoring and protecting AOCs can be generated by targeting the prominent impairments within each lake, coupled with an understanding of the physical properties of that lake. Here we use Thunder Bay as our sample Upper Great Lakes site, and Toronto and Cornwall as Lower Great Lakes sites. A sample Middle Lake site was not available as there are no Canadian AOCs in this region.

The physical properties that are unique to the Upper Great Lake (Lake Superior) are its large size and depth, and long retention time. The common beneficial use impairments are restrictions on fish and wildlife consumption, degraded fish and wildlife populations, degradation of benthos, restrictions on dredging activities, degradation of aesthetics, and loss of fish and wildlife habitat. Due to Lake Superior's large size, it is less susceptible to impacts of evaporation and thus also those impairments associated with reduced water levels. Lake Superior has not experienced the same levels of development, urbanization and pollution as the other Great Lakes. Most of the Superior basin is forested with clustered populations resulting in relatively few pollutants entering the lake from local sources. Under a changing climate, contaminate entry into the Lake Superior will increase threatening to cause impairments including restrictions on fish and wildlife consumption, degraded fish and wildlife populations, and restrictions on dredging activities. It will likely remain less susceptible to eutrophication and undesirable algae.

The Middle Great Lakes currently have the same impairments as the Upper Great Lakes but also include eutrophication or undesirable algae and beach closures (common features of the Lower Great Lakes) so they are somewhere in between.

Receding beaches or increased beach area may cause marinas and cottage docks to need shifted and exposing more rocky shore causing aesthetics impairments. As nearshore and wetland regions become more shallow or dry, loss of fish and wildlife habitat will continue to degrade fish and wildlife populations.

Water temperatures also influence phytoplankton growth. Bluegreen algae have been associated with taste and odour problems in drinking water (Anderson and Quartermaine, 1998) as well as tainting of fish flavour.

Under a changing climate, the most relevant Great Lakes characteristics affecting beneficial use impairments in the lower Great Lakes are average depth and shoreline exposure. Lake Erie has the lowest average depth and is highly vulnerable to reduced water levels causing increases in exposed beaches and degradation of aesthetics. Changes in water levels degrade fish and wildlife populations, benthos, can cause restrictions on dredging activities, degradation of aesthetics, loss of fish and wildlife habitat, eutrophication and beach closures. The effects of lower water levels may also fundamentally affect seasonal timing and connectivity, food web dynamics, and the distribution, structure, composition and abundance of fish communities in Lake Erie, Lake St. Clair, and associated connecting waters (Kling et al., 2003) impairing beneficial uses of fish and wildlife populations degradation and degraded fish and wildlife populations. To summarize, the lower Great Lakes will be highly influenced by temperature, and evaporation. The most susceptible beneficial uses in the lower Great Lakes under a changing climate are impairments associated with water temperature increases and water level decline. The most sensitive beneficial use impairments are degraded fish and wildlife populations, degradation of benthos, restrictions on dredging activities, loss of fish and wildlife habitat, and eutrophication or undesirable algae. Table 4 summarizes some of the physical properties of the lakes that make them vulnerable to certain impairments.

Table 4. Lake Sensitivities based on Physical Properties (Abdel-Fattah, 2012)

| | Lake Basin/ Region | Ecosystem Characteristics Vulnerable Impairment | Resultant of Impairments |
|---|---|---|---|
| Upper | Superior | High Retention Time | A,B,C,D,E,F,G |
| | | Shoreline Length | A,B,C,D,E,F,G,I,J |
| | | Largest Temp Increase | A,B,C,F,G,H,I,J,K,N |
| Middle | Huron | Exposed Shorelines | A,B,C,D,E,F,G,I,J,K |
| | | Low Water Levels | A,B,C,D,E,F,G,I,J,K |
| | | High Biodiversity | C,N |
| Lower | Erie | Low Water Levels | C,D,G,H,I,J,K,N |
| | | High Biodiversity | C,N |
| | | | |
| | Ontario | Variable Spring/Fall changes | A,C,N |
| | | | |
| | | Urbanization | A,B,C,D,E,F,G,H,I,J,N |

Impairments

A Restrictions on Fish and Wildlife Consumption
B Tainting of Fish and Wildlife Flavor
C Degraded Fish and Wildlife Populations
D Fish Tumors or Other Deformities
E Bird or Animal Deformities or Reproductive Problems
F Degradation of Benthos
G Restrictions on Dredging Activities
H Eutrophication or Undesirable Algae
I Restrictions on Drinking Water Consumption or Taste and Odor
J Beach Closings
K Degradation of Aesthetics
N Loss of Fish and Wildlife Habitat

Examining these local sensitivities will allow policy makers to build a framework of adaption strategies that address the expected changes, and enable the restoration and resilience of beneficial uses.

## 6.0 Conclusions

Major stressors encountered in the Great Lakes will have different effects in each of the Great Lakes according to their physical properties and the climatic changes expected. Coastal wetlands and connecting channels are all highly susceptible to climate change effects throughout the Great Lakes. Vital beneficial uses will be at risk through climate change. One impairment propagates another leading to many chain of risk for the

Great Lakes Basin. Clearly, environmental restoration of sensitive areas could be hindered by a changing climate and an altered hydrological regime (Rhodes et al., 1993). Efforts to restore beneficial uses under Annex 2 of the GLWQA need to recognize, anticipate and adapt to climate change impacts on ecosystem structure and function.

Fully understanding the impairments, local sensitivities and relating them to local basin sites will aid in developing effective local management plans. It is important that in addition to basin-wide management through policy that there exist local plans that may be more manageable, traceable and enforceable.

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# CHAPTER FIVE

## A Review: Adaptive Management and Resiliency to Climate Change

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## Abstract

Climatologists have estimated the manner in which the increase of carbon dioxide emissions will affect the climate in the Great Lakes basin. Models show that at twice the pre-industrial carbon dioxide level, the climate of the basin will be warmer by 2-4°C and slightly damper than at present. Experts predict that this could have serious implications for the ecosystems and economies of the region. In order to enhance and protect the resilience of the Great Lakes, predicting future outcomes of climatic changes, particularly in already degraded geographical areas is instrumental to success. Developing and recommending adaptation measures that could be implemented under a new Great Lakes Water Quality Agreement enables policy makers to act on binationally coordinated programs in Canada and the US. Major concerns presented in this paper include how a changing climate will likely affect water quality, wildlife and fish populations, habitat, and the onslaught of aquatic invasive species. This report discusses the climate drivers of beneficial use degradation (where beneficial uses are derived from Annex 2 of the 1987 Great Lakes Water Quality Agreement) and proposes adaptation options for achieving resilient beneficial uses.


**Key Words:** Great Lakes, Beneficial Uses, Climate Change, Adaptation, Policy, Resilience

## Introduction

The magnitude of the Laurentian Great Lakes water system is difficult to appreciate. The lakes contain about 23,000 $km^3$ of water, covering a total area of 244,000 $km^2$. The Great Lakes are the largest system of fresh, surface water on earth, containing roughly 18 percent of the world's stock (Environment Canada, 2010).

The Great Lakes are susceptible to ever increasing atmospheric carbon dioxide concentrations which may be modifying the climate at a rate unprecedented in history. Humans have increased the carbon dioxide present in the atmosphere since the industrial revolution and some predict that the concentration will reach twice its pre-industrial levels by the middle of the next century (U.S. EPA, 2008).

Climatologists, using the General Circulation Model (GCM), have estimated the manner in which the increase of carbon dioxide emissions will affect the climate in the Great Lakes basin. Several of these models show that at twice the carbon dioxide level, the climate of the basin warm by 2-4°C and be slightly damper than at present (U.S. EPA, 2008). Warmer climates mean increased evaporation from the lake surfaces and evapotranspiration from the land surface of the basin. Due to evaporation it is estimated that the amount of water contributed by each lake basin to the overall hydrologic system will decreased 23 to 50 percent. The resulting decreases in average lake levels are predicted to decline half a metre to two metres, depending on the GCM used (U.S. EPA, 2008). More recent studies from the NOAA Great Lakes Environmental Research Laboratory report on a new method for estimating evapotranspiration that contradict previously published climate change lake level scenarios for the Great Lakes. Previous models used air temperature as an indicator of energy input, but air temperature is also influenced by energy input from the sun, and also by greenhouse gases which bump up the mercury by slowing down heat’s escape from the earth and atmosphere. Thus both incoming and outgoing energy need to be considered and yield different results indicating less water will be lost than previously predicted. The most extreme water level swings happen on Lakes Michigan and Huron. Under the older modeling system, some studies projected that Huron and Michigan would decline 6 feet or more this century. Models based on the new methodology suggest levels could Fall up to 3 feet (Lofgren, Hunter and Wilbarger, 2011).

Increases in evaporation may result in soil moisture deficits, reduction in base flows in streams, periods of lower lake levels and more droughts throughout; affecting the ability of the system to recharge and flush contaminants. Large declines in lake levels could also increase the concentration of contaminants in the Great Lakes and would adversely affected and coastal habitats. Increased evapotranspiration and soil moisture reduction, coupled with increased winds associated with more frequent and intense storms, could worsen soil erosion and sedimentation with corresponding high sediment and nutrient loadings to streams and tributaries. More frequent strong wind events, leading to more intense wave action, may increase the re-suspension of lake-bed sediment resulting in greater occurrences and higher concentrations of pollutants in the water column. In addition, precipitation intensity will increase to a degree that a higher percentage of rainfall will be runoff rather than infiltration and groundwater recharge resulting in less water available as soil moisture for terrestrial and aquatic life.

Based on these predicted changes in lake processes that we examine adaptation could address the impacts of climate change on the coastal zone. We propose that the measure we outline below, taken proactively, can reduce damages and take advantage of potential opportunities that climate change may present.

Context: The Great Lakes Water Quality Agreement

In 1972 the United States and Canada (the Parties) signed the Great Lakes Water Quality Agreement to protect and restore the waters of the Great Lakes Basin Ecosystem. Its strengths include a structure and process that place focus on strategies for restoring and protecting the ecosystem rather than prioritizing national agendas (Alliance for the Great Lakes, 2007). Since its inception much progress has been made and many promises of the agreement have been fulfilled but many have not. The responsibility of meeting these goals falls to the governments and agencies of the two nations jointly. Since the original version, the Agreement has been revised several times and was renegotiated and revised from 2010-2012. This report provides findings about projected climate impacts and related adaptation recommendations to inform the implementation of the new Agreement by the Parties.

## Building Resilience of Beneficial Uses

Recent studies by credible scientists indicate that even if the $CO_2$ concentration in the atmosphere was fixed at current level, surface air temperatures would continue to warm by up to 1.6ºF or 0.9 ºC by 2100 (International Panel on Climate Change, 2007). Progress in mitigation and reduction of $CO_2$ concentrations has proven difficult due to lack of planning and cost-effective alternative energy technologies, as well as political difficulties at national and international levels. While climate change mitigation is complex and necessary, the focus of this paper is on understanding the ramification of current and projected climate related changes, in order to plan for and respond to plausible ecosystem impacts through adaptation strategies.

Given that at least 25 years have been devoted in numerous communities to restore beneficial uses in the Great Lakes Areas of Concern, strategies that improve the likelihood of sustaining the improvements are particularly valid. An impairment of a beneficial use is defined as a change in the chemical, physical, or biological integrity of the Great Lakes system sufficient to cause any of the results in Table 1(Canada and the United States, 1987).

Table 1. Beneficial Use Impairments (Canada and the United States, 1987)

1. Restrictions on fish and wildlife consumption
2. Tainting of fish and wildlife flavour
3. Degradation of fish wildlife populations
4. Fish tumours or other deformities
5. Bird or animal deformities or reproduction problems
6. Degradation of benthos
7. Restrictions on dredging activities
8. Eutrophication or undesirable algae
9. Restrictions on drinking water consumption, or taste and odour problems
10. Beach closings
11. Degradation of aesthetics
12. Added costs to agriculture or industry
13. Degradation of phytoplankton and zooplankton populations
14. Loss of fish and wildlife habitat

Remedial Action Plans (RAPs) are required by Annex 2 of GLWQA to: "classify Areas of Concern by their stage of restoration progressing from the definition of the problems and causes, through the selection of remedial measures, to the implementation of remedial programs, the monitoring of recovery, and, when identified beneficial uses are no longer impaired and the area restored, the removal of its designation as an Area of Concern" (Canada and the United States, 1987).

Adaptation measures that focus on reducing vulnerability of beneficial uses to both current and future climate variability and extreme events are necessary regardless of the rate of future climate change. We define adaptation measures as those actions which may be taken to prevent or reduce damage from climate change by responding to the risks posed to human economic and social activities, and to natural environment, making them more climate resilient (National Round Table on the Environment and the Economy, 2007). Adaptation actions may involve behavioural changes, operational modifications, technological interventions, revised planning, as well as improved regulations and legislation (Natural Resources Canada, 2007).

In most circumstances anticipatory planned adaptation will incur lower long-term costs and be more effective than reactive adaptation (Natural Resources Canada, 2007). Furthermore, many adaptation measures are ‘no-regrets’ options, characterized by measures that would generate net social and/or economic benefits irrespective of whether or not climate change occurs. They generally have the double benefit of reducing short-term exposure to climate variability as well as long-term vulnerability to climate change. Examples of water ‘no-regrets’ adaptation measures include increased efficiency in the use of water, the designation of flood hazards, and measures to reduce water demand.

The variety of climate change repercussions call for highly diverse adaptation measures. Many of the changes expected will impact multiple components of the ecosystem. For example, increasing temperatures are linked with the invasion of exotic species that can disrupt biological systems and water chemistry. Temperature rise also corresponds to increasing incidents of algae, and water level declines, both of which impact water quality and beneficial uses. Intense precipitation events allow for sometimes harmful runoff to enter the lakes impacting fish and wildlife populations, causing beach closings, and exacerbating fish consumption with long term implications.

We assessed the impacts on climate change on beneficial uses systematically and provide adaptations strategies that can strengthen the resilience of beneficial uses.

## Climate Change in the Great Lakes Basin

There are many changes that are expected to affect the entire Great Lakes region. An increase in annual and seasonal temperatures for the Great Lakes watershed is predicted (Abdel-Fattah, 2012). The greatest range in projected temperature increase is in the Spring (0.75 to 5.0°C) while Summer is predicted to have the least (1.5 to 4.0°C) (Great Lakes Water Quality Board, 2003). Summer daily temperatures are projected to gradually increase towards 2030 and then a more rapid increase could have daily average Summer temperatures 10°C higher than the 1960-1990 average by 2100 (Kling et al., 2003). More recent projections by the IPCC indicate on annual-mean warming to vary from 2°C to 3°C along the coastal edges of North America to more than 5°C in the northern region (Christensen et al., 2007). The same study indicates the largest projected warming to occur in Winter over northern parts of Canada reaching 10°C due to the positive feedback from reduced snow cover.

Overall, annual average precipitation is expected to increase. Winter and Spring modeling scenarios show consistent increases in precipitation while Autumn scenarios show precipitation decreases (Abdel-Fattah, 2012). Analyses of precipitation extremes in global climate models (GCMs) and regional climate models (RCMs) indicate more heavy precipitation events, fewer moderate events and more dry days or days with light precipitation (Trenberth, 1999, Christensen et al., 2007). Changes in precipitation, combined with temperature increases, will influence soil moisture, ground water recharge, and runoff (Abdel-Fattah, 2012). Warmer air temperatures in Winter and early Spring will result in snow precipitation that previously fell as rain (Abdel-Fattah, 2012). As a result, more runoff may occur in Winter and less snow may accumulate and become intermittent (Great Lakes Water Quality Board, 2003).

How these changes will impact the beneficial uses of the Great Lakes as identified in Annex 2 of the Great Lakes Water Quality Agreement is important for program and policy approaches that aim to sustain beneficial uses. The variables considered are air temperature, precipitation events, evaporation rates (affecting water supply levels) and the resulting expected ecosystem changes (Abdel-Fattah, 2012).

## Air Temperature

Temperature increases and corresponding increases in evaporation will allow for increase growth of algae, changes in aquatic benthic communities, reduced water levels, expansion of beaches, and decreased wetlands; all which will impact beneficial uses.

Warming results in water temperature thresholds being reached for certain species (Abdel-Fattah, 2012). Climate change impact assessments have projected that fish ranges could move more than 500-600 kilometres northward leading to invasions of warmer water fish and extirpations of colder water fish (Magnuson et al., 1997). Breeding windows may be compressed or shifted. Optimum temperatures for lake trout spawning in the Autumn is 8°C to 11°C and Spring spawning for northern pike is 4°C to 12°C (Wall, 1998); warming could affect biological cycle timing. Some fish will have to find new niches and may change feeding habits to survive.

The spread of invasive species could be exacerbated. Species currently limited to southern states may be able to extend northward into the Great Lakes region. Species such as carp, zebra mussel, purple loosestrife, curly-leaf pondweed, and Eurasian milfoil are examples of species whose introductions have affected the Great Lakes ecosystem (Kolar, 2002). At present, zebra mussel is primarily found in the lower Great Lakes while the coldwater of Lake Superior limits its expansion (Easterling and Karl, 2001). Warmer water temperatures would allow zebra mussel to become more widespread in Lake Superior.

Water temperatures also influence phytoplankton growth; blue-green algae dominate at the highest temperatures, followed by green algae, then flagellates and finally diatoms at lowest temperatures (Magnuson et al., 1997). Blue-green algae have been associated with taste and odour problems in drinking water (Anderson and Quartermaine, 1998). Fishy and musty odours occur. Warmer water temperatures may increase algal blooms and may result in added costs for drinking water treatment.

In the case of temperature increases, adaptation strategies must focus on predicted impacts. This includes increase efforts to protect benthic communities, wetland habitats, biodiversity and aquatic alien species invasion prevention and rapid response, which we describe in greater detail later in this paper.

## Increased Precipitation and Storm Events

With more intense precipitation events, more pollutants reach watercourses directly and rapidly through surface runoff. Intense precipitation leads to soil erosion, land and water quality degradation, flooding, and infrastructure failure. More frequent thaw and freezing episodes will contribute to increased runoff while Summer and Fall flows may become even lower due to higher air temperatures, greater evapotranspiration and reductions in groundwater base flow (IPCC, 1996). With more intense precipitation events, adaptation strategies must address limiting pollutants that reach the watercourses through surface runoff. Strategies can include adaptive planning measures to avert soil erosion, land and water quality degradation, flooding, and infrastructure failure.

## Increased Evaporation and Reduced Water Levels

Wetlands are predicted to experience reductions in water levels; changes in timing and amount of water flowing through a wetland affecting flushing, sedimentation, nutrient input; and length of ice cover. The implications of flow ultimately influences

Great Lakes water levels, in-stream assimilative capacity, habitat deterioration, shoreline exposure and access to water for irrigation, drinking water, and hydropower. Indirect effects of lower lake levels include oxidation of wetland bottoms (Mortsch, 1998). Low water levels will impact the degree of shoreline exposure (Wall, 1998).

Adaption strategies to address changes relating to increased evaporation and water level declines will need to focus on reducing the impacts of declines on shoreline exposure and vulnerable areas such as wetlands that may retreat or be threatened by drought.

The next section will discuss more specifically how beneficial uses as outlined in Annex 2 of the Great Lakes water Quality Agreement will be affected by these changes.

## Beneficial Uses Affected by Climate Change

Climate stressors that are expected to widely impact the entire Great Lakes basin, Areas of Concern (AOCs) and impact associated beneficial uses are shown in Table 2. Fish tumours and bird or animal deformities or reproduction programs and not considered to be directly impacted by climate change. These types of abnormalities are largely caused by chemical contamination. There is almost overwhelming epidemiological evidence, that some of the cases of cancers reported in Great Lakes fishes are caused by carcinogenic anthropomorphically deposited chemicals (Baumann et al., 1990). Table 2 illustrates that temperature and precipitation impact all other beneficial uses and these are also the major climate drivers. Since evaporation exacerbates reduced water levels, those beneficial uses depending on historic water levels will be affected most by evaporation.

Table 2. Beneficial Uses Affected by Climate Change (Abdel-Fattah, 2012)

| | Climate Variability and Climate Change Effects | | | | |
|---|---|---|---|---|---|
| **Beneficial Use Affected** | **No. of Canadian AOCs impaired (% of 14)** | **Air Temperature Increases** | **Intensity of precipitation and storm events, increased runoff** | **Evaporation/ Evapo-transpiration (water levels)** | **Shortened Snow Seasons and reduced ice cover** |
| 1. Restrictions on fish and wildlife consumption | 11 (79%) | X | X | | |
| 2. Tainting of fish and wildlife flavour | 0 (0%) | X | X | | |
| 3. Degradation of fish/wildlife populations | 9 (64%) | X | X | X | X |
| 4. Fish tumours or other deformities | 3 (21%) | - | - | - | - |
| 5. Restrictions on Dredging Activities | 13 (93%) | X | X | X | |
| 6. Bird or animal deformities or reproduction problems | 2 (14%) | - | - | - | - |
| 7. Degradation of benthos | 13 (93%) | X | X | X | |
| 8. Eutrophication or undesirable algae | 6 (43%) | X | X | | |
| 9. Restrictions on drinking water consumption, or taste and odour problems | 3 (21%) | X | X | X | |
| 10. Beach closings | 8 (57%) | X | X | X | |
| 11. Degradation of aesthetics | 9 (64%) | X | X | X | |
| 12. Added costs to agriculture or industry | 1 (7%) | X | X | | |
| 13. Degradation of phytoplankton and zooplankton populations | 3 (21%) | X | X | X | |
| 14. Loss of fish and wildlife habitat | 12 (86%) | X | X | X | X |

Increased precipitation and increased runoff affect beneficial uses that are impaired due to poor water quality impacts associated with contaminants entering the Great Lakes from point and non-point sources. These include restrictions on fish and wildlife, tainting of fish and wildlife flavour, degradation of fish/wildlife populations, restrictions on dredging activities, degradation of benthos, eutrophication or undesirable algae, restrictions on drinking water consumption or taste and odour problems, beach closings, degradation of aesthetics, added costs to agriculture or industry, degradation of phytoplankton and zooplankton populations, and loss of fish and wildlife habitat.

Dropping water particularly affect nearshore areas such as wetlands, important fish and wildlife populations and habitats. Shortened snow seasons and reduced ice cover will also have an impact on fish and wildlife populations and their habitats.

Based on these findings, we conclude that the impact of climate on water quality issues, water levels and altered seasons put the most pressure on beneficial uses (Table 3).

Table 3. Climate Related Drivers of Degradation of Beneficial Uses

| | Drivers of Degradation | | |
|---|---|---|---|
| **Beneficial Use Affected** | **Water Quality Issues** | **Water Levels** | **Altered seasons** |
| 1. Restrictions on fish and wildlife consumption | X | | |
| 2. Tainting of fish and wildlife flavour | X | | |
| 3. Degradation of fish/wildlife populations | X | X | X |
| 4. Restrictions on Dredging Activities | X | X | |
| 5. Degradation of benthos | X | X | |
| 6. Eutrophication or undesirable algae | X | | |
| 7. Restrictions on drinking water consumption, or taste and odour problems | X | X | |
| 8. Beach closings | X | X | |
| 9. Degradation of aesthetics | X | X | |
| 10. Added costs to agriculture or industry | X | | |
| 11. Degradation of phytoplankton and zooplankton populations | X | X | |
| 12. Loss of fish and wildlife habitat | X | X | X |

Although aquatic invasive species are not discussed as part of beneficial uses under the current GLWQA, climate change will have a large effect on non-indigenous species and this needs to be included in discussions below, surrounding the new Agreement and adaptation strategies. Based on these findings, we proceed to recommend adaptation strategies for climate-sensitive beneficial uses.

## Degradation, Impacts and Adaptation

### Water Quality

As described above, the climate related effects on beneficial uses are linked to air temperature increases, increased precipitation and storm events, and evaporation causing decreased water levels.

Climate change is expected to directly and indirectly influence water quality (Murdoch et al., 2000). Increases in water temperature are likely to affect water-borne organisms, favouring more toxic forms of water-borne algal blooms, such as cyanobacteria and dinoflagellates or beneficial use impairment eutrophication of undesirable algae.

A changing climate is expected to bring with it increased storms. Stormwater can carry with it human and animal bacteria as well as pathogens particularly when sewage treatment plants overflow. Runoff that carries with it harmful pollutants or pesticides can cause beneficial use impairments including restrictions on fish and wildlife consumption, degradation of fish and wildlife populations, beach closings and in future result in restrictions on dredging activities. Poor water quality will lead to a higher risk of water-borne diseases and increased treatment costs to water plants as well as added costs to agriculture and industry.

Limiting harmful runoff would greatly improve water quality issues and the associated beneficial uses they support. Actions for inclusions of climate change adaptation strategy to address runoff concerns are:

1. Strategies to reduce sewage overflows by increasing vegetation in runoff interfaces, permeable pavement to reduce sewer overflows in key watersheds and re-routing or separating rainwater from sewage drains.
2. Sewage plant and sewage treatment upgrades in infrastructure and technology to accommodate higher hydrolic loads and prevent overflows and bypasses.
3. Pre-treatment or alternative storage of manure to eliminate pathogens and toxic gases from entering the Great Lakes.
4. Building benthic descriptors to identify degradation and water health. This will allow for new additional criteria for lake health. Understanding the vital benthic communities that keep the lake healthy will allow for better analysis of lake health through monitoring.

## Water Levels

In general, changes in water levels are expected to have an impact on distribution and abundance of different wetland types, thus affecting habitat suitability and eventually the populations of certain fish and wildlife as well as degradation of important phytoplankton and zooplankton populations. Reduced water levels contribute to wetland or shoreline habitat loss. The loss and degradation of habitat throughout the Great Lakes poses a serious threat to water quality resulting in restrictions on water consumption or taste and odour problems. Reduced water levels will cause the shoreline to retreat, and expose more beach area, or become too shallow for operating marinas or piers which can be common tourist areas. Some specific adaptation strategies that address habitat threat and dropping lake levels include:

1. Setting the goal of protecting and restoring habitat in a way that enhances water quality in light of lake level fluctuation. Action regarding habitat, species and biological integrity, should include wetlands protection, conservation, and provision of nearshore structures should lake levels drop exposing and drying up protected wetlands.
2. The choice of wetlands and other significant nearshore habitats to be restored should be based on their contribution to improving water quality and likelihood of withstanding dropping lake levels. This strengthens resilience of beneficial uses that are sensitive to water quality threats in light of climate change.
3. Informational/mapping of biodiversity should be developed to increase monitoring of populations of aquatic life and wildlife dependant on the Great Lakes. This should include recreationally important fish species as well as mammals and birds in order to more quickly identify ecosystem changes, including detection of aquatic invasive species.
4. A focus should be placed on restoration of native species, including lake trout, lake sturgeon, and other species in order to enhance natural ecosystem health.

## Altered Seasons

Altered seasons affect the phenology of animals and plants. Thermal responses determine a species' phenology and seasonality in a given environment and can be used to understand the influence of temperature on their development (Régnière and Logan, 2003).

Phenology is perhaps the simplest process to track changes in the ecology of species in response to climate change. As a result many long term phonological data sets have been collected and studied for trends that reflect responses to recent climate change (Bairlein and Winkle, 2001). Birds, butterflies and wild plants include popular and easily identifiable species. Common changes in the timing of Spring activities include earlier breeding or first singing of birds, earlier arrival of migrant birds, earlier appearance of butterflies, earlier shooting and budding of flowering plants and trees, and spawning in amphibians (Walther et al., 2002).

In general, Spring activities have occurred progressively earlier since the 1960s. Some evidence also indicates a later onset of Autumnal phonological events, but these shifts are less pronounced and show a more heterogeneous pattern. Studies reveal some birds delay Autumn migration (Gatter, 2002).

Vegetation is reacting to increasingly warmer temperatures, particularly in Winter and Spring. The warming trend corresponds to a decline in the number of freezing days below 2.2 °C each Winter and Winters ending sooner; the date of last freezing occurs an average of 1.5 days earlier each decade. Changes to the timing of last frost and leaf growth can end up damaging plants. When plants start growing further in advance of the last date of freezing, they risk heavier frost damage (Schwartz, Ahas and Aasa, 2006).

Responses by individual species to these changes may disrupt their interactions with others at the same or adjacent tropic levels. When closely interacting or competing species display divergent responses to change, the outcome of their interactions may be altered (Saetre et al., 1999); this could result in a decoupling of interactions.

Winder and Schindler (2004) demonstrated in Lake Washington that earlier ice breakup and stratification has created a temporal mismatch between the peak Spring phytoplankton bloom and the population dynamics of some species of zooplankton. A later study by Schindler et al. (2005) found that earlier ice breakup was associated with higher Summer Daphnia densities as well as higher growth rates of planktivorous juvenile sockeye salmon.

Current modeling technology makes possible the analysis of climate change impacts on the distribution of native and introduced species as long as sufficiently detailed information on their thermal responses is available. It is possible to estimate the range changes that can be expected using developmental physiology. More detailed models predicting not only seasonality, but also the degree of risk through climate-related impacts to critical aspects of pest organisms' life histories improves this estimate (Logan and Powell, 2001). With additional knowledge of the ecological relationships between a species and its food, competitors and predators, it is possible to determine a species' potential geographical range and its ability to achieve an adaptive seasonality in any given environment.

Although it is not plausible to attempt to prevent altered seasons, it is possible to plan for these changes by estimating the adaptive seasonality of species and attempt to protect those at most risk or develop management plans to respond to potentials for species collapse.

## Aquatic Invasive Species

In addition to addressing the beneficial uses under Annex 2, the potential impact of climate change on invasive species distributions can alter the physical, chemical and biological characterizing of the Great Lakes. The ability of the Great Lakes ecosystem to decontaminate pollutants can be hindered by aquatic invasive species. Aquatic invasive have the ability to fundamentally change the food web, species distribution, habitats and water chemistry and have also been implicated in the reproductive failures of some fish species including walleye, lake trout, yellow perch and lake herring (Great Lakes Regional Collaboration, 2005).

With climate changes, it is expected that species will migrate to climates that correspond to their thermal optimums causing new species to enter new parts of the lakes. Zebra and Quagga mussels and the round goby have played a significant role in altering the ecological balance of the lakes. With climate change increasing the risk of invading species establishment, a strategy to limit invasion and include precautionary measures includes intensified rapid response plans to deal with new invasions. More specific adaptation strategies include:

1. In order to quickly response to the increased speed and number of invasions expected with a warming climate a formal Binational Great Lakes AIS Rapid Response Plan in cooperation with AIS management agencies would harmonize response actions and promote mutual cooperation between U.S. and Canadian Great Lakes institutions.
2. Implement an aggressive prevention program at a Binational level.
3. Provide for and encourage swift and effective information sharing and communication between U.S and Canadian Great Lakes agencies as well as with the public in order to establish potential invaders and their possible points of entry so that barriers can be implemented.
4. Effective ballast water regulations are in place, however, other vectors such as aquarium food, and bait fish need to be similarly regulated in order to reduce the possible modes of entrance into the Great Lakes in a changing climate.

## Conclusion

Climate change adaptation is an important issue to be addressed during the implementation of the new Great Lakes Water Quality Agreement (to be released in 2012). It is clear that higher temperatures, increased events of intense precipitation and storms as well as increased evaporation will impact water levels, water quality, wildlife and fish as well as exacerbate the introduction of new aquatic invasive species.

Under the Great Lakes Water Quality Agreement, Canada and the United States are responsible for restoring and maintaining the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem. An important aspect of this task is to address climate change and develop strategies to reduce the impacts.

Since the last revision of the Agreement in 1987, new information on climate change has become more readily available. While substantial effort has been in place to develop initiatives to restore these geographically degraded Areas of Concern, 25 years of working towards restoration could be in jeopardy in the face of climate change. New emerging threats will require increasing attention to adaptation measures to meet the purpose of the Agreement.

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# CHAPTER SIX

## Using Expert Elicitation as a technique to assess Adaptation to Climate Change and Policy Solutions for the Great Lakes

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## Abstract

This paper explores adaptation strategies relating to climate change and water management in the Great Lakes region. The research involved a multi-round, interactive survey of experts in the field of climate change, policy and adaptation. Participants were asked to first about their opinions of climate change and its predicted impacts in the region and whether current policies adequately addressed the issue.  Second they were asked whether certain adaptation strategies would be successful and feasible for implementation. The third round aimed to gain a consensus among participants. The answers provide a starting point for understanding scientific opinions surrounding climate change in the Great Lakes, and possible adaptation strategies to inform policy development and recommend preventable measures for building resiliency to climate change.

**Keywords**: Great Lakes, Delphi, experts, adaptation, policy, climate change

## 1.0 Introduction

As the body of knowledge about the science of climate change increases, there is growing recognition that beyond mitigation, adaptation is vital. The scale of the action required to adapt to future impacts of climate change may be very significant (Parry et al., 2008). Thus far in the Great Lakes region, Remedial Action Plans have been the principle programs to approach ecosystem management (Krantzberg, 2012). With the imminent impacts of a changing climate it may be appropriate to plan precautionary steps and adaptation strategies to reduce risk and minimize future environmental threat and associated costs. This paper aims to contribute to this endeavour by presenting a novel framework that conceptualizes climate change actions. The framework is intended to analyze climate change risks and identify possible adaptation strategies through a panel of experts.

In the IPCC definitions and the analysis of Smit et al. (2000), adaptation is a response to an environmental stimulus. The measure that is proposed as a means for ameliorating the anticipated adverse consequences associated with climate change can be any adjustment, whether passive, reactive or anticipatory (Stakhiv, 1993). Adaptations are processes or adjustments made by human systems to minimize or prevent an unwanted response. Adaptation involves adjustments to enhance the viability of social and economic activities and to reduce their vulnerability to climate, including its current variability and extreme events as well as longer-term climate change (Smit, 1993,Smit et al., 2000). Developing adaptation strategies requires common concepts to map different adaptation strategies. To address this, our study aimed to first assess the perceived climate risk in the Great Lakes scientific community. It was also important to assess how well we are prepared to adapt to climate change in the region and if current policy primary policies were adequate. Once there was consensus on the risks, adaptation strategies were presented to experts in order to gain their feedback on their effectiveness.

We conducted an anonymous three round Delphi Survey involving experts in the Great Lakes areas within government, industry, academia, and non-profit organizations. Round one collected their feedback on their basic perceptions on how climate would change in the Great Lakes region and their opinions on the effectiveness of some adaptation strategies in light of climate change. The second round gave participants the opportunity to reflect on their answers by providing them with feedback of others answers and their opinions as well as adding some policy specific questions. The third round allowed the participants to rank the most relevant and agreed upon adaptation options from round two as to their feasibility of implementation.

It has been difficult to assess and quantify what the goals of adaptation should be. Should adaptation strive to maintain climate-related risks at present levels, reduce risks from current levels if risks are already too high or unacceptable, or to minimize exposure to new threats or highly vulnerable regions? Adger et al. (2009) explain that this lack of consensus is a reflection of the diverse and contested values in society and this may represent a barrier to adaptive science. As such, this paper avoids an analysis of the quantification of adaptation and instead focuses on adaptation strategies and the strength of their implementation.

While the paper mainly analyses adaptation interventions singly, in response to climate change, the research field gains complexity by considering adaptive capacity. Brooks (2003) distinguishes between actual adaptation and adaptive capacity, being potential for adaptation that does not necessarily become real. Adaptive capacity links adaptation to the discourses on vulnerability and resilience (Engle, 2011). Unfortunately, adaptive capacity does not automatically lead to actual adaptive action (Adger and Barnett, 2009). In order to aid in this discussion, panel experts were asked to consider barriers to adaptive strategies, such as desirability, social feasibility, economic feasibility, human resource capacity, and enforceability.

It is crucial to note here that the framework and analysis presented in this paper serves as a basic unit of analysis. Complex real-world adaptations need to be analyzed through cost analysis, environmental impact assessments and re-combined in different ways to consider interrelated actors (Eisenack and Stecker, 2011).

# 2.0 Methods

## 2.1 The Delphi Technique

Since its design at the RAND Corporation in the 1950s, the Delphi Technique has been a tool for measuring and aiding forecasting decisions in a variety of disciplines. The technique is meant to be a procedure to obtain the most reliable consensus of opinion of a group of experts. This is achieved through a series of questionnaires interspersed with controlled opinion feedback (Dalkey and Helmer, 1963). The benefit of the Delphi is that it allows for a method of input from a varied and large number of respondents that can be anonymous, and geographically dispersed. It is meant to be used in areas of uncertainty where human judgment is needed or statistical methods may not be practical.

Four key elements are needed for an efficient Delphi; anonymity, iteration, controlled feedback and the statistical aggregation of results (Rowe and Wright, 1999). It is important that individuals have the opportunity to express their opinions privately, without judgment. This allows participants to consider each idea on the basis of merit alone. Iteration allows the individual the opportunity to change their opinions without judgment if swayed by another expert opinion. Between each round, feedback is provided as a simple statistical summary of the group response. In this survey, each iteration provided many of the same questions from the previous round that needed consensus but also included new questions fuelled from the previous round and with more specificity. The number of rounds is variable though seldom goes beyond one or two iterations. In this questionnaire, the question iteration terminated when there was some consensus for that specific question. All rounds are terminated once a statistical average from the group seems to meet some consensus or stability, or there is a majority opinion. If panelists' responses were more than two answers away from the mean, they were asked to give reasons why they believe their selections were correct against the majority opinion. The final forecast opinion is represented by the median in the final round for that specific question.

## 2.2 The Approach

An expert survey approach was adopted to assess both opinions on climate change in the Great Lakes region and also the possible adaptation solutions and policy gaps. The approach involved identification of relevant experts and the circulation via email of online questionnaires. We used the online survey service Survey Monkey to facilitate gathering data and data storage as well as providing some statistical results. The survey consisted of three rounds, and each round provided respondents with results and feedback from others on the previous survey so they could reflect and if convinced alter their previous responses. Participation was anonymous, even to the researchers. Due to this anonymity there was no way to track individuals across rounds. In the first survey, broad categorical data was requested about job role, and years of experience but no identifiable information was requested nor could this be traced through rounds. It was requested of all participants that they participate in all rounds, but this was not traceable. It was suspected that through rounds there maybe some consensus on possible adaptations as experts assessed each other's opinions.

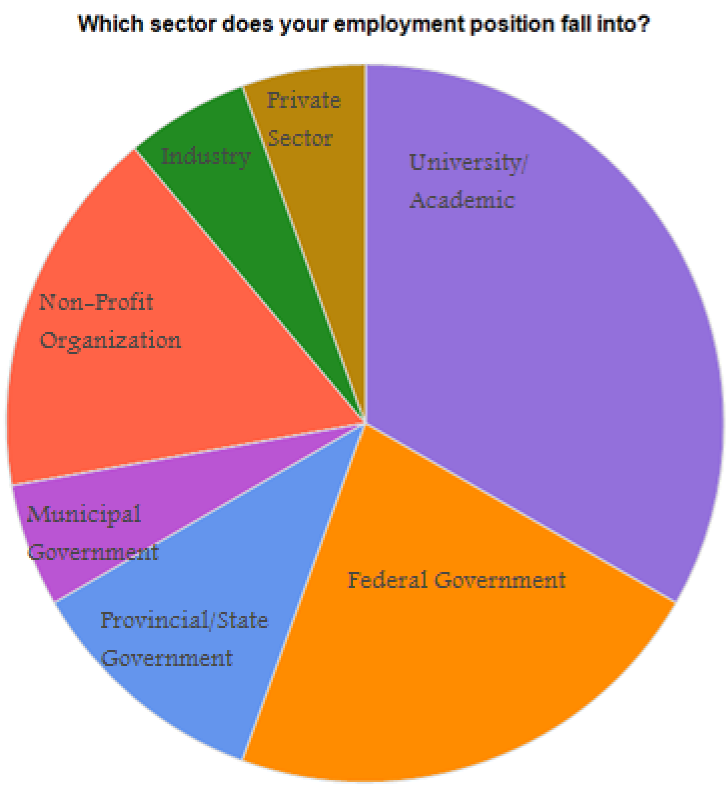
## 2.3 Identifying Experts

Central to any survey of experts is the definition of experts to be surveyed. In our study, an expert was deemed anyone having special knowledge based on experience with the issue examined. Experts were selected based on their job title and if it related to climate change, policy development and water resource management. Many participants were known through published results on this topic or from presentations. Experts with involvement in climate predictions and/or with a role in decision- making and management were necessary. We endeavoured to invite a group that broadly represented multiple jurisdictions, job roles, and related fields of interest. A totally of 80 experts were sent the survey. Usable responses from each round varied from 11-13 participants per round.

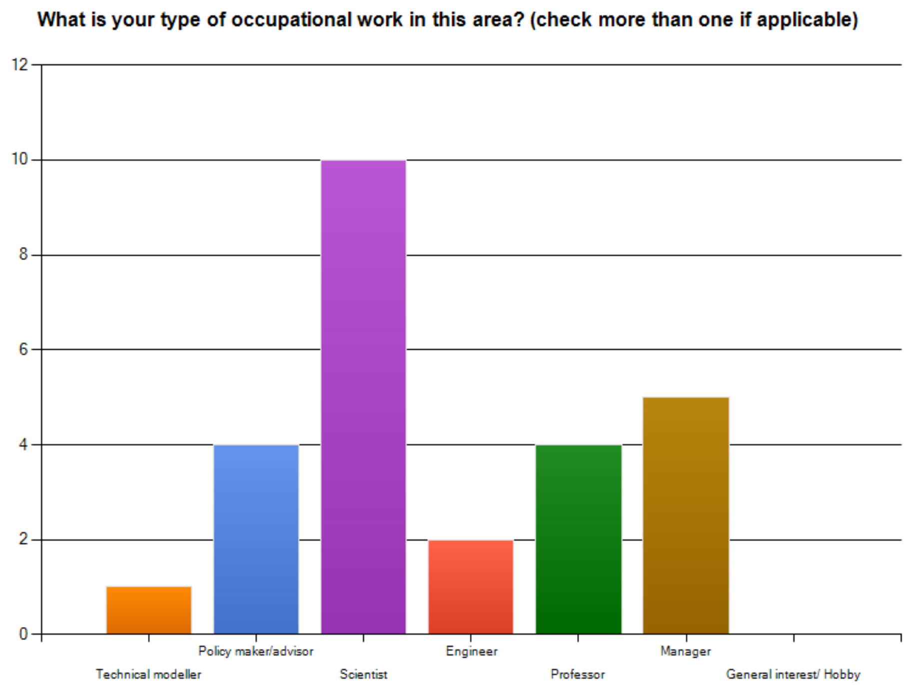
Participants were invited from Ontario and U.S. Great Lakes States via email that included an overview of the study and it's rational. Each invitee was an expert from government, industry, academia, or social society. Broad categorical data was requested through the initial survey that would identify the participants sector and type of work, number of years of experience, and how closely their field related to the issues of this survey. The average number of years of experience was 17. Most participants were scientists (60%), 30% were at management level, 24% were policy makers or advisors, 24% were professors, 12% were engineers and 6% were technical modellers. Experts were able to choose more than one category when qualifying their experience. Other categorical information about participants is shown in Figure 1 (a and b).

Figure 1. Categorization and experience in expertise

a) Employment Position



b) Type of Occupational Work




**2.4 Survey Design**

Each survey served an individual goal. Although there was repetition of questions in order to gain consensus, each iteration contained new questions specific to the goal of that questionnaire set. The following describes the goal of each questionnaire round: Round 1- Gain background information about participant qualification as experts and their opinions on how climate is changing in the Great Lakes region and whether current policies are adequate.

Round 2- Obtain expert opinion on specific adaptation strategies and their effectiveness. A rating of effectiveness of adaptation strategies based on desirability, social, economic, and enforceability feasibility, as well as human resource capacity

Round 3 – Last round in order to gain consensus among participants and gain clarity in response.

Each subsequent round provided responses from the previous round for participants to reflect on. Once all responses were received, the results were analyzed for consensus and for value to the research subject.

Round one first gained some insight into the expertise of the participant. This included how many years they have been involved in Great Lakes management or research, their type of occupational work (modeller, policy advisor, scientist, engineer, professor or manager), and which sector they work in (Government, Non-profit, Industry, Academic). Participants were also asked how directly their work related to Great Lakes climate change impacts and whether their position involved policy review or formation.

Once this preliminary assessment was made, the survey asked questions regarding the state of climate change in the Great Lakes and they were asked to state whether they highly agree, agree, were neutral, disagree, or highly disagree with the following statements:

- The situation in Ontario with regard to climate change in the Great Lakes is a serious one.
- Each of the Great Lakes will experience different degrees of climate change.
- Upper Great Lakes will experience greater variance from normal in temperature and precipitation than lower Great Lakes.
- Lower Great Lakes will experience more extreme impacts on water levels, quality, beach closures, and eutrophication than Upper Great Lakes due to the characteristics of the lakes.

Participants were then asked questions regarding mitigation, planning and policy gaps and asked to state whether these were not adequate, somewhat adequate, neural, very adequate, or extremely adequate:

- Climate change adaptation or climate mitigation need to be included in planning and preparedness action plans.
- To what extent does the Great Lakes Water Quality Agreement (GLWQA)[1], including Remedial Action Plans (RAPs)[2] account for impacts of changes that may occur to provide a buffer against future changes?
- To what degree are adaptation strategies being developed?

Participants were also asked if they believed different criteria were needed for declaring a beneficial use restored given the predicted impacts of climate change. The last part of questionnaire one aimed to elicit opinions regarding adaptation strategies and their effectiveness.

[1]The Great Lakes Water Quality Agreement (1972 and 1978) is the was signed between the Government of Canada and the Government of the United States of America to enhance and restore the waters of the Great Lakes Basin Ecosystem and to continue to be concerned about the impairment of water quality on each side of the boundary to an extent that is causing harm to fish, wildlife and humans.

[2]The Governments of Canada and the US, in consultation with the jurisdictions, , through the GLWQA have developed Remedial Action Plans as a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in Areas of Concern or in open lake waters.

This area was grouped by beneficial uses[3];

(i) Beneficial uses related to Fish and Wildlife populations and habitats

- Preventing the spread of invasive species (through biological, chemical or physical control) is important in order to protect fish and wildlife; and their habitats in light of climate change.
- Regulating residential and commercial zoning permits to accommodate expected climate changes for actions such as preserving ecological buffers such as wetlands.
- Carefully limiting harvests for select fish and improving hatchery functions to protect fish populations to preserve native fish populations that may diminish under climate change.

(ii) Beneficial uses related to water quality, drinking water restrictions, beach closures, and dredging restrictions

- Increasing the capacity of storm water collection for increased precipitation.
- Modifying urban landscapes (improving infrastructure and increasing vegetation) to reduce water contamination from runoff.
- Controlling water pollution through stricter fines to enhance water quality and associated drinking water and keep beaches open.
- Upsize water infrastructure for the rare severe weather event.
- The use of artificial floating islands as a means of using plants to remove excess nutrients in the water body.
- Controlling water pollution through lower water allowances through a regulatory approach.

(iii) Changes in water levels due to temperature increases

- Finding new groundwater sources and enhancing existing groundwater supplies through aquifer storage and recovery to enhance water supply prepreparedness action in light of climate change.
- Low flow plumbing and rain water collections to control the water supply.

[3]Annex two of the GLWQA identifies Impairments of beneficial use(s)to mean a change in the chemical, physical or biological integrity of the Great Lakes System sufficient to cause any of the following: (i) restrictions on fish and wildlife consumption; (ii) tainting of fish and wildlife flavour; (iii) degradation of fish wildlife populations; (iv) fish tumors or other deformities; (v) bird or animal deformities or reproduction problems; (vi) degradation of benthos; (vii) restrictions on dredging activities; (viii) eutrophication or undesirable algae; (ix) restrictions on drinking water consumption, or taste and odour problems; (x) beach closings; degradation of aesthetics; (xii) added costs to agriculture or industry; (xiii) degradation of phytoplankton and zooplankton populations; and (xiv) loss of fish and wildlife habitat.

- Develop advanced wastewater treatment capacity for water reuse, such as grey water sources to prepare for water scarcity during climate change.

Round two repeated many of the questions from round one, providing participants with feedback and results in order to gain consensus and clarity. Participants were also given the option to add comments throughout the survey. This round also asked participants to provide feedback about the effectiveness of the four most highly rated adaptation strategies from the previous round. They were asked to assess whether the strategies were highly, very, somewhat, unlikely or not at all feasible under the following categories: desirability, socially, economically, human resource capacity and enforceability. Participants were also asked to give open feedback on the following policy related questions:

- Is it necessary for Climate change adaptation responses and mitigation to be included in the revised Great Lakes Water Quality Agreement?
- What issues do you believe need to be under consideration in policy revision in light of climate change?
- Who should be responsible for enforcing/ monitoring adaptation measures?
- Should we re-visit, review, and revise RAPS to include climate change beneficial use impairments?
- Is it feasible to order which BUIs are most susceptible to climate change in order to prioritize actions for adaptation measures?

The third round of this survey was designed to gain consensus, and formalize conclusions from the survey by repeating any questions where levels of agreement were low. This round eliminated the “neutral” response in order to elicit participants to form a clear decision.

## 3.0 Results

Our three-round invited 80 individual experts from across the Great Lakes basin. The study achieved participation rates of 24% in round 1, 16% in Round 2, and 19% in Round 3. According to standards for Delphi methods, this was deemed an adequate sample size. The Delphi group size does not depend on statistical power, but rather on group dynamics for arriving at a consensus (Okoli and Pawlowski, 2004). For this study it was not important to identify any relationships existing between independent variables of the respondents (number of years of experience, sector of work or any other socio-demographic data).

When it comes to quantitatively determining the results of the study, a data analysis on the participants' responses to the statements in each of the surveys was performed. Descriptive statistics are used to analyze the central tendencies of the data and are discussed under the mean and mode. These statistics provide a broad summary of the data.

One of the aims of using Delphi is to achieve greater consensus amongst surveyed experts. Empirically, consensus is determined by measuring the variance in responses of Delphi panelists over rounds, with a reduction in variance indicating that greater consensus has been achieved (Rowe and Wright 1999). It is expected that in each subsequent round, variance of opinion is reduced until stability is obtained or consensus is reached. Consensus is defined as the "majority of opinion" or "general agreement" and in general this study it was 60% or greater. A five point Likert scale was used in the Delphi survey statements. Table 1 provides a mean ranking for each question rated on the Likert scale. The closer the values are to the likert scale values indicated the general rating of the group (for example a mean value of 1.76 indicated the responses were between 1 and 2, highly agree and agree).

It was clear that experts believe climate change in the Great Lakes was an important issue. There was also a strong consensus that adaptation planning is not well developed or adequate for the region. The panel strongly agreed that the Great Lakes Water Quality Agreement (GLWQA) and Remedial Action Plans do not adequately plan or account for changes what are expected in the region. There was weaker agreement regarding the specifics of how climate would be altered in the region; however it was generally agreed that each of the Great Lakes would experience different impacts and the impacts in the lower Great Lakes would be more severe. Based on this response, it was agreed that criteria for delisting beneficial uses would need to be modified given the impacts of climate change and that mitigation and adaptation policies would need to be included in management.

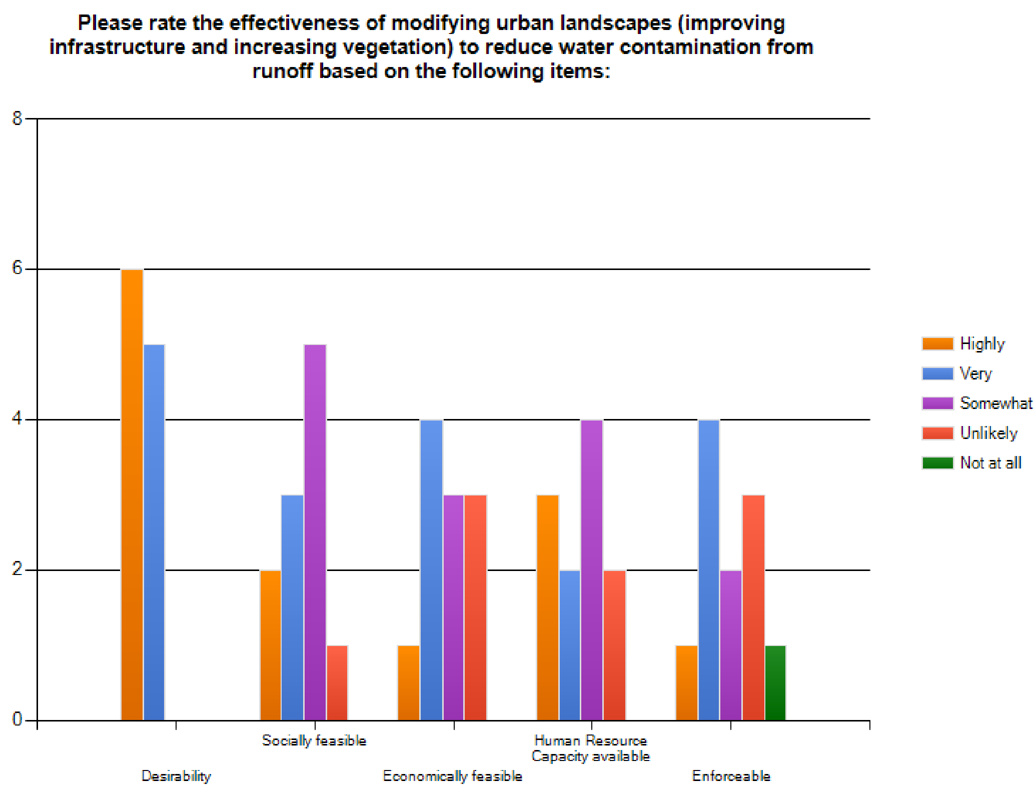
Table 1. Survey Responses over Rounds

| | | Rating Mean Per Round | | | | |
|---|---|---|---|---|---|---|
| | Survey Question | Round 1 (N=18) | Round 2 (N=13) | Round 3 (N=15) | Mean Change in Response | Likert Scale |
| 1 | The Situation in Ontario with regard to climate change in the Great Lakes is a serious one. | 1.76 | 1.69 | - | 0.07 | 1= Highly Agree, 2= Agree, 3= Neutral, 4= Disagree, 5= Highly Disagree |
| 2 | Each of the Great Lakes will experience different degrees of climatic change. | 1.65 | 1.54 | 1.33 | 0.16 | |
| 3 | If you agreed with the previous statement, Upper Great Lakes will experience greater variance from normal in temperature and precipitation than Lower Great Lakes. | 2.31 | 2.38 | - | 0.07 | |
| 4 | Lower Great Lakes will experience more extreme impacts on water levels, quality, beach closures and eutrophication than Upper Great Lakes due to the characteristics of the Lakes. | 2.06 | 2 | 1.92 | 0.07 | |
| 5 | Different criteria for declaring a beneficial use restored need to be established given the predicted impacts of climate change. | 2.12 | 2.5 | 2 | 0.06 | |
| 6 | Climate change adaptation or climate change mitigation need to be included in planning and preparedness action plans. | 1.29 | - | - | - | |
| 7 | To what extent does the Great Lakes Water Quality Agreement, including RAPs account for impacts of changes that may occur or provide a buffer against future changes? | 1.65 | 1.67 | 1.25 | 0.2 | 1=Not Adequate, 2= Somewhat Adequate, 3= Neutral, 4= Very Adequate, 5= Highly Adequate |
| 8 | To what degree are adaptation strategies being developed? | 1.53 | 2 | 1.25 | 0.14 | |
| 9 | Preventing the spread of invasive species (through biological, chemical or physical control) is important in order to protect fish and wildlife; and their habitats in light of climate change when feasible for specific species. | 2.6 | 2.75 | 2.38 | 0.11 | 1= Definitely Effective, 2= Probably Effective, 3= Neutral 4=Probably Ineffective, 5= Definitely Ineffective |
| 10 | Regulating residential and commercial zoning permits to accommodate expected climate changes for actions such as preserving ecological buffers such as wetlands. | 2 | 2.33 | 1.54 | 0.23 | |
| 11 | Carefully limiting harvests for select fish and improving hatchery functions to protect fish populations to preserve native fish populations that may diminish under climate change. | 2.69 | 1.92 | 2.38 | 0.155 | |
| 12 | When fish populations are impacted by fishing activities and further complicated by associated land based development, the ecosystem shift directly and indirectly attributed to climate change adds further stress. One management option to contribute to sustainability is through reducing the pressures of fishing. | - | - | 1.85 | - | |
| 13 | Increase the capacity of storm water collection for increased precipitation. | 2.2 | 1.92 | 1.58 | 0.31 | |
| 14 | Modify urban landscapes (improving infrastructure and increasing vegetation) to reduce water contamination from runoff. | 1.73 | 1.58 | | 0.865 | |
| 15 | Control water pollution through stricter fines to enhance water quality and associated drinking water and keep beaches open. | 2.73 | 2.67 | 2.17 | 0.28 | |
| 16 | Upsize water capture and drainage infrastructure for severe weather event. | 2.47 | 2.17 | 1.75 | 0.36 | |
| 17 | Use artificial floating islands as a means of using plants to remove excess nutrients in the water body. | 3.23 | 3 | 2.58 | 0.325 | |
| 18 | Control water pollution through lower water allowances through a regulatory approach (Limit household use or industry use of water). | 2.93 | 2.75 | 2.67 | 0.13 | |
| 19 | Find new groundwater sources and enhancing existing groundwater supplies through aquifer storage and recovery to enhance water supply prepreparedness action in light of climate change. | 3.47 | 3.25 | 2.9 | 0.285 | |
| 20 | Use low flow plumbing and rain water collections to control the water supply. | 2.13 | 2 | 1.91 | 0.11 | |
| 21 | Develop advanced wastewater treatment capacity for water reuse, such as grey water sources to prepare for water scarcity during climate change. | 2.25 | 1.75 | 1.73 | 0.26 | |

The portion of the surveys that addressed adaptation strategies and their feasibility had more variance in the responses. It was clear that in most rounds, the strength of consensus increased. However in this survey, it appears that when panelists altered their estimations to conform to the group they did not actually change their position, but became more confident in their response (such as choosing "very likely" as opposed to "likely". Similarly, Erffmeyer and Lane (1984) correlated post-group individual responses to final group scores and found that there was significantly more acceptance and thus higher correlation between these measurements by the final round. It was also evident that opinions on some issues were more concrete, thus there was a lower mean change in response, but this could also correspond to high consensus validating opinions. Analysis after round one indicated that experts thought that some adaptations strategies were more effective than others. These were included in the round two survey to order assess the specific feasibility based on desirability, economically, human resource capacity social feasibility, and enforceability. Enforceability in this case meant well to how easily these actions could be monitored and regulated.

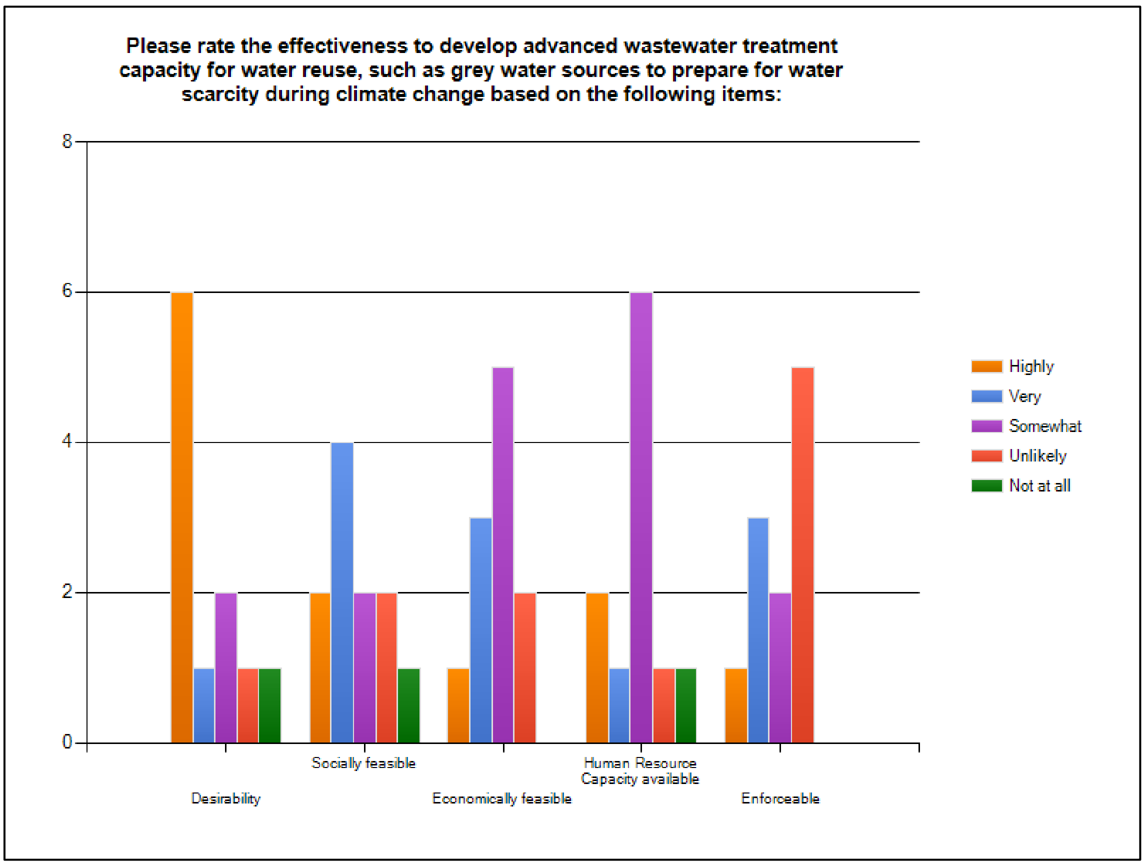
All adaptations strategies tested for feasibility were rated as highly desirable. Experts believe that modifying urban landscapes through improving infrastructure and increasing vegetation to reduce contamination from runoff was an effective adaptation strategy, through iteration, belief in the strength of this adaptation improved. In round one 93% believe it would be effective (combined results from definitely effective and probably effective). In round two 100% of participants rated this as effective, with a higher proportion rating it as highly effective than in round 1. Similarly it was rated by 100% of participants as desirable. However when addressing the social feasibility, only 45.5% believed it would be well accepted while 27.3% indicated it may be only somewhat socially feasible. The economic feasibility was more dismaying; only 9.1% believe it was highly feasible, 36.4% thought it was very feasible while 27.3% thought it was somewhat feasible and a whopping 27.3% thought it was unlikely that it would be economically feasible (Figure 2 shows the results of feasibilities).

Figure 2. Feasibility of Modifying Urban Landscapes



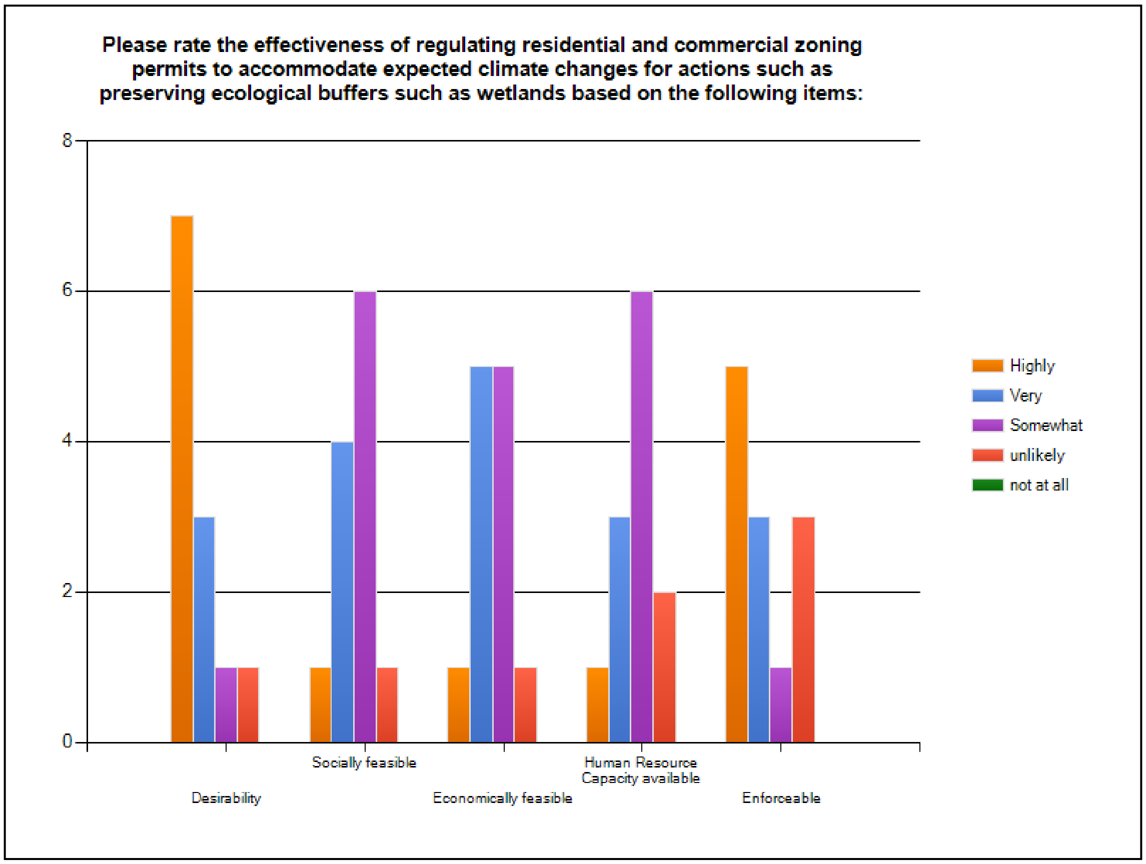

To develop advanced wastewater treatment capacity for water re-use such as greywater sources was thought to be highly effective, and this opinion strengthened through rounds. It was however highlighted by an expert that if the grey water is full of laundry additives and other chemicals treatment would be highly expensive and may be prohibitive. For this reason it was expected that the economic costs may be excessive. Experts agreed; 36.4% thought it was economically feasible, 45.5% thought it was somewhat feasible and 18.2% thought it was not (Figure 3 shows the results of feasibilities).

Figure 3. Feasibility of Advanced Wastewater Treatment or Re-use



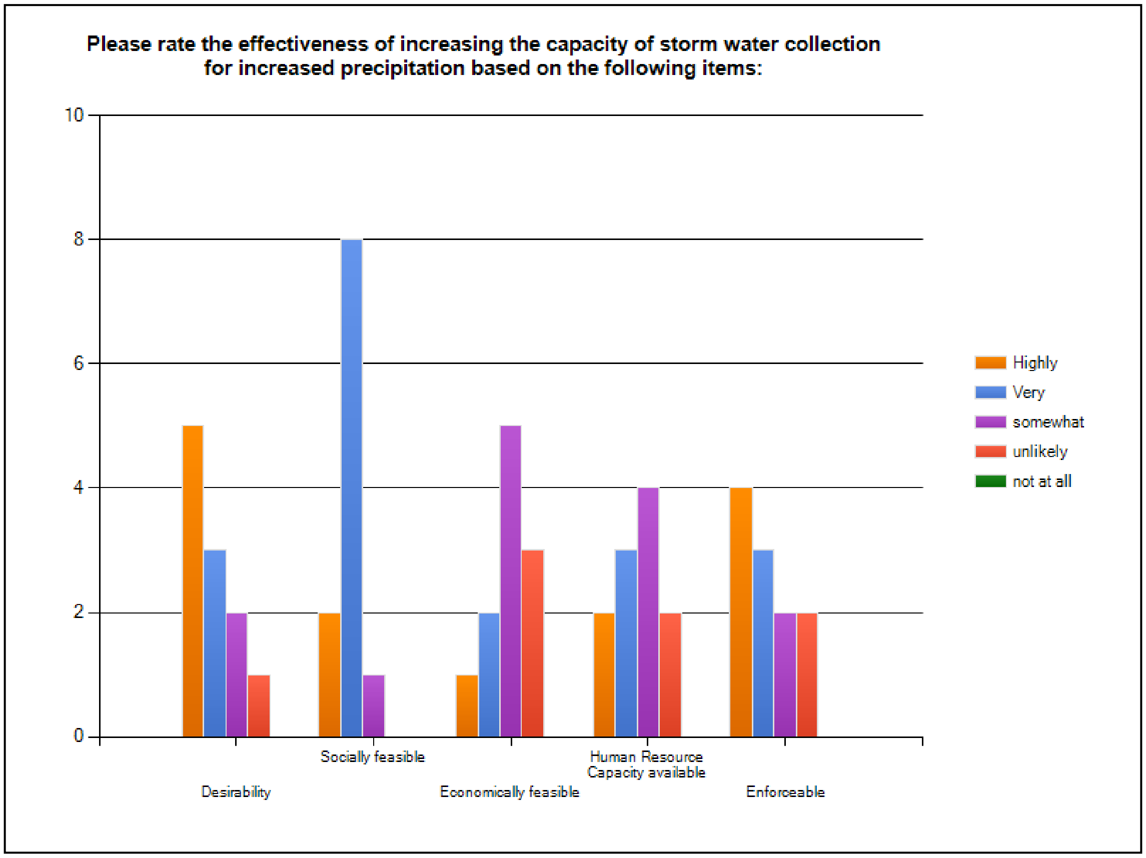

Regulating residential and commercial zoning permits to preserve ecological buffers such as wetlands was rated as slightly less feasible than the previous adaptation strategies discussed, with lower feasibility rankings for social, and economic feasibility. However this strategy was ranked as highly enforceable by experts. One expert explained that zoning instruments could be adapted to better manage effects of development and the use on surface and ground water, including aquifer recharge areas (Figure 4 shows the results of feasibilities).

Figure 4. Feasibility of Regulating Zoning Permits




Increasing stormwater collection for increased precipitation was viewed as both effective and desirable. It was also valued as very socially feasible and potentially economically sound depending on how it was implemented (Figure 5 shows the complete results of feasibilities).

Figure 5. Feasibility of Increasing the Capacity of Storm Water Collection




It was suggested by one of the experts that a more cost-effective and pragmatic solution would be to address the increased precipitation before it enters the collection system by using storm-ceptors, localized ponding and slow release infiltration to the ground water. It was further suggested to reduce the hard surfaces in urban areas, promote more sustainable farming (such as reduced tillage) to dampen the pressure of high precipitation events on existing collection system components.

The issue however in most cases was that the economic and human resource capacity were lacking for these initiatives. Human resource capacity feasibility responses varied highly for each adaptation. Developing an idea of who would be responsible for these actions and what their capacity for action was highly difficult to assess at this stage of assessment.

Other adaptations that were not thought to be successful included stricter fines to enhance water quality and associated drinking water and keep beaches open. In round two 40% thought this was probably ineffective or definitely ineffective. Adaptations that included fines, or strict regulation were generally not well accepted by experts overall although it was evident that some individuals were strong advocates of improved regulation, and enforcement particularly in respect to pollutants. Similarly, controlling water pollution through lower water allowances through a regulatory approach by limiting household use or industry use of water was not ranked highly effective. Only 36% thought it would be effective, while, 36% were neutral, 21% thought it was probably ineffective, and 7% definitely ineffective. Most thought it was improbable to aim to find new groundwater sources and did not think this should be included in planning. Preventing the spread or invasive species was generally thought to be effective, but not cost-effective, or highly practical. Attempting to control species may lead to subsequent shifts in ecosystems that may not be under our ability to control or manage.

Other adaptation methods that were not brought forward by the researchers but were suggested by the experts include aquifer management, upstream interventions that reduce the impact of peak flow events to prevent downstream calamities.

It was suggested that more information is needed about the proactive limits and tipping points for nutrient concentration in surface and ground waters specifically eutrophication and the impacts those changes would have on species and ecosystems.

It was clear through expert feedback that combining some of the adaptation strategies would be most effective. For example reducing water use, coupled with rainwater collection and reuse along with public information would prepare communities for higher precipitation periods as well as periods of drought.

Through the survey, it was clear that experts believed (88% of responses) that it is necessary for Climate change adaptation responses and mitigation to be included in the revised Great Lakes Water Quality Agreement and/or its' policy implementation.

When asked who should be responsible for enforcing/ monitoring adaptation measures most responses mentioned that it should be multiple levels of government including, local municipal, provincial and federal governments, it cannot be just one, and that climate change response must be integrated across all sectors.

When asked should we re-visit, review, and revise RAPS to include climate change impacts and adaptation strategies to sustain beneficial uses, 50% of respondents said yes and 50% said no. Two of the responses given for why it should be no were because "the goal of RAPs is to identify and fix locally controllable sources contributing to BUIs. RAPs are not the appropriate process for dealing with basin scale drivers such as population growth and climate change" or because "RAPs should not be around in the next 5 years. Delist or become an area of recovery and deal with climate change alongside the rest of the Great Lakes basin."

When asked if it is desirable to order which BUIs are most susceptible to climate change in order to prioritize actions for adaptation measures the majority responded yes, and also agreed that it was feasible to order which BUIs are most susceptible to climate change and this was important in order to prioritize actions for adaptation measures.

It is evident that there was clear consensus and agreement among experts on the state of climate change in the Great Lakes and potential adaptation strategies.

## 4.0 Discussions

The uncertainties surrounding the impacts of climate change in the Great Lakes region presents a dilemma to those responsible for determining the appropriate response.

However, not taking actions now may have more risk both environmentally and economically in the future. In order to understand the current views on the issues and verify plausible adaptations strategies, the Delphi is a useful first step. It is important to realize that the Delphi does not provide specifics about the economic costs of project implementation and monitoring as well as the specific organizations that would be charged with these tasks, thus this would have to be analyzed subsequently.

One main advantage of the Delphi is the achievement of consensus in an area that has large uncertainty or lack of empirical evidence (Murphy et al., 1998). The feedback between rounds can stimulate new ideas and provide information that can influence participants' fundamental knowledge base. However, Sackman (1975) explains that this consensus may be a watered down version of the best opinion. Sackman also proposes that anonymity may lead to a lack of accountability and may encourage hasty decisions. The fact that experts are exclusively chosen may reduce this impact. Another bias of the Delphi is due to the fact that participants are asked to explain their views if they chose a value more than two away from the mean. Participants may choose a value closer to the mean in order to reduce their time to complete the response and explain their view in written form or have to justify their ideas. A drawback of using the Delphi is the long time it requires to complete. This may diminish the opportunity for the kind of spontaneous discussion that may occur through in contact or through real-time brainstorming (De Loe, 1995).

Some controversy exists whether a reduction in variance over rounds reflects true consensus (reasoned acceptance of a position) or whether it is an innate pressure to conform (Rowe and Wright 1999). Conforming eliminates the need to explain why they believe their selections were correct against the majority opinion. In this study participants became somewhat more proactive in their responses, increasing levels of feasibility overall and changing their rankings to the stronger extreme (such as from agree to highly agree). Alternatively, Bardecki (1984) reported that respondents with more extreme views tended to drop out of a Delphi Procedure.

Another aspect of the accuracy of the Delphi that is difficult to assess is the role of Delphi panelists and how their attributes related to the material. The expertise or knowledge ability may be stronger on some survey questions than on others. It is also difficult to know which experts from which fields responded to each particular question and whether this was their expertise due to the anonymity of the survey. A possible solution to this would be to have experts perform a self-rating survey to select panel members, however many might be opposed to this type of questioning and this type of survey may contain many personal biases. In some cases questions combined two ideas into one question which skewed some of the results. For example we asked if it was effective to use low flow plumbing and rain water collection systems. Many experts were heavily in agreement with rain water collection but not with low flow plumbing.

Overall, for this study the Delphi served the purpose it was designed for, to obtain expert opinions of climate change in the region, and gain their consensus on possible adaptation strategies and their feasibility.

## 5.0 Conclusion

The first principle of any action is an underlying intention and goal. The intention in this case is directed toward the impact of climate change. Adaptations require the use of resources that are actively available through planning and budgeting for monitoring and maintenance. It is important to consider that planning may substantially curb costs incurred particularly if remediation is necessary. Thus, the Delphi process is only part of the answer, a thorough social and economic analysis of the issue needs to be carried out as adaptations require the resources as means to achieve desired goals.

Through this Delphi application it was clear that the GLWQA should be updated to state a commitment to climate change issues. It is also highly visible that many adaptation strategies suggested in this study were rated as highly effective, desirable as well as feasible. These include regulating residential and commercial zoning to preserve ecological buffers, increasing stormwater collection and reuse, modifying urban landscapes and increasing vegetation, developing wastewater re-use strategies, regulating fishing and public and institutional regulation of both water use and water pollution. As a follow up to the specific adaptation strategy recommendations in this paper, there are some important general factors that need to be included such as identifying goals and objectives for protecting and restoring so that they can serve to protect water quality, building a network of accountability and roles and responsibilities defined and strengthening existing programs, and creating new ones as needed, to achieve these objectives with multi-jurisdictional cooperation. Actions and strategies should be prioritized and include objectives and setting timelines for completion.

Our finding suggest that the governments create a board of experts and stakeholders to study the state of regional climate change knowledge, models, and adaptation measures to determine priorities for programs and projects. Experts, such as shown in the Delphi, can provide valuable insight and feedback in order to understand or place a significant emphasis on adaptation measures and resilience strategies and their implementation logically. This information exchange should be transparent and include regular public communication, monitoring of climate change outcomes, planning programs and adaptation strategies.

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# CHAPTER SEVEN

# What should we expect from the revised Great Lakes Water Quality Agreement?

## Section 1.0: Background

The magnitude of the Laurentian Great Lakes water system is difficult to appreciate. The lakes contain about 23,000 $km^3$ of water, covering a total area of 244,000 $km^2$. The Great Lakes are the largest system of fresh, surface water on earth, containing roughly 18 percent of the world stock (Croley and Lewis, 2006).

This important water body is susceptible to ever increasing carbon dioxide emissions which may be modifying the climate at a rate unprecedented in history. Climatologists, using the General Circulation Model (GCM), have estimated that the increase of carbon dioxide emissions will affect the climate in the Great Lakes basin (Kling et al., 2003, Abdel-Fattah, 2012). Several of GCM models exist and show that at twice the carbon dioxide level, the climate of the basin will be warmer by 2-4°C and slightly damper than at present. Warmer climates mean increased evaporation from the lake surfaces and evapotranspiration from the land surface (Kling et al., 2003). This in turn will change the percentage of water vapour that is returned to the atmosphere. Due to evaporation it is estimated that the amount of water contributed by each lake basin to the overall hydrologic system will be decreased by 23 to 50 percent. The resulting decreases in average lake levels will be from half a metre to two metres, depending on the GCM used (Environmental Protection Agency, 2011). More recent studies indicate this could be much lower but still relevant particularly for shallow lakes and wetlands.

These changes will have serious impacts on the Great Lakes. Increases in evaporation may result in soil moisture deficits, reduction in base flows in streams, periods of lower lake levels and more droughts throughout the area. Large declines in lake levels will create large-scale economic concern for the commercial users of the water system. Shipping companies and hydroelectric power companies would suffer economic repercussions, harbours and marinas would be adversely affected and coastal habitats, in particular wetland systems would be lost or damaged (Abdel-Fattah, 2012). Increased evapotranspiration and soil moisture reduction coupled with increased winds due to more frequent and intense storms could worsen soil erosion and sedimentation with corresponding high sediment and nutrient loading in streams and drains. In addition, precipitation intensity will increase to a degree that a higher percentage of rainfall will be runoff rather than infiltration and groundwater recharge resulting in less water available as soil moisture for plants (Natural Resources Canada, 2006). While the precision of climate projections remains uncertain, the possible implications will have important long-term implications for the Great Lakes and presents a potential risk that cannot be ignored. Adaptations to address the impacts of climate change, taken proactively, can help minimize damages and allow us to take advantage of potential opportunities that climate change may present. The vulnerability to climate change can be determined by examining both the impacts of a changing climate on biophysical and social systems and the capacity of these systems to adapt to the impacts. Policy recommendations that result in ecosystem resilience to climate change will aim at long term recovery of historically degraded locations and prevent damage to susceptible regions.

## Section 2.0: Introduction

In 1972 the United States and Canada created the Great Lakes Water Quality Agreement (the Agreement) to protect and restore the waters of the Great Lakes. Its strengths include a structure and process that place focus on strategies for restoring and protecting the ecosystem rather than prioritizing national agendas (Alliance for the Great Lakes, 2007).

Since its inception much progress has been made and many promises of the Agreement have been fulfilled but many have not. The responsibility of meeting these goals falls to the governments and agencies of the two nations jointly. Since the original version, the Agreement has been revised several times and was being renegotiated and revised from 2010 - 2012. This report aims to provide statements about concerns and recommendations to inform the revision of the Agreement by the parties and its implementation, particularly focused on climate change.

The main inclusions to the revision of the Agreement presented in this report include:

- Measures that emphasize adaptation options to protect water quality and correspondingly protecting human health and productivity of native fish, and wildlife;
- Planning for climate change adaptation strategies for declining water levels;
- Limiting the invasion aquatic invasive species in light of a changing climate; and
- Relating adaptation responses to the beneficial uses describe in Annex 2 of the Agreement (Table 1)

Table 1. Beneficial Use Impairments

1. Restrictions on fish and wildlife consumption
2. Tainting of fish and wildlife flavour
3. Degradation of fish wildlife populations
4. Fish tumours or other deformities
5. Bird or animal deformities or reproduction problems
6. Degradation of benthos
7. Restrictions on dredging activities
8. Eutrophication or undesirable algae
9. Restrictions on drinking water consumption, or taste and odour problems
10. Beach closings
11. Degradation of aesthetics
12. Added costs to agriculture or industry
13. Degradation of phytoplankton and zooplankton populations
14. Loss of fish and wildlife habitat

This report is designed to build the case for these conclusions and why they should be carefully considered when implementing the revised Agreement.

## 2.1 Why the Agreement needed to Change

There are many reasons why the Agreement and its implementation needed to be changed, with a particular emphasis on emerging threats. Many scientific advances have occurred since 1987, the last revision of the Agreement, with new findings and new science that have highlighted manifestations which have only come into view in more recent years.

Over the last two centuries the parties have made only limited progress on Annex 2; only four of the 43 “hot spots” have been removed from the list of the Areas of Concern since 1987.

While substantial effort has been in place to develop initiatives to restore these degraded areas, 25 years of working towards restoration could be in jeopardy in the face of climate change. Many attributes of the climate system in the Great Lakes basin ecosystem are projected to change, specifically air temperature, precipitation events, evaporation rates (affecting water supply levels). Climate change has potentially catastrophic implications for water quality in the Great Lakes-St. Lawrence River system because it will exacerbate existing chemical, physical, and biological stressors and create new problems on top of the current problems.

Recent studies by internationally credible scientists indicate that even if the $CO_2$ concentration in the atmosphere was fixed, surface air temperatures would continue to warm by up to 1.6ºF or 0.9 ºC by 2100 (International Panel on Climate Change, 2007). Progress in mitigation and reduction of $CO_2$ concentrations has proven difficult due to lack of planning and cost-effective alternative energy technologies, as well as political difficulties at national and international levels. Therefore, some degree of future climate change and the related ecosystem impacts is certain and needs to be taken into consideration through adaptation strategies.

Adaptation refers to those actions which may be taken to prevent or reduce damage from climate change by managing the risks to human economic and social activities, as well as the natural environment, in short making them more climate resilient (National Round Table on the Environment and the Economy, 2007). Adaptation measures that focus on reducing vulnerability to both current and future climate variability and extreme events are necessary regardless of the rate of future climate change. The variety of climate change repercussions call for highly diverse adaptation measures. For example, lower water levels in the Great Lakes will have environmental as well as economic impacts in numerous sectors, each of which will require a specific coping strategy. Adaptation actions may involve behavioural changes; operational modifications; technological interventions; revised planning, as well as improved regulations and legislation (Natural Resources Canada, 2007).

Given the uncertainty of how the climate will change, proactive policies can result in needless costs while reactive policies can be much more expensive. In most circumstances anticipatory planned adaptation will incur lower long-term costs and be more effective than reactive adaptation (Natural Resources Canada, 2007). Furthermore, many adaptation measures are ‘no-regrets’ options, meaning a measure that would generate net social and/or economic benefits irrespective of whether or not climate change occurs. They generally have the double benefit of reducing short-term exposure to climate variability as well as long-term vulnerability to climate change. Examples of water ‘no-regrets’ adaptation measures include improved management of water resource infrastructure, increased efficiency in the use of water, and designation of flood hazards. Adaptation measures to reduce water demand could allow for increased water flows to the lakes and thus would help mitigate negative effects of low water levels without having serious cost or risk. Some of these ‘no-regrets’ options may result in large environmental benefits.

A contemporary Agreement must acknowledge the scope and scale of climate change impacts and the serious gaps in understanding and the need for strategies to mitigate the effects. How these changes will impact the beneficial uses of the Great Lakes as identified in Annex 2 of the Great Lakes Water Quality Agreement is important for program and policy approaches that will enable the restoration of beneficial uses that are resilient to climate change impacts in the Areas of Concern. Creating adaptation strategies will be important for ensuring the future of the Great Lakes.

# Section 3.0: Climate Change in the Great Lakes Basin

## 3.1 Air Temperature Increase

Temperature change will have the largest impact on the Great Lakes and beneficial uses. Temperature increases and corresponding increases in evaporation will allow for increase growth of algae, changes in aquatic benthic communities, reduced water levels, expansion of beaches, and decreased wetlands; all which will impact beneficial uses. Warming results in water temperature thresholds being reached for certain species. The spread of invasive species could be exacerbated. Species currently limited to southern states may be able to extend northward into the Great Lakes region. Water temperatures also influence phytoplankton (algae) growth (Magnuson *et al.,* 1997). Blue-green algae have been associated with taste and odour problems in drinking water (Anderson and Quartermaine, 1998) and may result in added costs for water treatment. Reduced water levels will exasperate water quality issues by enhancing their concentration but will also result in expanded shoreline exposure. This will require adaptive planning for the effect this will have on marinas, piers, and boardwalk areas as well as residential waterfront properties.

In the case of temperature increases, adaptation strategies include increase efforts to protect benthic communities and wetland habitats. Implementation of the revised Agreement must pay specific attention to aquatic alien species invasion prevention and rapid response as well as preserving and protecting local ecosystem habitats and diversity.

## 3.2 Increased Precipitation and Storm Events

With more intense precipitation events, more pollutants reach watercourses directly and rapidly through surface runoff. Intense precipitation leads to soil erosion, land and water quality degradation, flooding, and infrastructure failure. More frequent thaw and freezing episodes will contribute to increased runoff causing a higher risk for flooding in Winter months (IPCC, 1996). In urban areas, longer periods of dry weather between rainfall events allow more pollutants to accumulate on road and land surfaces. This combined with more intense precipitation events, adaptation strategies must address limiting pollutants that reach the watercourses through surface runoff. Harmful runoff may enter the Lakes through sewage overflows, agricultural runoff containing pesticides and manure, or even street runoff containing litter and debris. Strategies should include revisions to land use planning, adaptive measures to avert soil erosion, land and water quality degradation, proactive approaches that improve predictions of flooding and mitigation methods, and predictions of infrastructure failure that necessitates measures to address extremes in hydraulic loads.

## 3.3 Increased Evaporation and Reduced Water Levels

With changing climate, wetlands, including those that have benefited from restorative interventions, would experience adverse changes. The increased frequency of both droughts and flooding are expected to impact fluctuations of stream flow, lake levels, and ground water. Flow ultimately influences water levels, in-stream assimilative capacity, habitat deterioration, irrigation, drinking water, and hydropower. Indirect effects of lower lake levels include oxidation of wetland bottoms (Mortsch, 1998) and degree of shoreline exposure (Wall, 1998).

Adaption strategies to address changes relating to increased evaporation and water level declines should focus on reducing the impacts of water levels declines by addressing the impacts that this will have such as increased shoreline exposure, planning for drought, streamflow fluctuations and reduced groundwater. Addressing the access for water when wetlands dry up and wildlife have to adapt, or to reduced water availability for irrigation, hydropower and drinking water is important.

## Section 4.0: Degradation and Adaptation

As discussed, climate changes such as air temperature increases, increased precipitation and storm events, and evaporation causing decreased water levels will directly impact water quality issues, lower water levels and aquatic invasive species. Identifying adaptation strategies for each is necessary. This section supplies some recommendations for improved implementation of the GLWQA of 2012.

## 5.1 Water Quality

Warmer water temperatures reduce dissolved oxygen concentrations; this will directly impact benthic communities and may result in degradation of benthos and degradation of phytoplankton and zooplankton populations. Higher temperatures also change the rate of chemical reactions in the water column, sediment-water interface, and the water-atmosphere interface (Murdoch *et al.*, 2000). Higher sediment and nutrient loadings, due to more intense runoff events, with corresponding increases in water temperature are likely to affect water-borne organisms, favouring more toxic forms of water-borne algal blooms, such as cyanobacteria and dinoflagellates or eutrophication and undesirable algae.

The following are specific recommendations regarding sediment management in light of a changing climate:

1. Strict regulations should be enforced to minimize the use of products that contain harmful contaminants, particularly in areas that could potentially become suspended in runoff such as farms or municipally owned parks or roadways, particularly since runoff will be exacerbated under a changing climate. This may include finding innovative replacements for current practices including salting, and pesticide or insecticide use.

2. Predicting the bioaccumulation and reaction rates of common chemicals under the expected climate change may indicate how serious sediment contamination may be in certain areas. Implementation planning under the revised Agreement can highlight areas that are prone to extensive runoff or currently have excessive sediment contamination issues and create location specific priority adaptive plans for these regions.

3. All efforts should be made to stop contaminants from entering the water course through barriers, including vegetated buffer zones.. Contamination through runoff

will be exacerbated in future climate predictions causing heightened problems areas and could resulting in more locations where there will be restrictions on dredging. Already contaminated sediment should be remediated to prevent excursion of sediment plums into the open waters.. For areas where contamination cleanup had taken place but beneficial uses have not yet been restored, special measures should be taken to ensure all sources of contamination have been controlled, and that all necessary actions of clean-up have been carried out. These areas need to be highly monitored, and recovery of beneficial uses tracked.

Runoff that carries with it human and animal bacteria as well as pathogens, harmful pollutants, or pesticides can cause restrictions on fish and wildlife consumption, degradation of fish and wildlife populations, beach closings and in future result in restrictions on dredging activities.

Some recommendations for implementation to highlight runoff concerns are presented below.

1. A re-commitment to the goals of virtual elimination of persistent toxic substances and the goal of zero discharge, with new programs aimed at determining the relationships of loadings with a changing climate.

2. Strategies should be developed to prevent toxic substances from entering the Great Lakes ecosystem under a changing climate. This could be implemented through source control and through comprehensive sewer use by-laws and sewer infrastructure improvements.

Many of the municipal treatment systems in the Great Lakes were designed to combine the flow from both storm drains and waste sewers (Alliance for the Great Lakes, 2007). This results in overflows during storm events causing treatment plant waste water and untreated sewage, high in nutrients and bacteria, to be released into the Great Lakes. In addition many of these systems are aging and inadequately able to handle the current increased volume of wastewater. A central adaptation strategy needs to concentrate on infrastructure improvements and innovations in the region to prevent sewage and combined sewer overflows. Watershed management programs that concentration on increased infiltration, and water conservation to reduce waste water loadings, are important and feasible adaptation measures for reducing the impacts of these problems.

Some suggestions for sewage overflow adaptation initiatives in light of increased precipitation and increased runoff in light of climate change are as follows:

1. Strategies to reduce sewage overflows may include increasing vegetation in runoff interfaces, permeable pavement to reduce sewer overflows in key watersheds and re-routing or separating rainwater from sewage drains.

2. Sewage plant and sewage treatment upgrades in infrastructure and technology efforts are required to prevent overflows.

3. An adaptation strategy to mitigate agricultural runoff may include requiring pre-treatment or movement of manure storage facilities to eliminate pathogens and toxic gases from entering the Great Lakes.

## 5.2 Water Level Fluctuations and Declines

In general, changes in water levels are expected to have an impact on distribution and abundance of different wetland types, thus affecting habitat suitability and community structure, as well as phytoplankton and zooplankton populations.  Reduced water levels contribute to wetland or shoreline habitat loss. Vital ecosystem services such as filtration, silt trapping, flood water storage and oxygen enrichment must be preserved and restored to support wildlife populations, and prevent degradation of benthos.

Fundamental principle for adaptive responses in the habitat context are as follows:

1. The Agreement implementation plans and actions should contain a goal of protecting and restoring habitat that enhances water quality. The adaptive capability of ecological niches and protected or preserved conservation areas should be assessed as priority regions. This would include an assessment of species and biological integrity, wetlands size and depth, and the wildlife population of the region in order to highlight areas that are at increased risk in case of water level declines, water quality issues and drought. These areas could then be addressed as needed to prevent degradation.

2. The choice of wetlands and other significant nearshore habitats to be restored should be based not only on their contribution to improving water quality, but on projections on their likelihood of establishment under dropping lake levels.

3. The Agreement implementation strategy should include informational/mapping of biodiversity particularly as a changing climate will have implications of fish habitat, temperature tolerance and recruitment. Increased monitoring of populations of aquatic life and wildlife dependant on the Great Lakes, including for recreationally important fish species as well as mammals and birds.

4. A focus should be places on restoration of native species, including lake trout, lake sturgeon, and other species to provide resilience to pressure imposed by a changing climate and invasive species. Preserving local ecosystems and native species will aid in keeping the natural web of interactions viable and improve the health of the Great Lakes.

## 5.3 Onslaught of Aquatic Invasive Species

Physical and chemical contaminants pollutants are not the only factors affecting water quality. Aquatic invasive have the ability to fundamentally change the food web, species distribution, habitats and water chemistry. Aquatic invasive species have also been implicated in the reproductive failures of some fish species including walleye, lake trout, yellow perch and lake herring (Great Lakes Regional Collaboration, 2005). Non-native species have earned their negative reputation as "invasive species" due to their successful rate of survival. A non-native animal may survive better than a native, not only because it has no natural enemies in the new environment, but because it grows more quickly or is better able to cope with unfavourable conditions. This has the added effect of creating more competition for resources for native species.

The Great Lakes now host at least 185 non-native species (Sturtevant et al., 2010). Many in the scientific community believe that the Great Lakes contain many more invasive species than have been identified, due to a lack of a coordinated, basin-wide program to monitor new nonindigenous species (Sturtevant et al. 2010). With climate changes, it is expected that species will migrate to climates that correspond to their thermal optimums causing new species to enter new parts of the lakes. Invasive species have been responsible for billions of dollars in water utility infrastructure maintenance and repair as well as government costs to attempt to control them. Zebra and quagga mussels and the round goby have played a significant role in altering the ecological balance of the lakes. These invaders are filter feeders that strip the waters of plankton on which native species depend. Other biological invaders include large predacious fish like the sea lamprey, and microscopic plankton like *Bythotrephes*. Sea lamprey control programs have been highly effective but other programs to control zebra mussels, round goby and spiny water flea have been sparse.

Aquatic Nuisance Species can be controlled by several general methods, including chemical, biological, mechanical or physical, and habitat management practices. Proper evaluation may provide effective control of aquatic invaders with a minimum of ecological hazard or other side-effects. Management decisions need to consider safety, public health and water quality issues, and non-target impacts.

The revised Agreement needs to include an implementation strategy to limit invasion and include precautionary measures. The Agreement also needs to result in rapid response plans to deal with new invasions. A rapid response plan would prioritize regions that are most susceptible to early invasions and gather baseline data on the local ecosystems in the region in order to best preserve them. Also, institutionalizing a monitoring program and data management will be necessary to improve ecosystem resiliency and the adaptive capacity and employing an adaptive management framework through regional coordination.

Climate change adaptation management plans and activities, particularly those focused on ecosystem-based adaptation, should incorporate invasive species management as a key tool to reduce pressure on local ecosystems and to enhance ecosystem resilience. More specific actions are as follows:

1. Prevent the introduction of new non-native species to minimize the subsequent impacts; this can be done through barriers.
2. Eradicate or control priority existing invasive species with the potential to fundamentally alter ecosystem composition and services, thereby enhancing ecosystem resilience before impacts of climate change are heightened.
3. Developing rapid response plans for dealing with new species including using pesticides to safely and eradicated unwanted invaders while protecting local ecosystems.

## Section 6.0: Policy Statements

In addition to the specific adaptation strategy recommendations, there are some important provisions that we believe should result during the implementation of the revised Agreement. These broader issues have been included for the reader's consideration.

### 6.1 General Statements regarding the Renegotiated Agreement

1. Identify goals and measurable, quantitative objectives for protecting and restoring water quality and re-devote to unfinished pledges to clean up toxic sediments, control phosphorus and address airborne pollutants.

2. Focus on accountability with the parties' and other stakeholders' roles and responsibilities clearly defined.

3. Strengthen existing programs, and create new ones as needed, with an emphasis on the nearshore zone, based on multi-jurisdictional cooperation.

4. Ensure public involvement in the Remedial Action Plan and Lakewide Management process continues, and build place-based governance models based on an analysis of the last 25 years of Annex 2 implementation.

5. Strengthen management cooperation and enforcement and compliance with the Agreement.

6. Re-examine the Great Lakes governance structures and systems which are complicated by multiple jurisdictions and agencies and their overlapping responsibilities.

## 6.2 Climate Change Statements

Since the last revision of the Agreement in 1987, new information on climate change has become more readily available. Having these statements included in a binational agreement will assist in efforts to regenerate Great Lakes resilience;

1. The governments should create a board of experts and stakeholders to study the state of regional climate change knowledge, models, and adaptation measures for the Areas of Concern and other nearshore-zone programs.

2. Place a significant emphasis on adaptation measures and resilience strategies and their implementation.

3. Information exchange should be transparent and include regular expert gathering on Great Lakes-St. Lawrence River system climate change trends, impacts and adaptation strategies to foster communication among climate change researchers.

4. Develop both proactive and reactive plans for dealing with extreme events.

5. Governments should commit to develop and implement aggressive water conservation and efficiency programs.

6. The Agreement should support the major goal of protecting and restoring habitat that enhances water quality. Emphasis on habitat, species and biological integrity, including wetlands protection, conservation, and resilience, should be an outcome of the Agreement and contain considerations on changing climate projections in improving habitat resilience and strengthening biotic integrity.

7. Develop and implement a formal Binational Great Lakes AIS Rapid Response Plan in cooperation with AIS management agencies to harmonize response actions and to promote mutual cooperation between U.S. and Canadian Great Lakes institutions to deal with new invaders.

8. Implement an aggressive aquatic invasive species prevention program at a Binational level.

9. Effective ballast water regulations should be expanded to minimize transport from other vectors such as aquarium food, bait fish, and others.

In addition to renewing, revising and updating current programs and mandates, for the Great Lakes Water Quality Agreement to meet its stated purpose requires specific and institutional adaptive strategies. The climate is certainly changing and although we may not be able to avert these impending meteorological changes, we can enhance our adaptive capabilities to minimize the risk to the Great Lakes. The Great Lakes Water Quality Agreements needs an aggressive focus on Climate Change and the adaptation responses to avoid the degradation that is predicted.

## Section 7: What is in the New Agreement?

Unlike previous processes, there has been very limited discussion with citizen's groups and there are no citizen observers in this process as there were in 1987. The

Canadian delegation did have an advisory group, however, the U.S. delegation declined this opportunity, claiming the inconvenience of dealing with the Federal Advisory Committee Act rules (Great Lakes United, 2011).

Great Lakes United and other groups requested that the negotiators release a draft position or options paper on key points in the new Agreement followed by a 60-day public comment period, and then provide another comment period after the governments have completed their first round of negotiations. They also requested that the team release a final draft of a complete revised Great Lakes Water Quality Agreement for comment prior to completing negotiations and to hold public hearings in both countries on this draft Great Lakes United, 2011). This open approach to the negotiations that has been so successful in the past has been lacking in the current revisions. There have been working group input and webinars held to try to appease the public involvement demand. It is clear that comments from the working group have provided useful feedback from concerned experts.

On Climate Change and invasive species, among conclusions from the working group were (Agreement Review Committee, 2007, Kranzberg, 2012):

Additional authority to address climate change should be articulated in the Agreement's introductory language; A new annex should be created for the Agreement to support climate change-related monitoring and research or Annex 17, "Research and Development," and Annex 11, "Surveillance and Monitoring", should include specific authorities for joint climate change-related monitoring and research.

Regarding Invasive Species, reviewers concluded that a new annex to the Agreement should be created to specifically address invasive species by establishing clear goals and accountability mechanisms.

Great Lakes United and other citizens groups recommended actions such as: replacing the current administrative body for the Agreement, the Binational Executive Committee, with a new binational committee that would have a larger role for the public, and would produce specific work plans to meet Agreement objectives that include benchmarks for measuring progress, and analysis of domestic environmental laws and regulations in both nations to determine where there are gaps or outdated provisions that stand in the way of addressing the complex problems of the Great Lakes. They also suggested there should be a commitment of funding by both nations, including efforts already in place, such as the U.S. Great Lakes Restoration Initiative (GLRI). It should also be included that enforcement of environmental laws and a focus on preventive measures (such as preventing the degradation of important watersheds or habitats) are necessary. Great Lakes United also insisted that periodic reports to Congress and Parliament on progress towards objectives, as well as anticipated threats and recommended responsive actions, accompanied by oversight hearings in which the public can participate and provide comment are needed (Compilation of Binational.net Comments, 2010).

Krantzberg (2012) states that "the degree of engagement in a future Agreement, including scope, issues of significant importance, governance and collaboration will hinge on a thorough analytical process, so far seemingly absent, coupled with real consultation, so far marginally evident" indicating that the process thus far has lacked the coupling of science and policy in an effective way. Krantzberg explains a major flaw of the renegotiation include lack of public engagement, which was key in former revisions.

## Section 8: Conclusion

It is important to include climate change information and adaptation strategies in the implementation of a contemporary Great Lakes Water Quality Agreement to enhance its ability to restore and protect the Great Lakes. Under the Great Lakes Water Quality Agreement, Canada and the United States are responsible for restoring and maintaining the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem. It is vital that authorities hear the voice of citizens that speak for the environment to make the best decisions long-term. It will be important to see how well the new Agreement and its implementation address and manages these emerging issues.

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# CHAPTER EIGHT: SUMMARY

(Chapter 15 in Great Lakes: Lessons in Participatory Governance]

## Sustaining Restoration in Light of Climate Change

[Abdel-Fattah, S. Sustaining Restoration in Light of Climate Change, Chapter in Book Great Lakes: Lessons in Participatory Governance, May 15, 2012 by Science Publishers Editor(s) Velma I Grover, and Gail Krantzberg, May 2012]

## Introduction

The ecosystems and human economies of the Great Lakes region, profoundly shaped by human activities, are now further threatened by climate change (Millerd, 2007). Climate change can be seen in the region through the temperature increases in the northern hemisphere by more than 0.5°C, lengthened growing seasons, and precipitation increases by 5 to 10% since 1900 (Kling et al., 2003). Other indicators that the climate is warming include documented losses of alpine glaciers, sea ice, and seasonal snow cover (Chao et al., 1999). Changes in precipitation patterns and temperature changes will cause increased evaporation and evapotranspiration, and more coastal storms. These changes will affect many ecosystem components including water temperatures, water levels, soil moisture, seasonal flow and timing, vegetation type and animal habitats as well as other systems.

As we look to the future, consensus is building that the biggest threat to the Great Lakes Basin ecosystem is climate change (Krantzberg, 2008). We must adapt management tools, such as the Canada-US Great Lakes Water Quality Agreement (GLWQA) of 1972, to address the threat of climate change. The GLWQA expresses the commitment to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem (United States and Canada 1972, 1978, 1987). There have been no changes to the programs, policies, or priorities within the GLWQA since 1987. By no means has science, technology, and public policy remained static in that time. Although the GLWQA has had substantial influence on the remediation and restoration of features of the regional ecosystem, threats to the Great Lakes in the face of climate change have been overlooked in the legislation and thus demand a renewal of program and policy approaches to the restoration of beneficial uses.

Restoration of beneficial uses under Annex 2 of the GLWQA should be better adapted to anticipate climate change impacts on ecosystem structure and function. Already delisted beneficial uses will need to be included in policy recommendations to ensure that restoration is restored or sustained as the climate changes. Management responses related to beneficial uses need to accommodate uncertainties anticipated regarding climate change impacts on ecosystem structure and function.

**Climate Change in the Great Lakes Basin**

The Intergovernmental Panel on Climate Change (IPCC, 2001) defines climate change as "statistically significant variations of the mean state of the climate or of its variability, typically persisting for decades or longer." Climate change occurs by the greenhouse effect that has for millions of years warmed the Earth, by naturally occurring gases in the atmosphere that trap heat within the atmosphere. Many studies report that human-induced climate change, particularly the burning of fossil fuels, has played a more significant role in climate fluctuation.

Climatologists using the General Circulation Model (GCM) have been able to determine the manner in which the increase of carbon dioxide emissions will affect the climate in the Great Lakes Basin. Climate scenarios developed from GCMs produce changes in the mean values of climatic elements by applying 1XCO2 and 2XCO2 ratios to historic base-case climate.

There are many basin-wide changes that are expected to affect the entire Great Lakes region. An increase in annual and seasonal temperatures for the Great Lakes watershed is predicted. The greatest range in projected temperature increase is in the Spring (0.75 to 5.0°C) while Summer had the least (1.5 to 4.0°C) (Great Lakes Water Quality Board 2003). Summer daily temperatures are projected to gradually increase towards 2030 and then a more rapid increase could have daily average Summer temperatures 10°C higher than the 1960-1990 average by 2100 (Kling et al., 2003). Numerous GCM experiments have determined that the daily temperature range, the difference between the daily high and daily low temperature, tends to decrease with increasing greenhouse gas (Stone and Weaver, 2002).

Overall, annual average precipitation is expected to increase. Winter and Spring modelling scenarios show consistent increases in precipitation while Autumn scenarios show precipitation decreases. Analyses of precipitation extremes in GCMs and regional climate models (RCMs) indicate more heavy precipitation events, fewer moderate events and more dry days or days with light precipitation (Cubash al., 1995; Hennessy et al., 1997; Jones et al., 1997, Trenberth, 1999). The distribution of precipitation throughout the year will be altered. Sharif and Burn (2006) estimate that only the months of January, March and October will have increased monthly precipitation while the other months may see a decrease in precipitation, including the months between April to September when water demand is the highest. Changes in precipitation, combined with temperature increases, will influence soil moisture, ground water recharge, and runoff in the Great Lakes watershed. Warmer air temperatures in Winter and early Spring affect the form of precipitation. It is expected that frequency of temperatures rising above the 0°C threshold and precipitation that previously fell as snow may Fall as rain. As a result, more runoff may occur in Winter and less snow may accumulate and become more intermittent (Great Lakes Water Quality Board, 2003). There will be slightly different changes for each of the Great Lakes dependent on the differences in the physical characteristics of the lakes and local climatic differences.

It is important to investigate these changes, and identify trends in order to accurately assess the ecological, social and economical impacts.

### Ecological Impacts due to Climate Change

Many attributes of the climate system in the Great Lakes watershed are projected to change, specifically air temperature, precipitation events, evaporation rates, water levels, ice cover, water quality, natural ecosystems and biodiversity. A changing climate may put added stress on beneficial uses, especially those that are already impaired (see Fig.15.1.), creating heightened sensitivities as well as new risks within ecologically healthy areas.

Figure 15.1 Beneficial Use Impairments in Canadian AOCs

| | Lake Basin/ Region | AOC (Canadian and Binational) | Beneficial Use Impairments | Common Basin Impairments |
|---|---|---|---|---|
| Upper | Superior | Thunder Bay | A,B,C,D,F,G,J,K,M,N | A,C,F,G,K,N |
| | | Nipigon Bay | A,B,C,F,G,H,K,N | |
| | | Jackfish Bay | C,D,F,G,K,N | |
| | | Peninsula Harbour | A, C, F, G, I, N | |
| Middle | Huron | Severn Sound | A,C,F,G,H,K,N | A,C,F,G,H,J, K,N |
| | Middle Connecting Channels | St. Mary's River | A,C,D,F,G,H,J,K,N | |
| | | St. Lawrence River (Cornwall) | A,C,F,G,I,J,N | |
| | | Niagara River | A,C,E,F,G,H,I,J,K,N | |
| Lower | Erie | Currently no Canadian AOCs - Wheatley Harbour recently delisted. | | A,C,F,G,H,J, K,N |
| | Ontario | Hamilton Harbour | A,C,D,E,F,G,H,J,K,M,N | |
| | | Bay of Quinte | A,C,F,G,H,I,J,K,M,N | |
| | | Port Hope | G | |
| | | Metro Toronto | A,C,F,G,H,J,K,N | |
| | Lower Connecting Channels | St. Clair River | A,D,F,G,H,J,K,L,N | |
| | | Detroit River | A,D,F,G,J,K,N | |

| | Beneficial Uses |
|---|---|
| A | Restrictions on Fish and Wildlife Consumption |
| B | Tainting of Fish and Wildlife Flavour |
| C | Degraded Fish and Wildlife Populations |
| D | Fish Tumours or Other Deformities |
| E | Bird or Animal Deformities or Reproductive Problems |
| F | Degradation of Benthos |
| G | Restrictions on Dredging Activities |
| H | Eutrophication or Undesirable Algae |
| I | Restrictions on Drinking Water Consumption or Taste |
| J | Beach Closings |
| K | Degradation of Aesthetics |
| L | Added Costs to Agriculture or Industry |
| M | Degradation of Phytoplankton and Zooplankton Populations |
| N | Loss of Fish and Wildlife Habitat |

Environmental restoration of sensitive areas could be hindered by a changing climate and an altered hydrological regime (Rhodes and Wiley, 1993). Twelve of the 14 beneficial uses were identified as having a potential vulnerability to climate change. The two beneficial uses impairments' that were considered not directly affected by climate change are fish tumours or other deformities and bird or animal deformities or reproduction problems (IJC, 1991). These two beneficial use impairments are largely related to water quality issues such as chemical contaminants (through human waste such as pharmaceuticals), and anthropogenic pollutants. These may be secondary impacts of climate change, for example increased contamination through runoff and thus will be included under the direct impact. In an attempt to identify the potential risks posed by climate change to the beneficial uses of the Great Lakes, an evaluation of ecosystem impairments particularly at risk in light of projected impacts of climate change are examined below. The most significant ecosystem changes discussed are temperature, precipitation, and evaporation.

***Increased Temperature***

An increase in annual and seasonal temperatures for the Great Lakes watershed is expected. The greatest range in projected temperature increase is in the Spring (0.75 to 5.0°C) while Summer had the least (1.5 to 4.0°C) (Great Lakes Water Quality Board 2003). Air temperature plays an important role in defining the length of the growing season, the frost-free season and thus also species breeding seasons. Increases in air temperature drive water surface temperatures and affects freeze and thaw cycles, the rate of chemical reactions, and biological productivity (Great Lakes Water Quality Board 2003). Since the moisture-holding capacity of the atmosphere is enhanced with increased temperature, the potential for loss of water to the atmosphere through evaporation and evapotranspiration demand is expected to also increase. In a humid region such as the

Great Lakes, atmospheric moisture content is a very important factor. Mean annual lake surface evaporation is expected to increase by +6 to +39 % due to an increase in lake surface temperatures (Lofgren et al., 2002) which will impact water levels, soil moisture content and wetlands.

Rising surface temperatures may amplify the negative consequences of eutrophication, as well as hypoxia (Kennedy, 1990) and their subsequent pressures on benthic communities. Benthic communities are vital to lake health. Many species of *chironomids* and *tubificidoligochaetes* are tolerant to low dissolved oxygen, such that these become the dominant in lakes with hypoxic hypolimnia. As hypoxia becomes more severe tubificids can become dominant over chironomids. In cases of prolonged anoxia, the common variety of benthic organisms might disappear entirely (Mackie, 2004).

Warming will also result in water temperature thresholds being reached for certain species. Earlier warming of Spring temperatures and later cooling of temperatures in Autumn contribute to an earlier start for plant growth and a longer growing season. Natural adaptation of flora and fauna by migration assumes that species are able to move rapidly enough to remain within their preferred climate zones even with natural and human-caused barriers. Temperature changes can influence the timing of breeding and bird migration (Kerr and Packer, 1998); rare and endangered species will be particularly vulnerable. These populations have more specific habitat requirements or habitat niches and thus are the most susceptible to changes and have the least adaptation options (Great Lakes Water Quality Board, 2003).

Cold-water fish may lose important habitat as temperatures rise above their thermal thresholds (Meisner, 1990). Climate change impact assessments have projected that fish ranges could move more than 500-600 kilometres northward leading to invasions of warmer water fish and extirpations of colder water fish (Magnuson et al., 1997). Breeding windows may be compressed or shifted. Optimum temperatures for lake trout spawning in the Autumn is 8°C to 11°C and Spring spawning for northern pike is 4°C to 12°C; warming could affect biological cycle timing. Egg development is largely temperature dependent, as is the period following hatching when juveniles rely on the local nutrients. For some fish, such as salmon, juveniles remain in the gravel for several weeks surviving on the nutrients in their yolk sacs before beginning exogenous feeding and emerging. The timing of emergence from the gravel has likely evolved in response to selection for a presumably optimal time for survival (e.g., temperature and flow), food availability and competitive advantages. If Winter temperatures increase following climate change, egg incubation will be shortened and result in earlier juvenile emergence from the gravel, in the future. Such a shift away from optimal timing for juvenile emergence is likely to result in increased mortality. Moreover, if climate change results in increased Winter flows, as many models predict, gravel shifts caused by flooding may become more frequent and larger, increasing the susceptibility of incubating eggs to destruction (Fleming and Jensen, 2002).

Species currently limited to southern states may be able to extend northward into the Great Lakes region. Thus, the spread of invasive species could be exacerbated. Species such as carp, zebra mussel, purple loosestrife, curly-leaf pondweed, and Eurasian milfoil are examples of species whose introductions have affected the Great Lakes ecosystem. At present, zebra mussel is primarily found in the lower Great Lakes while the coldwater of Lake Superior limits its expansion (Easterling and Karl, 2001). Warmer water temperatures would allow zebra mussel to become more widespread on Lake Superior. Changes to the natural ecosystems and the inhabitants of the region will ultimately affect the entire dynamics of the system.

Increased temperatures may better allow for bacteria and viruses to survive and disease local plants, trees and animals. Dutch elm disease contributed to an almost extinction of this species throughout the region in the 1970s. Oak wilt is another disease that exists in many parts of the region, although it mostly affects the northern portion. Other forest-related diseases and pests that are found in the region in non-epidemic numbers include spruce budworm, cankerworms, forest tent caterpillar, white pine blister rust, white pine weevil, basswood thrips, butternut canker, and Asian long-horned beetle (Great Lakes Water Quality Board, 2003). New diseases may become prevalent in the region and retard plant growth or animal illness.

Climate change is expected to directly and indirectly influence water quality (Murdoch et al., 2000). Warmer water temperatures reduce dissolved oxygen concentrations. Higher temperatures also change the rate of chemical reactions in the water column, sediment-water interface, and the water-atmosphere interface. Water temperatures also influence phytoplankton growth; blue-green algae dominate at the highest temperatures, followed by green algae, then flagellates and finally diatoms at lowest temperatures (Magnuson et al., 1997). Blue-green algae have been associated with taste and odour problems in drinking water (Anderson and Quartermaine, 1998).

As temperatures rise, the ability of the atmosphere to hold moisture increases allowing for increased and more intense precipitation events.

***Precipitation***

Overall, annual average precipitation is expected to increase. Winter and Spring modelling scenarios show consistent increases in precipitation while Autumn scenarios show precipitation decreases. Changes in precipitation, combined with temperature increases, will influence soil moisture, ground water recharge, and runoff in the Great Lakes watershed. Whether projected increases in precipitation will be offset by more water loss due to higher evaporation is the concern especially during Summer and Autumn. In the basin, these seasons are typically characterized by low stream flow. Low flow conditions could become more extreme become more vulnerable to water level decreases (Great Lakes Water Quality Board, 2003).Winter in the Great Lakes region is a period with reduced runoff due to ice coverage; most precipitation Falls as snow and is stored in snow pack. Warmer Winter temperatures could lead to more rainfall events, which create runoff. Often infiltration is reduced at this time due to frozen ground conditions and more overland runoff may occur. In response, flow in rivers and streams will increase, causing a higher risk for flooding. Peak flows can be high if the snow cover melts quickly. Earlier Spring warming may bring on an earlier melt. Since there may be less snow stored in the snow pack, the amount of water available to runoff and contribute to the peak flow will be less. These changes could cause an increase in mean flow which will ultimately influence Great Lakes water levels, instream assimilative capacity changes affecting water quality, habitat deterioration, and access to water for irrigation, drinking water, and hydropower.

Extreme precipitation and high runoff is expected to increase causing the risk of soil erosion, land and water quality degradation, flooding, and infrastructure failure. With more intense precipitation events, more pollutants reach watercourses directly and rapidly through surface transport by runoff. In urban areas, longer periods of dry weather between rainfall events allow more pollutants to accumulate on road and land surfaces. Spring can be a high pollution-loading period because of pesticide application combined with little vegetative cover (Soil and Water Conservation Society, 2003). Although benthic macroinvertebrates are moderately long-lived, contamination and toxicity of sediment caused by runoff will affect those sensitive benthic organisms (Mackie, 2004).

Wildlife is susceptible to extreme climate events. Droughts and periods of excessive wetness can affect habitat as well as food supply. Extreme weather also plays a role in regional forest destruction. Lightning, high winds, hail, or tornadoes can destroy trees. Exceptionally cold or hot weather can also retard growth or kill trees depending on the duration and location of such weather (Great Lakes Water Quality Board, 2003). Wildlife will also be highly susceptible to increased evaporation that may cause wetlands, streams and rivers to dry-out and reduce animal access to fresh water.

***Evaporation and EvapotranspirationIncreases***

The frequency of both droughts and flooding are expected to increase due to fluctuations of stream flow, lake levels, and ground water due to increased evaporation and evapotranspiration. Summer and Fall low flows may become even lower due to greater evapotranspiration and reductions in ground water base flow. Dry periods reduce recharge and water levels in aquifers. Shallow aquifers consisting of unconsolidated sediment, weathered or fractured bedrock are more vulnerable to these changes. Although a changing climate may result in higher total annual precipitation, ground water levels will likely decrease (Nastev et al., 2002). Development of dry, crusty tops on soils due to increased temperature will impede infiltration reducing ground water levels (Piggott et al., 2001). As a result, the low water levels experienced in the Great Lakes during 1999 to

2001 could occur more frequently. Minimum levels occur in late Autumn and early Winter; and rise in Spring with snowmelt and reach a maximum from July to September. Then, they decline in Autumn due to evaporation and reduction in runoff. Distinct shifts are being detected in the seasonal cycle of water levels for the Great Lakes. In Lakes Erie and Ontario, during the period 1860 to 1990, the annual rise and Fall of levels occurred one month earlier; Spring levels are becoming higher while Fall levels are becoming lower sooner (Lenters, 2001). Lake Huron water levels have declined due to a combination of lower precipitation, higher air temperatures, and increased evaporation over the past eight years. As cold, dry air masses pass over warmer Lake Huron waters in the Fall and Winter, the potential exists for lake levels to plummet to their lowest point in 36 years (Schwartz, 2001). Michigan-Huron exhibited higher levels in Winter and reflected a shift, since 1965, to more runoff in Winter and less Spring runoff. Studies have indicated that Lake Huron water levels are projected to decline by as much as 1 m by 2050 (Mortsch et al, 2000).In Lake Superior, Summer and Fall levels are decreasing (typically the high period) while Spring and Winter levels remain roughly the same. Declining water levels will produce wider beaches and may influence shoreline erosion (Schwartz, 2001).

Wetlands would experience changes including reduction in water levels; changes in timing and amount of water flowing through a wetland affecting flushing, sedimentation, nutrient input; and length of ice cover. Indirect effects of lower lake levels include oxidation of wetland bottoms (Mortsch, 1998).

Increasing air temperatures combined with evaporation and alterations to precipitation amount, timing, and duration could lead to more variability of water supply in the Great Lakes region. Thus it can be seen that the terrestrial and aquatic ecosystems that make up the biosphere provide vital goods and services to humanity, including food, water, recreation, and natural beauty.

**Social and economic impacts caused by climate change**

The economy of the region is largely diversified and includes manufacturing, tourism and recreation services, agriculture, and forestry (Sousounis and Glick, 2007). The region is also a major shipping corridor, with traffic generating US$3 billion business revenue annually and 60,000 jobs (Kling et al., 2003). The Great Lakes themselves are a recreation and tourist attraction with more than 15 million people in the Great Lakes states participate in fishing, hunting, or wildlife watching; a revenue of US$18.5 billion in sales annually (Kling et al., 2003).With a changing climate there would be a corresponding change in social dynamics and economy of the Great Lakes. Particularly, commercial fisheries, recreation and hunting, local industry including water purification and environmental conservation will be economically and socially affected.

**Commercial Fish Market and Recreational Fishing and Hunting**

Due to warmer water temperatures there would be an increased warmer water species and aquatic life that is tolerant to warmer temperatures. There would also be a shift away from cold-water fisheries (Atkinson et al., 1999). A predicted warming of 2.5ºC over the next 70 years would decrease the habitat space of brook, rainbow, cutthroat and brown trout by one-fourth, possibly even down to one-third (Dempsey et al., 2008). Climate change will also alter growth rates, mortality rates, reproductive capacity and distribution of fish which may cause a shift in contaminant uptake leading to greater restriction on fish consumption (Brander, 2006). Some smaller, localized species may undergo severe population reductions or even extinction. These changes may affect which types of fish can be commercially viable. This may mean that some fish need to be farmed to reduce contamination. Recreational fishing will need to be reduced or monitored if fish populations become at risk, or contaminated. If wildlife habitats are put at risk or diminished, hunting may need to be reduced or monitored to protect native species.

Warmer water temperatures may also lead to the invasion of non-native species. This invasion of both exotic species and or warm water fish is difficult to prevent. Fish populations have also been impacted heavily by the parasitic sea lamprey which is expected to flourish in warmer temperatures (Holmes et al., 1994). These problems will impact the fisher's ability in catching healthy fish to sustain revenue and local fish prices could rise as a consequence. In Lake Ontario, scientists have identified invasive mussels as a main culprit responsible for the collapse of the lower food web and mussels are thought to be part of the causal mechanism of the botulism outbreaks that are responsible for the death of thousands of fish and fish-eating seabirds. This could increase the cost habitat cleanup and conservation efforts. Many of these impairments can also be very cost intensive for industry.

**Industry and water sanitation and purification**

Climate change is expected to directly and indirectly influence water quality (Murdoch et al., 2000). As air temperature increases, water temperatures mirror that rise.

Warmer water temperatures predicted with climate change will enhance productivity of algae blooms (Poff et al., 2002). These compounds occur in lakes, reservoirs and rivers. Blue-green algae have been associated with taste and odour problems in drinking water (Anderson and Quartermaine, 1998). They possess musty, earthy odours at very low thresholds. Moreover, these compounds tend to accumulate in fish flesh where they significantly alter fish taste. They can also markedly reduce the quality of drinking water. An increase in algal blooms may result in added costs for drinking water treatment. Healthcare costs could rise if contamination enters drinking water causing human sickness.

Within the Great Lakes region, the zebra mussel infestation has created a severe economic problem. Zebra mussels have an impact on facilities that use raw surface water, such as utility plants, factories, and water treatment plants. These mussels colonize inside water intake pipes, wells, and can attach to many types of surfaces. In addition to clogging pipes and reducing the flow, zebra mussels infiltrate interior plant structures, causing obstruction of pump valves and leading to failures of some components. The cost of cleaning intake pipes and repairing failed components can be massive. Mussels have caused millions of dollars of damage in the Great Lakes region alone (The National Atlas of the United States of America, 2010). The invasion of the zebra mussel into the Great Lakes has not only caused a serious economic problem, but also threatens aquatic communities.

With water level declines and possible water scarcity there could be less potential for hydropower, and less water for industry operations. Farming industries may also be affected and possibly need to rely on less water intensive techniques or crops that are not as water dependant.

**Recreational use of Great Lakes Beaches, Cottages and Marinas**

The intensity of precipitation that is expected with climate change will have an impact on beach closings due to increased runoff as well as pollution or sewage waste that would result from overflows and affect the quality of beaches. Human sewage is a major source of bacteria in surface waters, and can come from combined sewer overflows caused by an abundance of stormwater. Runoff can also carry dangerous substances into the lakes. Heavy metals such as copper, lead, aluminum and zinc can be carried into the lakes and at higher concentrations these substances can be toxic to aquatic life.

Changes in the timing and duration, height and elevation of annual and seasonal water levels may also lead to beach closings. Lower lake levels will impact beaches, with the amount of new exposure a function of water depth, lakebed composition and slope, and water level decline (Wall, 1998), such that larger beach surfaces could affect recreation space. Furthermore, exposed mud flats could reduce shoreline aesthetics, and there is the potential that exposed lakebeds could include toxic sediment (Mortsch, 2000). Pollution problems may also be exacerbated on some beaches due to low water levels, resulting in more beach closures. With reduced water levels, there could be decreased depth of navigation channels, stranded docks and harbours impacting marinas and shipping ports.

Recent and ongoing global environmental changes—including climatic change, habitat fragmentation, pollution, and the spread of invasive species—are affecting the functioning of many ecosystems, and therefore the goods and services that they provide.

**Governance**

Clearly, the changes expected with a changing climate cannot be ignored. Polices must be developed to highlight these changes, and build adaptation strategies. Restored beneficial uses may be better adapted to cope with these changes in climate, but over time could become re-impaired. This problem will result in increased and advanced impairments in beneficial uses; whether currently impaired or restored. Many of the beneficial use impairments are affected by climate change determinants that are common. For example, algae blooms will respond to increased nutrient loadings associated with severe storm effects, which also effects drinking water, beach closings, and added costs to treat water for agriculture or industry. Further, water quantity issues associated with lake evaporation and increased temperatures will exacerbate the deterioration of fish and wildlife populations and loss of fish and wildlife habitat which are among the most widespread impairments. These are highly vulnerable beneficial uses; Fig. 15.2 identifies how ecosystem changes are could result in multiple beneficial use impairments.

Figure15.2 Beneficial Uses Affected by Climatic Change

| | Climate Variability and Climate Change Effects | | | | |
|---|---|---|---|---|---|
| **Beneficial Use Affected** | **No. of Canadian AOCs impaired (% of 14)** | **Air Temperature Increases** | **Intensity of precipitation and storm events, increased runoff** | **Evaporation/ Evapo-transpiration (water levels)** | **Shortened Snow Seasons and reduced ice cover** |
| 1. Restrictions on fish and wildlife consumption | 11 (79%) | X | X | | |
| 2. Tainting of fish and wildlife flavour | 0(0%) | X | X | | |
| 3. Degradation of fish wildlife populations | 9 (64%) | X | X | X | X |
| 4. Fish tumours or other deformities | 3 (21%) | - | - | - | - |
| 5. Restrictions on Dredging Activities | 13 (93%) | X | X | X | |
| 6. Bird or animal deformities or reproduction problems | 2 (14%) | - | - | - | - |
| 7. Degradation of benthos | 13 (93%) | X | X | X | |
| 8. Eutrophication or undesirable algae | 6 (43%) | X | X | | |
| 9. Restrictions on drinking water consumption, or taste and odour problems | 3 (21%) | X | X | X | |
| 10. Beach closings | 8 (57%) | X | X | X | |
| 11. Degradation of aesthetics | 9 (64%) | X | X | X | |
| 12. Added costs to agriculture or industry | 1 (7%) | X | X | | |
| 13. Degradation of phytoplankton and zooplankton populations | 3 (21%) | X | X | X | |
| 14. Loss of fish and wildlife habitat | 12 (86%) | X | X | X | X |

In order to highlight the most sensitive beneficial uses, an examination of common beneficial use impairments, forecasted ecosystem changes and the specific properties of the individual Great Lakes allows for insight into the future of the Great Lake Basin to aid in building policies that combat the main issues affecting the individual lakes (see Fig. 15.3).

Figure 15.3 Sensitivities

| | Lake Basin/ Region | Ecosystem Characteristics Vulnerable Impairment | Resultant of Impairments |
|---|---|---|---|
| Upper | Superior | High Retention Time | A,B,C,D,E,F,G |
| | | Shoreline Length | A,B,C,D,E,F,G,I,J |
| | | Largest Temp Increase | A,B,C,F,G,H,I,J,K,N |
| Middle | Huron | Exposed Shorelines | A,B,C,D,E,F,G,I,J,K |
| | | Low Water Levels | A,B,C,D,E,F,G,I,J,K |
| | | High Biodiversity | C,N |
| Lower | Erie | Low Water Levels | C,D,G,H,I,J,K,N |
| | | High Biodiversity | C,N |
| | | | |
| | Ontario | Variable Spring/Fall changes | A,C,N |
| | | | |
| | | Urbanization | A,B,C,D,E,F,G,H,I,J,N |

BeneficialUses

- A Restrictions on Fish and Wildlife Consumption
- B Tainting of Fish and Wildlife Flavour
- C Degraded Fish and Wildlife Populations
- D Fish Tumours or Other Deformities
- E Bird or Animal Deformities or Reproductive Problems
- F Degradation of Benthos
- G Restrictions on Dredging Activities
- H Eutrophication or Undesirable Algae
- I Restrictions on Drinking Water Consumption or Taste and Odour
- J Beach Closings
- K Degradation of Aesthetics
- N Loss of Fish and Wildlife Habitat

Due to the fact that climate is constantly changing, restored beneficial uses also need to be highly monitored and adaptation responses directed at these beneficial uses that are highly sensitive to projected effects of climate change and generally widespread across Ontario's AOCs should aid in achieving more resilient end points to sustain delisting activities.

A policy framework must be developed, but will need to be very adaptable as the climate changes, and include monitoring and assessments tools. Although there is much uncertainty in predicting the future, by looking at the past one can see that the climate has already changed. It is important to present possible future scenarios and policy goals around social and environmental impacts to push for a policy that aims to better our future. Thus, a renewed Great Lakes Quality Agreement, or efforts towards its implementation need to include two important considerations:

- Options for consideration to ensure restored beneficial uses remain restored
- Potential adaptation responses to enhance the resilience of beneficial uses

Maintaining the Great Lakes ecosystems in light of climate change is vital in preserving the surrounding habitats as well as our access to clean water and the beneficial uses the Great Lakes provide. A development of adaptive strategies to reduce the vulnerabilities of the conservation targets to actual or potential climate change effects is needed. It implies adjustments in ecological, social, or economic systems in response to actual or expected climate, for example, adaptation techniques to limit runoff or nutrient loading in the system.

One way of approaching the identification of policy options is to question what ecological, social or economic adjustments can be made to reduce the magnitude of the threats to a particular conservation target and thus reduce the vulnerability of beneficial uses and make them more resilient to climate change? For example, how might the threats of urban and agricultural runoff, dams and invasive species be reduced and ameliorate Great Lakes vulnerability to climate changes? What are some ecological, social or economic alternatives to be considered? This will allow for sequential consideration of the individual conservation targets for impaired beneficial uses and create a policy solution for including climate change in decision making in the Great Lakes. Adapting to the changes now, could reduce the potential impacts in the future. Progress will come from realizing that changes in global climate will have significant impact on local and regional hydrological regimes, which will in turn affect ecological, social and economical systems. The overall aim is to create suggestions for adaptations, and policy goals to include climate change into planning, remedial programs and improve the resilience and sustainability of the Great Lakes and its beneficial uses.

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# CHAPTER NINE: CONCLUSION

The overarching goal of this thesis was to translate climate-related research into real-world impact from a fundamental understanding of climate processes to climate impacts and mitigation technologies and policies. The researched achieved this through developing climate models to predict future forecasts on locations across the Great Lakes, translating this to impacts, and developing verified adaptation strategies and related policies.

The modeled data from the downscaling models predicted overall increased temperatures across the basin as well as increased precipitation (although lower at lower frequencies). Downscaled precipitation and temperature scenarios generated statistically significant differences between the three locations studied (Thunder Bay, Cornwall and Toronto), thus illustrating that within the basin regional modeling through downscaled scenarios is more relevant when evaluating the Great Lakes basin. The overall change from present is presented in Table 1. This shows the average seasonal change the next 100 years. The highest degree of change occurs in Lake Superior.

Table 1. Average Overall Change from Present

| Site | | Spring | Summer | Fall | Winter |
|---|---|---|---|---|---|
| Thunder Bay | PREC | 0.6 | 1.8 | 0.7 | 0.5 |
| | TMAX | 5.7 | 3.7 | 2.3 | 6.6 |
| | TMIN | 5.5 | 3.8 | 1.9 | 6.7 |
| Cornwall | PREC | 0.4 | 1.4 | 0.4 | 0.3 |
| | TMAX | 4.6 | 2.3 | 2.0 | 2.1 |
| | TMIN | 2.3 | 2.6 | 0.6 | 3.0 |
| Toronto | PREC | 4.3 | 3.0 | 1.4 | 5.3 |
| | TMAX | 0.6 | 1.3 | 0.6 | 0.5 |
| | TMIN | 5.3 | 2.5 | 2.1 | 2.7 |

Once the models were developed, it was necessary to process what impact this would have on the lakes. This could largely be done through a literature review. It was clear that temperature increases, increased precipitation and storm events, as well as evaporation impacting lake levels would have great consequences for the Great Lakes. These would drive degradation of water quality, water levels, and heighten the arrival of invasive species. A thorough analysis of how these drivers would impact impaired beneficial uses was then performed.

The downscaled tools were useful in predicting local impacts which could be translated to how these would affect local beneficial uses that were already degraded. One can dependably predict that degraded areas of the Great Lakes will experience greater stress due to climate change. This research examined the specific impaired beneficial uses to identify particularly sensitive beneficial uses and how those vary among lakes. For the purpose of prioritization of sensitive beneficial use impairments, a brief analyses of which uses are impaired at each AOCs was performed. The causal factors for this variance was explained by the physical differences in the characteristics of the lakes.

The major environmental issues of concern in Thunder Bay include fish consumption restrictions, dredging restrictions, loss of species abundance and diversity and reduced recreational activities. These impairments can largely be traced back to water quality issues. Contaminated sediments are a significant contributor to this problem. Increased runoff carrying with it harmful chemicals and pollutants could exacerbate this issue. Adaptation strategies specific to limiting runoff are important for the Thunder Bay AOC.

The Cornwall Area of Concern major environmental issues include Mercury, PCBs and other contaminants of concern in water, sediments and fish, bacterial contamination leading to beach closings, habitat destruction and degradation, and exotic species. Historically, contaminants have entered the St. Lawrence River through local industrial and municipal discharges, urban stormwater, agricultural runoff and other diffuse sources such as air deposition. For Cornwall it may be necessary to target specific industrial polluters in the area to push for better practices and stricter regulation.

In large cities like Toronto, very little of the rain that falls can be filtered into the ground. Instead stormwater runs off roofs, roads and parking lots and empties through storm sewers into our streams, rivers and Lake Ontario. Stormwater is a major source of pollution because it picks up oil, grease, metals, pesticides and other pollutants en route to watercourses. The problem becomes even greater in the older parts of Toronto where sewers carry both sanitary sewage and stormwater. In these areas, during large rainstorms, diluted sewage overflows into our rivers and the waterfront through combined sewers. Due to its debilitating effects on water quality, better management of stormwater in the Toronto needs to be priority for planning adaptation against climate change.

Based on the drivers of degradation, it was possible to build adaptation strategies to prevent further impairment of beneficial uses. These strategies were then presented to an expert panel to obtain their positions on the effectiveness and feasibility through the Delphi Method. Experts were not supplied with the results of the climate downscaling results. It was thought that this would force them to comply or conform to the researchers point of view and thus would bias their opinions. It was necessary to analyze experts existing opinions on climate change in the basin based on pre-existing scientific studies and their own experiences in order to understand the basic current scientific opinion in this area. Experts were also polled on their opinions regarding current policy gaps regarding climate change in the Great Lakes. It was clear that experts believed that current regulation lacked in regard to inclusion of climate impacts and believed adaptation strategies needed to be considered. Many of the adaptation strategies presented by the researchers were deemed as both desirable and effective. The Delphi served as an effective tool to obtain expert opinion and gain consensus in an area that contains high uncertainty. The results of the overall opinions of the experts on the best adaptation strategies are shown below in Table 2.

Table 2. Adaptation Strategy Overall Ranking

| Adaptation Strategy | Overall Ranking |
|---|---|
| Preventing the spread of invasive species (through biological, chemical or physical control) is important in order to protect fish and wildlife; and their habitats in light of climate change when feasible for specific species. | Probably Effective (2.6) |
| Regulating residential and commercial zoning permits to accommodate expected climate changes for actions such as preserving ecological buffers such as wetlands. | Definitely to Probably Effective (1.96) |
| Carefully limiting harvests for select fish and improving hatchery functions to protect fish populations to preserve native fish populations that may diminish under climate change. | Probably Effective (2.3) |
| When fish populations are impacted by fishing activities and further complicated by associated land based development, the ecosystem shift directly and indirectly attributed to climate change adds further stress. One management option to contribute to sustainability is through reducing the pressures of fishing. | Definitely Effective (1.85) |
| Increase the capacity of storm water collection for increased precipitation. | Definitely Effective (1.9) |
| Modify urban landscapes (improving infrastructure and increasing vegetation) to reduce water contamination from runoff. | Definitely Effective (1.65) |
| Control water pollution through stricter fines to enhance water quality and associated drinking water and keep beaches open. | Probably Effective (2.5) |
| Upsize water capture and drainage infrastructure for severe weather event. | Probably Effective (2.1) |
| Use artificial floating islands as a means of using plants to remove excess nutrients in the water body. | Probably Effective (2.9) |
| Control water pollution through lower water allowances through a regulatory approach (Limit household use or industry use of water). | Probably Effective (2.8) |
| Find new groundwater sources and enhancing existing groundwater supplies through aquifer storage and recovery to enhance water supply prepreparedness action in light of climate change. | Neutral (3.2) |
| Use low flow plumbing and rain water collections to control the water supply. | Probably Effective (2.0) |
| Develop advanced wastewater treatment capacity for water reuse, such as grey water sources to prepare for water scarcity during climate change. | Definitely Effective (1.9) |

Once data regarding policy gaps, and adaptation solutions was gathered, it was plausible to build informed policy suggestions for revision of the Great Lakes Water Quality Agreement. The main statement was that climate change needed to be included in the GLWQA.

The new Agreement, expected to be signed this year, will attempt to be more streamlined, less cumbersome, and publicly accessible through readability. It is expected to have a greater emphasis on pollution prevention and emerging issues. In recent years, Great Lakes scientists have lamented about data gaps in the areas of sewage plants unable to treat all pharmaceutical waste, in phosphorus runoff that leads to algae, in mercury depositions from the air that settle in water and make some fish hazardous to eat, and in reporting chemical spills. There is still a fear that the negotiations will not be well scientifically informed. This thesis attempts to fill some of those knowledge gaps about climate change impacts and adaptive management.

The contribution of this research to science is novel and holistic. This thesis is the first to downscale AOC sites using SDSM and ANN. It is also the first to translate ecosystem changes to beneficial use impairments at AOC sites based on technical downscaling predications. This research is first to survey Great Lakes experts using the Delphi technique to elicit their opinions on climate change, climate adaptive strategies and policy gaps. This research combines relevant technical modelling and survey techniques to provide practical adaptation strategies and policy recommendations. Table 3 shows illustrates the flow of the research and outcomes for adaptation strategies for each AOC site.

Table 3. Climate Sensitivities and Adaptation Strategies at AOCs

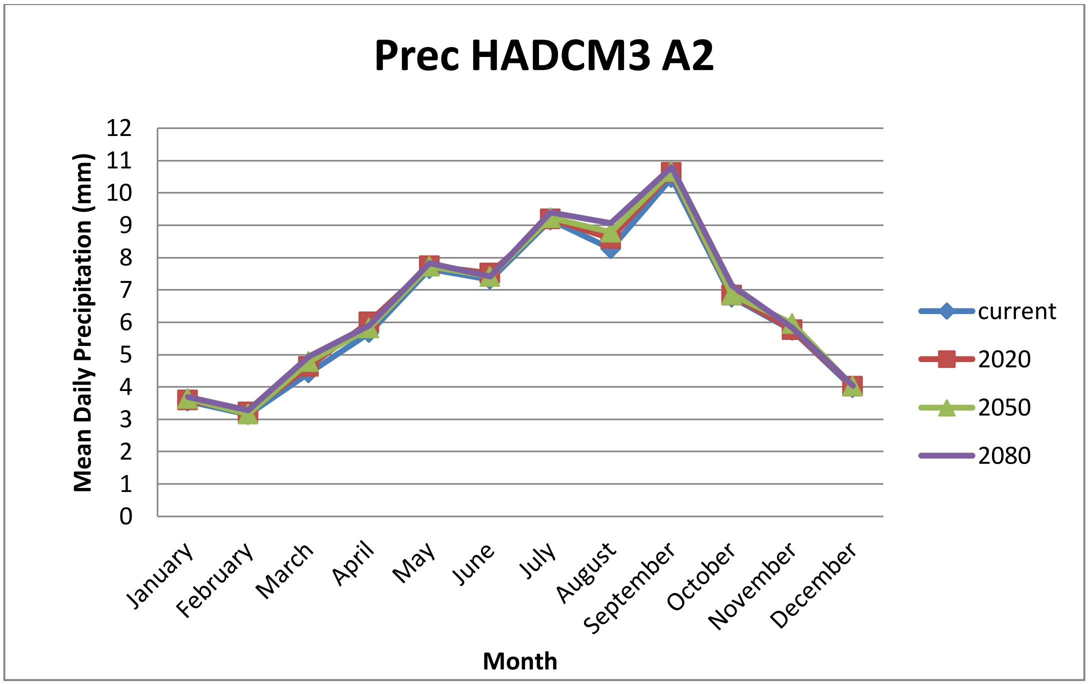
| AOC site | Ecosystem Characteristics /Sensitivities | Current Beneficial Use Impairments | Most Significant Impacts at location | Ranked Feasible Adaptation Strategy |
|---|---|---|---|---|
| Thunder Bay | high retention time, large shoreline length, largest temperature increase | A,B,C,D,F,G,J, K,M,N | Water Quality Issues and loss of Biodiversity | Runoff remediation, aquatic invasive species controls, residential and commercial zoning regulations, controlling water pollution through fines, and finding re-use for grey water. There may be more potential in Thunder Bay for groundwater sources than in the other AOCs since it is less urbanized. Fishing restrictions will be difficult due to the large native community; however fish stocking could be highly important for this region. |
| St. Lawrence River at Cornwall | exposed shorelines, lower water levels, high biodiversity | A,C,F,G,I,J,N | Water quality issues | Runoff prevention or treatment, residential and commercial zoning regulations, controlling water pollution through fines particularly the industrial contributors. Targeting large industrial polluters in Cornwall will be highly necessary. |
| Toronto | variable spring/fall changes, urbanization, water levels | A,C,F,G,H,J,K, N | Water Level Declines , water quality issues | Harmful runoff prevention particularly through infrastructure modernization, use of low flow toilets (which many in the region have already embraced). Rain capture and grey water re-use could be part of the runoff solution. Artificial floating Islands will likely not be feasible due to the huge recreational economy of Lake Ontario and the existing overpopulation of geese and that could potentially destroy its benefits. |

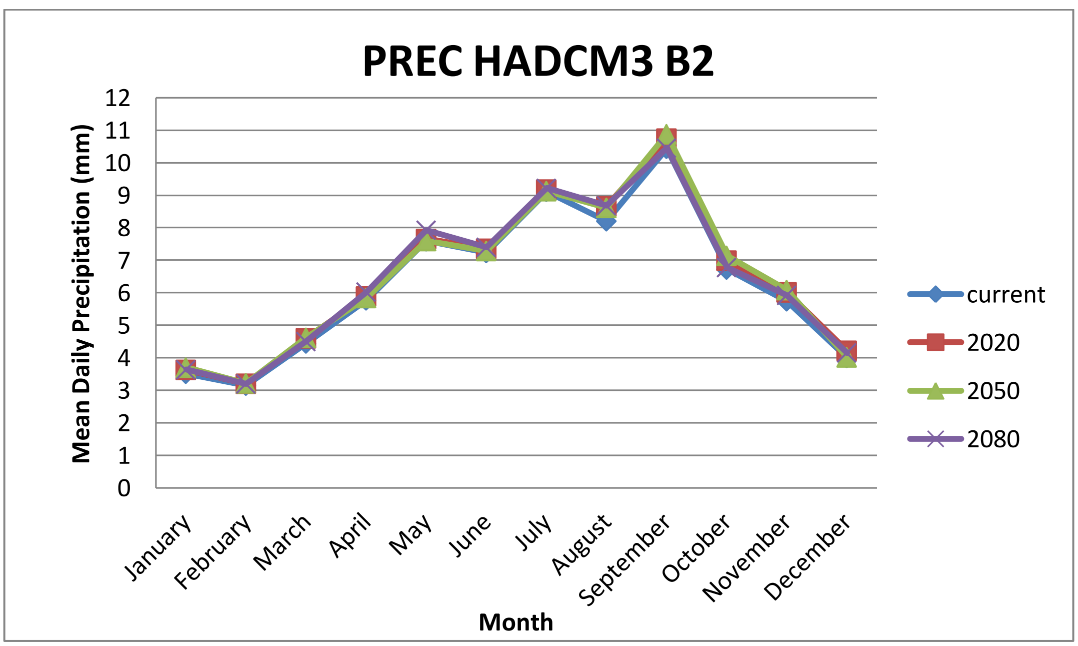
It is important to understand that management needs to be site specific, some recommendations may work best in one area and not in another. This is particularly relevant when proposing huge infrastructure changes or enforcing fines. Large infrastructure changes may not be economically feasible in one region and may be too labour intensive or disruptive in another. Similarly proposing a fine will depend on the local attitudes and willingness of the community to support the cause. As well controlling invasive species through chemical controls may be more plausible in Thunder Bay than in other regions because of the larger volume of water to dilute any after effects. It may be more difficult to enforce fishing regulations in Thunder Bay since it is an important part of the cultural heritage of the large native community. Analyzing the local community and their attitudes and values will be necessary in any planning and local initiatives.

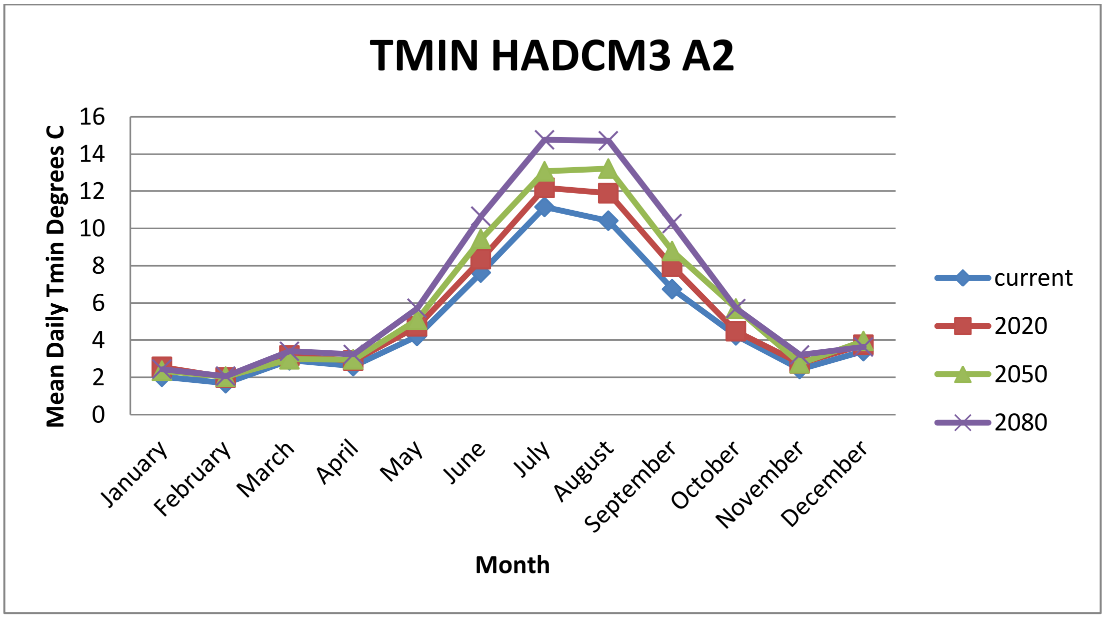
It was evident from this research that local trends can potentially be used to aid in site specific management planning for resiliency in the Great Lakes in light of climate change.

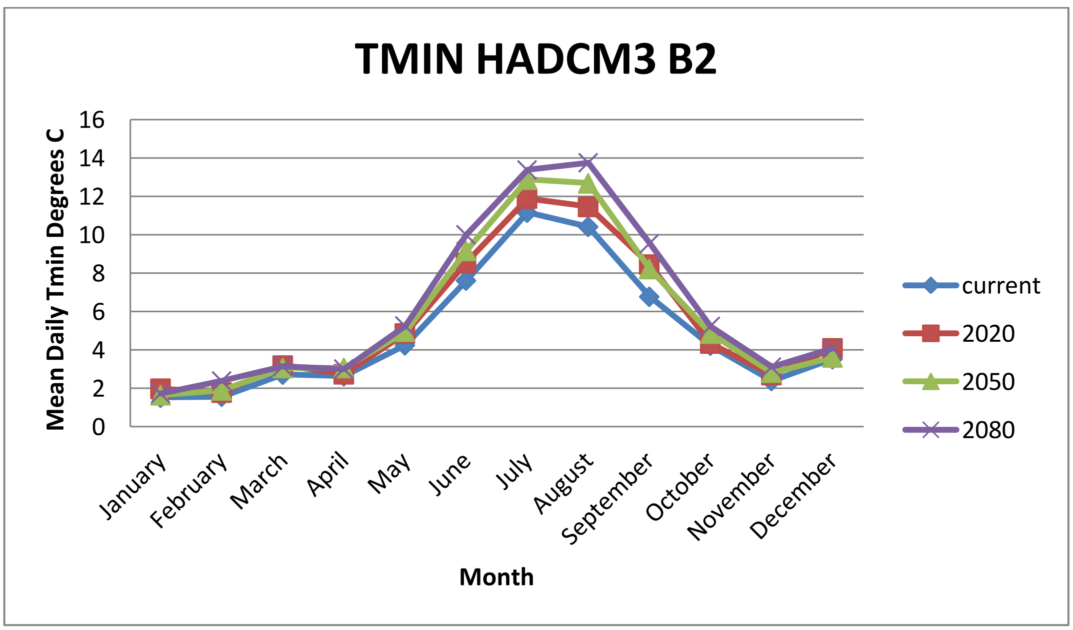
Appendix A

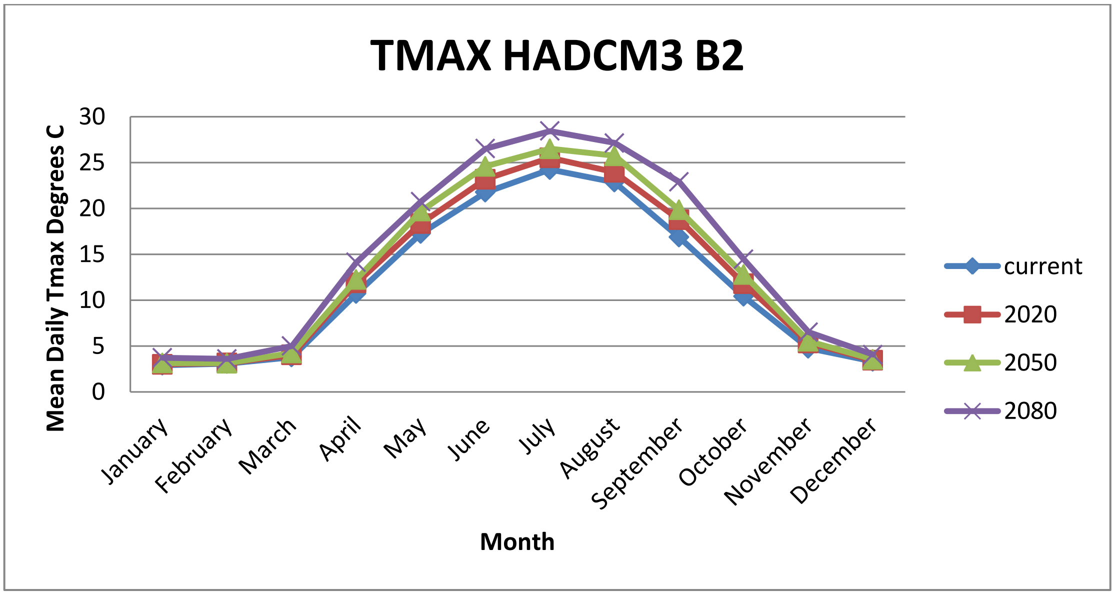
***Future Scenarios graphs for daily mean for HADCM3 A2 and B2 scenarios, Thunder Bay, ON Canada.***

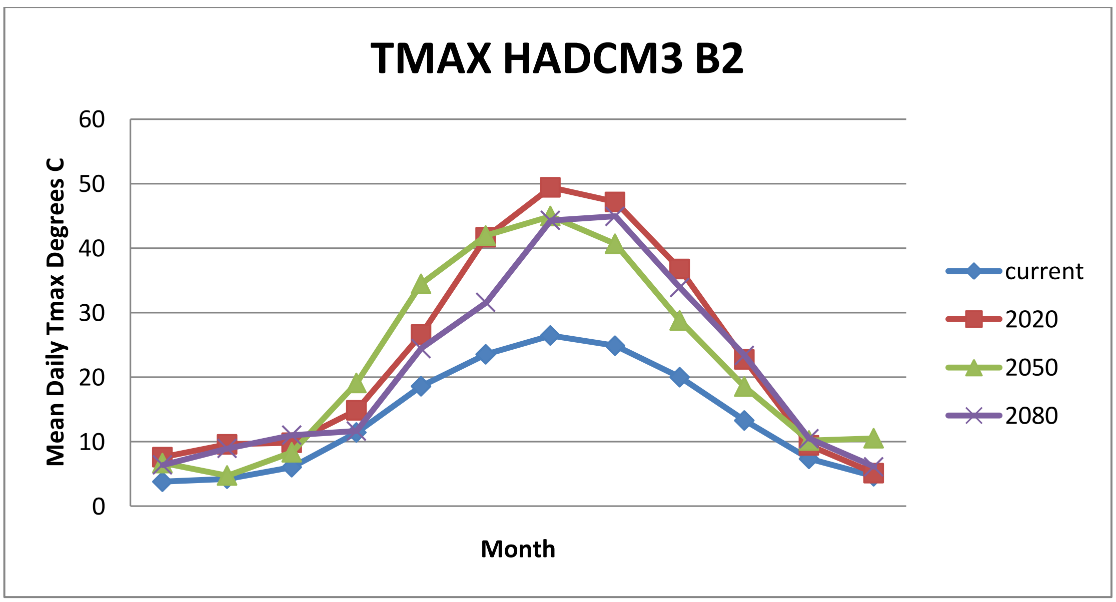


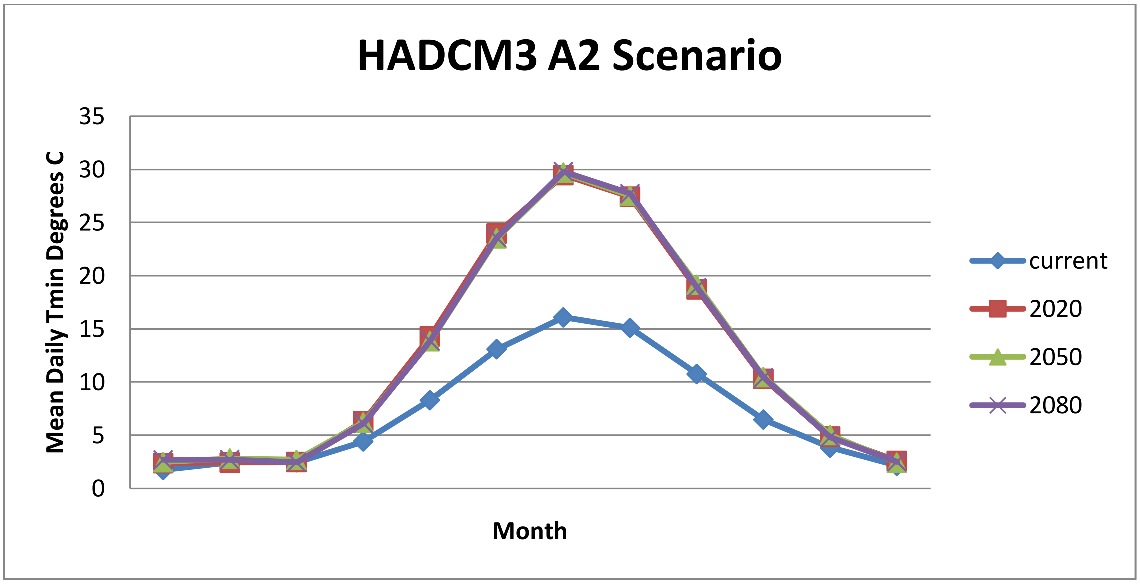

TMIN HADCM3 A2
Mean Daily Tmin Degrees C
16
14
12
10
8
6
4
2
0
January
February
March
April
May
June
July
August
September
October
November
December
Month
current
2020
2050
2080


TMIN HADCM3 B2
Mean Daily Tmin Degrees C
16
14
12
10
8
6
4
2
0
January
February
March
April
May
June
July
August
September
October
November
December
Month
current
2020
2050
2080


TMAX HADCM3 B2
Mean Daily Tmax Degrees C
30
25
20
15
10
5
0
January
February
March
April
May
June
July
August
September
October
November
December
Month
current
2020
2050
2080


TMAX HADCM3 B2
Mean Daily Tmax Degrees C
60
50
40
30
20
10
0
Month
current
2020
2050
2080

***Future Scenarios graphs for daily mean for HADCM3 A2 and B2 scenarios, Cornwall, ON, Canada.***



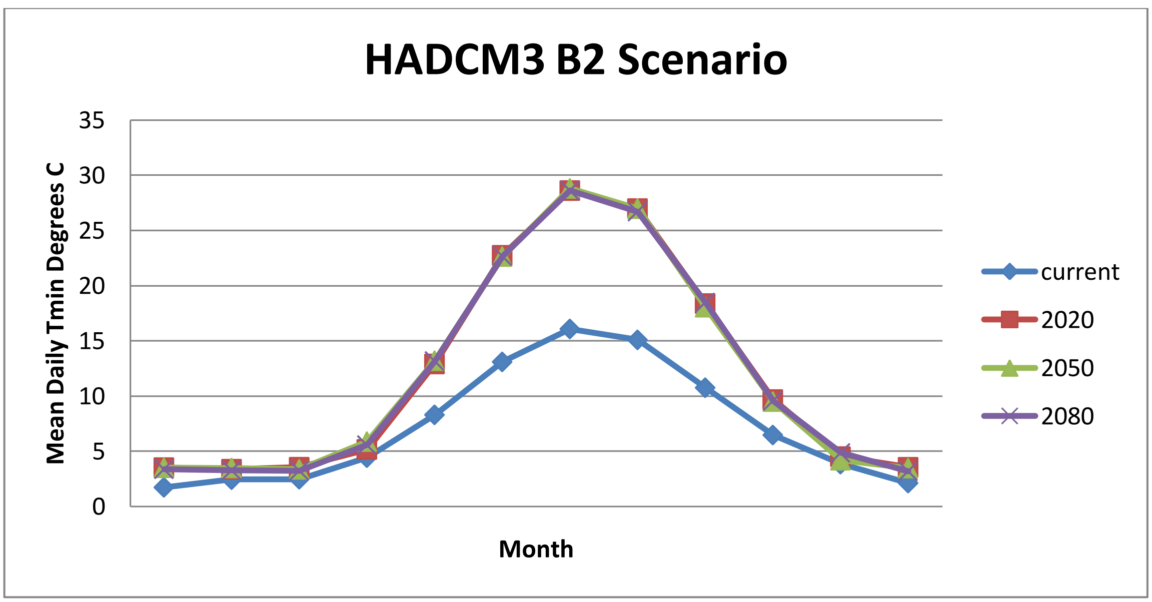



*Figure 5.7.4: Future Scenarios graphs for daily mean maximum temperature, for HADCM3 A2 and B2 scenarios, Cornwall, ON, Canada, SDSM.*