Lake Simcoe Watershed
Climate Change Vulnerability Assessment
Water Quality and Quantity

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Summary

Climate change projections from 10 climate models were used as input to a simple water balance model to determine the impact of climate change on the hydrologic cycle in the Lake Simcoe watershed. The current sensitivity of Lake Simcoe and its 18 subwatersheds was evaluated using a variety of indicators for water quantity and water quality. These analyses were used to evaluate the vulnerabilities, stressors and potential adaptation measures in the Lake Simcoe watershed. Climate change impacts on Lake Simcoe itself were estimated along with potential consequences. A method for assessing adaptive capacity for water quality and quantity is suggested.

Climate change is anticipated to result in increasing air temperatures and changes to the timing and amount of precipitation. Precipitation is predicted to increase in winter and spring but decrease in summer and fall. These changes will result in increased surface water runoff in the winter months and decreased water availability in the summer. Increases in the frequency of low water levels or drought in summer and flooding in winter are anticipated.

These changes to the hydrologic cycle may impact the lake itself resulting in lower water levels. Extreme weather events are anticipated which may result in increased flooding throughtout the year and sewage treatment bypasses as well as difficulties in drinking water treatment. Changes in the thermal regime of Lake Simcoe have already been observed and are correlated to increased in air temperature; these changes will continue resulting in earlier ice-off Lake Simcoe, a longer stratified period during the summer with ice cover occurring later in the winter months. The ice-free season is anticipated to increase by more than one month.

Acknowledgements

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INTRODUCTION

Ontario is a province with abundant freshwater resources, and Lake Simcoe is one of particular importance, due in part to its size and location. Lake Simcoe is the largest lake in southern Ontario (after the Great Lakes) with a surface area of 722 km^2. Situated only 50 km north of Toronto, Lake Simcoe is easily accessible to millions of people in southern Ontario and neighbouring U.S. states. The Lake Simcoe watershed is home to 350,000 people which is anticipated to increase to 500,000 by 2031. The lake supports recreational activities that generate over $200 million per year. Lake Simcoe has 6 drinking water treatment plants (WTPs) that provide a drinking water source for several communities on the watershed. It also assimilates wastewater from 14 municipal water pollution control plants (WPCPs) (Young et al., 2010).

Climate change is anticipated to result in increasing air temperature and changes in precipitation patterns. The objective of this analysis is to estimate the vulnerability of water quantity and water quality to climate change for Lake Simcoe and its watershed.

METHODS

The general approach followed is similar to the one used by the Lake Simcoe Region Conservation Authority (LSRCA) in the Watershed Report Card. Lake Simcoe itself is assessed separately as well as the 18 subwatersheds; at this time, sufficient information on the Upper Talbot subwatershed was not available for assessment. The methodologies used in each component of the vulnerability assessment are described below.

Exposure

The monthly temperature and precipitation projections from the Canadian Global Climate Model (CGCM) version 3.1 using the A2 scenario has been used per the guidance received for this analysis. Monthly temperature and precipitation projections for the period 2071 - 2100 were used as input to a simple water balance model (McCabe and Markstrom, 2007) to determine potential impacts on the hydrologic cycle. To provide perspective on these results the simple water balance was used with the projections from 9 other climate models. The 10 climate model projections were provided by the Water Budget Program of the Ministry of Natural Resources and represent a wide range of climate change projections (Figure 1).

Sensitivity: Subwatersheds

The nine indicators used to evaluate the 18 subwatersheds in the Lake Simcoe watershed were determined through a review of a compendium of reports prepared by the Lake Simcoe Science Advisory Committee (2008). The indicators along with a brief description of their derivation and their relationship to climate change impacts are shown in Table 1.

In general the methodology was quite simple; the current sensitivity was assessed by evaluating the range of values for the indicator, dividing the range into thirds and ranking the values by low, medium and high. For example, phosphorus loads from each subwatershed ranged from 377 to 8231 kg/yr. The low range was determined to be 377 to 2995 kg/yr, the medium range 2996 to 5613 kg/yr and the high range 5614 to 8231 kg/yr. The scores from each indicator were summed; subwatersheds with the highest scores are considered to be relatively sensitive.

The sources of the data for the indicators included:

1. Louis Berger Group Inc., 2010. Estimation of the Phosphorus Loading to Lake Simcoe. Report prepared for Lake Simcoe Conservation Authority, September 2010;
2. South Georgian Bay-Lake Simcoe Source Protection Committee, 2010. Draft Proposed Assessment Report, Chapter 3: Water Budget and Water Quantity Assessment Chapter;
3. Data and GIS layers provided by the Lake Simcoe Region Conservation Authorities.

Sensitivity: Lake Simcoe

A different approach involving indicators that vary temporally rather than spatially was used for Lake Simcoe. The climate change projections and potential changes to the hydrologic cycle are used to estimate how the indicators will change with time. The literature on how climate change can impact lakes was also used.

A variety of indicators were used for the assessment of Lake Simcoe: phosphorus concentration, lake temperature, and associated changes to the thermal regime including ice cover, dissolved oxygen, lake water level, beach closures and drinking water concerns.

Information and data about the quality and quantity of the Lake Simcoe water sector are available from recent reports such as:

- OMOE Lake Simcoe Water Quality Update, (Young et al. 2010)
- LSRCA, OMOE (2009) Report on the phosphorus loads to Lake Simcoe 2004–2007. Lake Simcoe Region Conservation Authority and Ontario Ministry of the Environment Joint Report

The indicators, along with a brief description of their current status, is provided in Table 2.

Adaptive Capacity

The Intergovernmental Panel on Climate Change has defined Adaptive Capacity as the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities or to cope with the consequences.

A methodology for assessing current adaptive capacity at a watershed scale is suggested. To assess the ability to adjust to climate change the current policies, programs or initiatives that could address climate change impacts are identified and assessed. This is achieved by first identifying potential climate change impacts and then the adaptation measures that can be taken to address those impacts. The existing policies, programs or initiatives that are related to the adaptation measure are identified and assessed. For example, water conservation is identified as an adaptation measure to address a projected reduction of water availability especially during the summer months. The current water conservation programs, such as in the City of Barrie, are identified and assessed.

A scoring system similar to that used for current sensitivity could be applied to the adaptive capacity assessment. A total vulnerability score (V) for each subwatershed could be calculated using (Fonataine and Steinemann, 2009):

$$V = (E + S) / A$$

where E = exposure, S = sensitivity and A = adaptive capacity. It could be assumed that at a watershed scale the exposure is the same and that the vulnerability score is the sensitivity divided by the adaptive capacity.

Due to limited time and resources, an assessment of current adaptive capacity could not be conducted.

RESULTS

Exposure

The temperature and precipitation projections from the 10 climate models are summarized in Table 3.

All but 2 of the models project an increase in annual precipitation. The seasonal variation of precipitation does vary between the models, but in general is the models predict higher precipitation in winter and spring, slightly lower precipitation in summer.

The water balance results using the monthly temperature and precipitation projections from all models is shown in Figure 2 and summarized below:

- Higher annual potential evapotranspiration and actual evapotranspiration;
- Total annual runoff does not change substantially;
- Higher runoff in winter, lower in spring, summer and fall;
- Higher water deficit in summer.

A comparison of the water balance results from 1971 – 2000 and the CGCM3 SRA2 model are summarized in Table 4.

Sensitivity - Subwatersheds

The five subwatersheds with the highest current sensitivity are shown on the map in Figure 3 and brief descriptions of their sensitivities are given in Table 5. The five high sensitivity subwatersheds provide a prioritization or focus of effort for more detailed assessment of impacts and for the development of adaptation measures.

Of the five high sensitivity subwatersheds, the East Holland, Beaver River and Barrie Creeks are undergoing Tier Two Water Budget and Stress Assessments for drinking water source protection. The goal of the Tier two is to use detailed and complex modeling tools to estimate availability of water within a subwatershed. The results of this work will be valuable for the development of adaptation measures.

Sensitivity – Lake Simcoe

Phosphorus Concentration

Phosphorus loading rates into Lake Simcoe have decreased due to steps taken since the 1980s. However, climate change is anticipated to result in an increase in surface runoff during the winter. The increase in winter precipitation may result in increased phosphorus loads, which could lead to increased phosphorus concentrations in Lake Simcoe during the winter months. Currently, phosphorus loads are often higher in the spring due to snow melt that runs off the land collecting phosphorus and transporting it to the lake. Increasing precipitation combined with decreasing air temperatures could result in pulses of phosphorus corresponding with the increased intense storms predicted by climate models. Climate models predict a decrease in surface runoff during the spring, summer and fall. As a result, phosphorus loads may decrease during these months due to decreased surface runoff. Atmospheric deposition of phosphorus to the surface of the lake could be impacted by anticipated changes in precipitation and wind speed due to climate change. Decreases in precipitation predicted during the summer could lead to decreases in soil moisture. Dry soil entrainment requires less wind energy, which could result in increased atmospheric deposition of phosphorus. Increases in wind speed due to climate change may also impact atmospheric deposition.

Lake Temperature

Using vertical temperature profiles of Lake Simcoe during the open-water period from 1980 to 2008, we evaluated trends in water column stability, the onset of stratification and the timing of fall turnover at three stations situated in the lake's two bays and its main basin. Dramatic changes were observed at the three stations: each stratified earlier in the spring, mixed later in the fall and remained stratified for more than a month longer in 2008 compared to 1980. Figure 4 shows the seasonal water column temperature contours in Kempenfelt Bay in 1980 and 2002. The temperature contours are wider in 2002 compared to 1980, which indicates the earlier onset of stratification, the increased length of the stratified period and later mixing of the water column in the fall.

Monotonic trends in the timing of the onset of thermal stratification, fall mixing and duration of stratification were significant. These trends resulted from changes in water column density that are strongly correlated with increasing average air temperatures over time, indicating that climate warming has already had a significant effect on the thermal regime of Lake Simcoe (Stainsby et al, *in press*).

The impact of climate change on the thermal dynamics of Lake Simcoe is difficult to predict. Wind events have been observed to cause periodic lake mixing (Borwick, pers. comm.). While increased air temperature may result in increased lake temperature and a lengthened stratified period in Lake Simcoe as observed over the last few decades, an increase in wind speeds coupled with increasing intense storms may result in increased periodic breakdowns of stratification.

Ice Cover

Earlier ice-off dates and a longer ice-free season have been observed in southern Ontario (Futter, 2003) and more generally in the northern hemisphere (Magnuson et al, 2000). Gao and Stefan (1999) use a multiple linear regression approach to relate lake ice cover dates with climate parameters, lake surface area and depth. This model was used in Figure 5, which shows the observed duration of the ice-free season along with predicted values for four stanzas (1971 – 2000, 2011 – 2040, 2041 – 2070 and 2071 – 2100) using the air temperatures for each stanza predicted using CGCM3 SRA2. The ice-free season is anticipated to last more than a month longer in 2100 as compared to 2000. These changes will likely have a dramatic impact on the lake and its ecosystem such as the trophic level shifts described below.

Dissolved oxygen

One of the main objectives of the LSPP (and previous lake management strategies) is to maintain hypolimnetic dissolved oxygen concentrations above a minimum level to provide suitable habitat for coldwater fish populations. Currently, due to decreased phosphorus loadings, an increasing trend in dissolved oxygen has been observed in Lake Simcoe (Young et al., *in press*). The LSPP has set a minimum end-of-summer hypolimnetic dissolved oxygen target of 7 mg/L. The other main objective of the LSPP is to reduce total phosphorus loads to the lake to achieve the dissolved oxygen target. The two objectives are linked through a series of relationships connecting nutrient inputs, algal growth and dissolved oxygen depletion, and are estimated using the empirical model developed by Nicholls (1997). While dissolved oxygen is not directly impacted by climate change, the vulnerability of this indicator must be assessed due to the critical role it plays in the LSPP.

Climate stressors that could impact the phosphorus load to Lake Simcoe include changes in surface runoff, increased flooding and intense storms, as well as decreases in soil moisture and increases in wind speed (as described in the section on phosphorus concentration above). Further research is needed to evaluate the impact of a longer stratified period on the dissolved oxygen depletion rate and lake temperature to determine the effect on the available aquatic habitat (Young et al., in press). Additional factors affecting phosphorus loads will be an increasing population on the Lake Simcoe watershed, which is predicted to grow from 350,000 to 500,000, resulting in increased phosphorus load to the lake via sewage treatment plants and surface runoff from urban areas. However, the Lake Simcoe Phosphorus Reduction Strategy (2010) aims to reduce the phosphorus load to the lake to 44 T/yr by 2045.

Sewage and flood control failures

More moisture in a warmer atmosphere is expected to cause an increase in extreme weather events — rain, snow, drought, heat waves, wind and ice storms. There are indications that this trend has already begun. Weather is also expected to be more variable and less predictable from year to year. Disruptions to critical community infrastructure, including water treatment and distribution systems, have occurred recently because of severe storm events across the province. The risk of such impacts in the future is expected to rise (Expert Panel, 2009).

Beach Postings

Beach closures are anticipated to increase as a result of increased extreme rain events resulting in increased in pathogen release. Data presented in Figure 6 are the total number of postings and the total number of days that beaches were closed from 2006 to 2008 (Young et al., 2010). During this time, most beaches had at least one posting or closure; only three beaches at the north end of the lake remained posting-free. Beaches along the south and east shore of the main basin were closed most frequently and for the longest duration. Advisories were rarely posted in Kempenfelt Bay, although all six beaches were pre-emptively closed for one day in 2006 after a major sewage spill occurred (Young et al, 2010).

Drinking water

Intense storm events are anticipated to increase, which would increase the turbidity of the water making it more difficult to treat, resulting in the closure of the intake of the water treatment plant.

During the closing of an intake, sufficient storage volume to meet demand may become an issue. Increased storm events may also result in increases in pathogen release resulting in challenging conditions for drinking water treatment. Water quantity may become an issue during summer months when precipitation is anticipated to decrease, as the demand for water increases with increasing population due to tourism and population growth in the watershed. Climate change may also result in shifts in community structure at various trophic levels in Lake Simcoe, which could potentially lead to taste and odour issues or concerns regarding algal toxins. For example, various species of cyanobacteria (blue-green algae) release taste and odour compounds and algal toxins, and as a group are favoured under conditions resulting from climate change including increased lake water temperatures, lengthening of the ice-free season and reduced water column mixing (Paerl and Huisman 2008).

Lake Levels
The effect of climate change on lake levels is uncertain, particularly because water levels in Lake Simcoe are regulated. It is anticipated that climate change may result in increased surface runoff during the winter, which could lead to higher lake levels; however, increasing air temperatures resulting in less ice cover during those months could result in increased evapouration thus reducing the water level of the lake. Surface runoff is anticipated to decline during the spring, summer and fall months resulting in lower lake levels during those seasons; however, precipitation is anticipated to increase. Lastly, increases in air temperature could result in increased evapouration contributing to lower lake levels during the ice-free season.

Habitat and Ecosystem Response
Changes in the thermal regime of the lake could result in a reduction of thermal habitats for some species and increases for others. Climate change is anticipated to result in seasonal variability in biotic responses and mismatches in the timing of life stage events and associated species interactions. This could result in shifts in community structure at various trophic levels. See “Vulnerability indicators for Lake Simcoe and the wetlands, streams and rivers within the Lake Simcoe watershed” for more information.

Adaptive Capacity

An assessment of adaptive capacity could not be completed with the available time and resources.

DISCUSSION

The identified impacts and vulnerabilities for Lake Simcoe and its subwatersheds are summarized in Tables 6 and 7.

RECOMMENDATIONS

Monitoring Gaps

- Stream gauges in all subwatersheds requiring a Tier 2 Water Budget and those determined to be highly sensitive from the current sensitivity assessment (to follow);

- Continuous water quality monitoring at all stream gauges. Automatic water quality samplers for determining storm loads.
- Soil moisture meters in Tier 2/sensitive subwatersheds to better observe and estimate drying of soil, evapotranspiration, groundwater recharge.
- Integrated monitoring station in Tier 2/sensitive watersheds, eg. shallow monitoring well(s) next to stream gauge to observe groundwater surface water interactions. Also at the same site a rain gauge (or a meteorological station), stream water quality monitoring, soil moisture meters, biological indicators (eg. benthic). This data useful for determining temporal trends, interactions, input to hydrologic models.
- Sufficient density of rain gauges to determine if more frequent intense storms.
- Use of remote sensing data, eg. soil moisture, snow cover, LIDAR for lake levels, vegetation type and extent
- Snow cover/depth monitoring locations in sensitive wildlife areas.

Lake Simcoe Performance Indicators

Monitoring Gaps

- Monitoring of ice on/off dates was monitored by Environment Canada from 1853 to 1995. A continuous and consistent approach is required.
- Severity of sewage by-passes; compilation of data on frequency and severity of sewage and flood control failures.
- Variability and trends of lake levels.

Water chemistry, including concentrations of total phosphorus, chlorophyll, chloride, metals, and dissolved silica is monitored in the lake, as are temperature and dissolved oxygen levels and phytoplankton and zooplankton communities. Tributaries are intensively monitored for total phosphorus, organic nitrogen, nitrate and ammonia, chloride and water temperature, with less frequent, routine sampling of a full suite of water chemistry parameters through the Provincial Water Quality Monitoring Network stream monitoring program. These monitoring efforts currently provide sufficient water chemistry data for Lake Simcoe itself.

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Tables

Table 1. Indicators used for Current Sensitivity Assessment for 18 subwatersheds

Water Quantity Indicator	Indicator Description	Climate Stressor
Water Use/Availability	Ratio of surface and groundwater withdrawals to mean annual stream flow	Higher summer temperatures with lower precipitation. Demand for water potentially exceeding supply.
Baseflow Index	Ratio of baseflow to mean annual streamflow	Decrease in low flow during summer. Potential impacts on aquatic ecosystems.
Wetland Cover	Percentage of area occupied by wetlands in each subwatershed	Decrease in groundwater discharge, variations in streamflow, invasive species (indirectly related to climate).
Groundwater Vulnerability	Percentage of area of high, medium and low groundwater vulnerability in each subwatershed.	Potential lower water tables in unconfined aquifers due to decreased recharge.
Forest Cover	Percentage of area occupied by forest/woodland in each subwatershed.	Increase in runoff due to increase rain events in winter, increase of precipitation in cold months, more frequent intense rain events
Water Quality Indicator	**Indicator Description**	**Climate Stressor**
Phosphorus Loading	Annual mass flux of P from subwatershed.	Increase in surface runoff and floods, increase in wind speed.
Variability of Streamflow	Ratio of the standard deviation of annual streamflow to mean annual streamflow	Variations in streamflow due to changes in precipitation distribution and runoff.
Floodplain Area	Percentage of area occupied by floodplain	More frequent intense rain events, more flooding, more transport of nutrients and contaminants
Sewage Bypass	Volume of primary and secondary sewage bypass	More frequent intense rain events, more flooding.

Table 2: Lake Simcoe Indicators and Their Current State

Indicator	Current State
Phosphorus Concentration	Phosphorus loading rates into Lake Simcoe have decreased due to steps taken since the 1980s. This has contributed to significant decreases in spring phosphorus concentrations in the lake and to significant decreases in annual phosphorus concentrations measured at the lake's outflow and at nearshore intake pipes of water treatment plants (Young et al. 2010).
Lake Temperature	Changes in thermal stratification have been observed. On average the lake remained stratified for more than month longer in 2008 compared to 1980. Increases in thermal stability have also been observed. Figure 4 below shows the observed temperature during the ice-free season for two typical years at the beginning (1980) and end (2002) of the period of record (Stainsby et al. in press).
Ice Cover	Earlier ice-off dates and a longer ice-free season have been observed (Futter, 2003)
Dissolved oxygen	Decreases in phosphorus concentrations have also contributed to an increasing trend in dissolved oxygen, which is an improvement (Young et al. in press).
Beach Postings	Most of the beaches around the lake had at least one posting or closurebetween 2006 and 2008; only three beaches at the north end of the lake remained posting-free. Beaches along the south and east shore of the main basin were closed most frequently and for the longest duration. Advisories were rarely posted in Kempenfelt Bay, although all six beaches were pre-emptively closed for one day in 2006 after a major sewage spill occurred (Young et al, 2010)..
Lake Levels	Lake level data is collected by Parks Canada. Anecdotally, flooding was a problem in 2008 and low lake levels were observed in 2010 (O'Connor, pers. comm.).

Table 3. Temperature and precipitation projections from 10 climate models.

	Projected Range	**1971 – 2000 Climate Normals**
Average Annual Temperature Range	9 to 12.5 °C	6.6 °C
Increase in Temperature	2.8 to 5.7 C° for January and July	
Annual Precipitation Range	881 to 1084 mm	938 mm

Table 4. Comparison of water balance results for 1971 – 2000 and climate model CGCM3, scenario SRA2

Water Balance Component	1971 – 2000 Water Balance (mm)	CGCM3 SRA2 Water Balance (mm)	% Change
Precipitation	938.7	1037.2	+10.5%
Potential Evapotranspiration	557.2	777.1	+39.5%
Actual Evapotranspiration	553.7	652.6	+17.8%
Water Deficit	3.5	124.6	+3460%
Snow Storage	413.8	188.7	-54.3%
Runoff	395.4	414.0	+5%

Table 5. Subwatersheds with high current sensitivity

Subwatershed	Current Sensitivities
East Holland	Low water availability, high P loading, high floodplain area.
Black River	Low water availability, high wetland cover, high sewage by-passes.
Beaver River	High wetland cover, low forest cover, high stream flow variability.
Barrie Creeks	Low water availability, high baseflow, low forest cover, high P loading.
Ramara Creeks	High baseflow, high wetland cover, high groundwater vulnerability, low forest cover, high floodplain area.

Table 6. Subwatershed Vulnerabilities, Stressors and Potential Adaptation Measures

Vulnerability	Climate Stressors	Non-Climate Stressors or Factors	Potential Adaptation Measures
Water Use/Availability	Higher summer temperatures with lower precipitation. Potential lower water tables in unconfined aquifers due to decreased recharge, lower summer flows. Demand for water potentially exceeding supply	Increase in demand due to: population increases, changes to crops; increase in population in areas dependent on shallow groundwater; eg. Talbot River; changes to forest and wetland cover.	Water conservation (demand); water re-use; change from groundwater to surface drinking water sources; protection of groundwater recharge areas; development of water harvesting/storage infrastructure; reforestation.
Reduction of groundwater recharge /discharge	Higher summer temperatures with lower precipitation leading to increased soil moisture deficit and less groundwater recharge; lower summer tributary flows due to decreased groundwater discharge	Development in groundwater recharge areas – increase of impervious area.	Protection/enhancement of groundwater recharge areas; reforestation
Wetland Cover	Decrease in groundwater discharge, variations in streamflow, invasive species	Wetlands are not to be developed under the Lake Simcoe Protection Plan	Protection/enhancement of wetland areas – integrity, resilience, biodiversity
Drought	Increase in frequency of summer low water levels, increased frequency of drought, potential increase in ET due to increased wind speed.	Increased water use during summer. It is estimated that the current watershed population increases by 50,000 people during the summer.	Water conservation; development of water harvesting/storage infrastructure, water re-use
Floods and Surface runoff	Increase in runoff due to increase rain events in winter, increase of precipitation in cold months, more frequent intense rain events	Percentage of area occupied by forest/woodland, percentage of impervious cover	Development of water harvesting/storage infrastructure, low impact development, flood control, storm water management, water re-use
Sewage Treatment Plant Bypasses	Increase in intense rain events in fall and winter	Increasing population coupled with more stringent objective and compliance limits	Water conservation; evaluation and adaptation of STP process to improve resiliency
Phosphorus Loading	Increase in surface runoff and flooding leading to increased transport of nutrient to Lake. Increased wind speed.	Increase in population, increase in cropland, intensified farming, loss of natural areas, aging infrastructure	Enhancement of phosphorus reduction strategies.
Snow and ice cover	Changes in areal extent, duration, and depth of ice/snow	Increase in development, changes in forest cover	Enhancement of snow and ice monitoring

Table 7. Lake Simcoe Impacts and Consequences

Anticipated Climate Change Impact	Estimated Lake Impact	Potential Consequence
Higher summer temperatures with lower precipitation.	Increased temperature in the epilimnion and metalimnion (upper layers of lake water during summer stratification). Increased evaporation due to increased temperature coupled with lower precipitation may lead to lower lake water levels. Warmer, drier summers will result in increased phosphorus loadings due to increased wind erosion and dust deposition.	Loss or damage to habitats. May result in the reduction of thermal habitat for some species and increases for others. May result in shifts in community structure at various trophic levels. Potential increases in phosphorus loads to the lake will result in a decrease of dissolved oxygen potentially reducing the available critical summer habitat for cold water fish species.
Warmer temperatures in spring and fall.	Earlier onset of stratification and later fall mixing leading to an increase in the length of the stratified period. Earlier melting of ice in the spring; later ice cover in the winter.	Loss or damage to ecosystems. Possible changes in the depth and persistence of the thermocline. Seasonal variability in biotic response and mismatches in the timing of life stage events and associated species interactions, such as larval fish feeding requirements and zooplankton pulses. May result in increased growth of aquatic plants including algae and cyanobacteria. May result in shifts in community structure at various trophic levels
Increase in precipitation in fall and winter	The increase in precipitation is anticipated to result in increases in sediment and nutrient loading as a result of increased flooding. Increased flooding may result in increases in pathogens released to the lake as a result of increased failure of sewage and flood control infrastructure.	Loss or damage to ecosystems and infrastructure. Increases in phosphorus loads to the lake will result in a decrease of dissolved oxygen potentially reducing the available critical summer habitat for cold water fish species. Increases in pathogen release could potentially result in challenging conditions for the successful operation of WPCPs and result in more frequent beach closures.

Figures

Figure 1. Graph showing annual temperature and precipitation projections from 80 climate model/scenarios for the Barrie WPCC climate station. The 10 projections used in this study are denoted by the yellow dots.

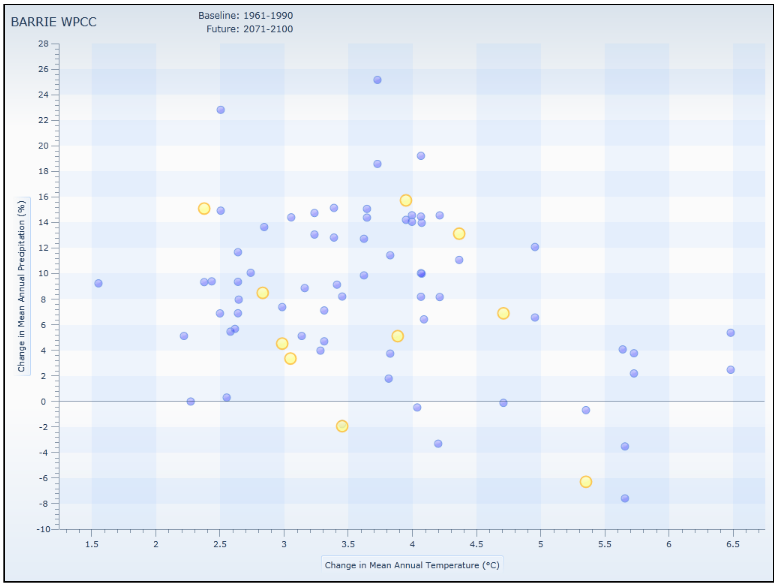


Figure 2. Comparison of water balance results from 10 climate models and 1971 – 2000 climate normals.

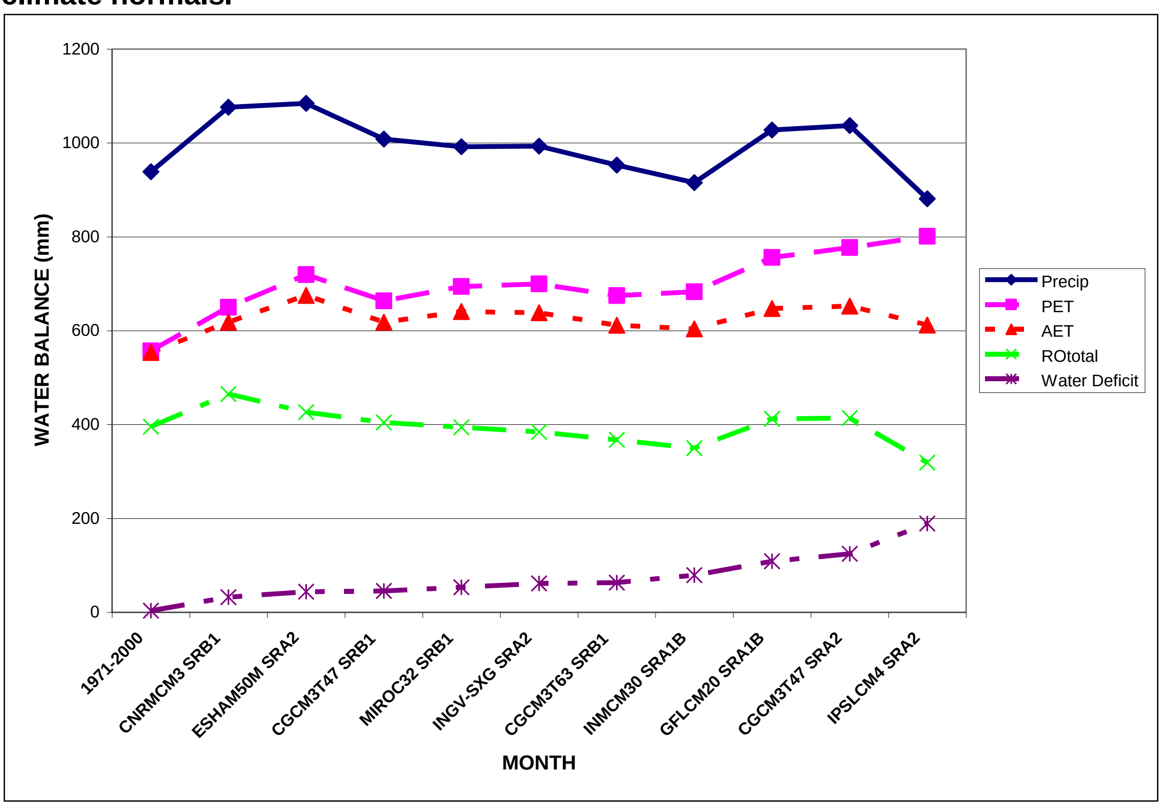


Figure 3. Subwatershed Current Sensitivity Assessment

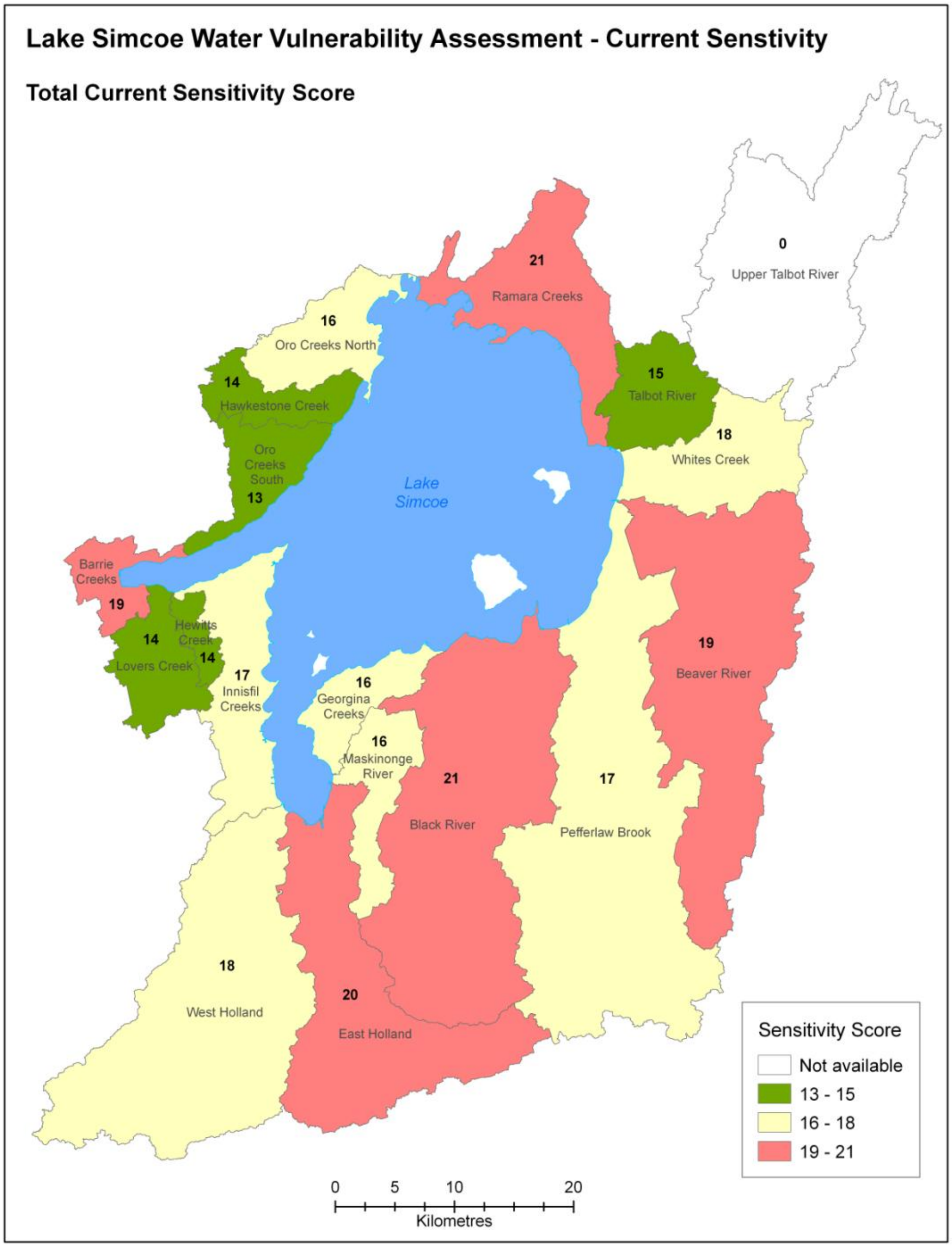


Figure 4: Seasonal water column temperature (contours) in Kempenfelt Bay in 1980 and 2002. The temperature contours are wider in 2002 compared to 1980 which indicates the earlier onset of stratification, the increase length of the stratified period and later mixing of the water column in the fall.

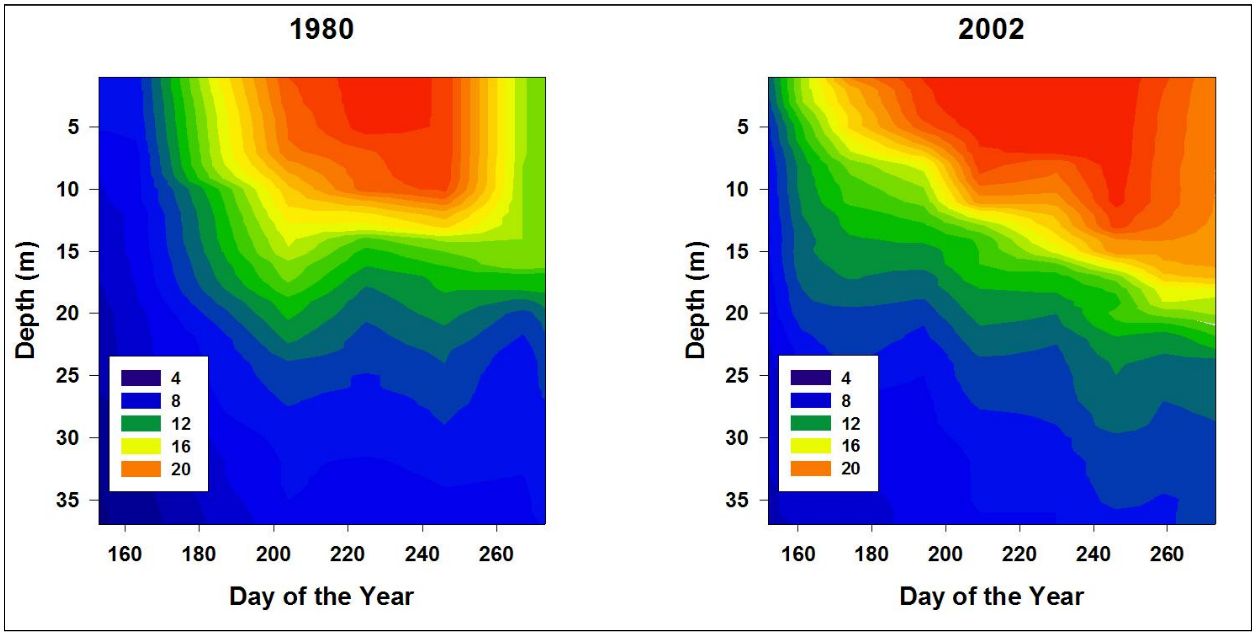


Figure 5: Modelled and observed duration of ice-free season on Lake Simcoe. The ice-free season is anticipated to last more than a month longer in 2100 than in 2000. Observations provided by Environment Canada's Ice Watch Program and the Lake Simcoe Fisheries Assessment Unit (La Rose, pers. comm.) Climate change impacts predicted using Gao and Stefan (1999) with air temperature from CGCM3 SRA2

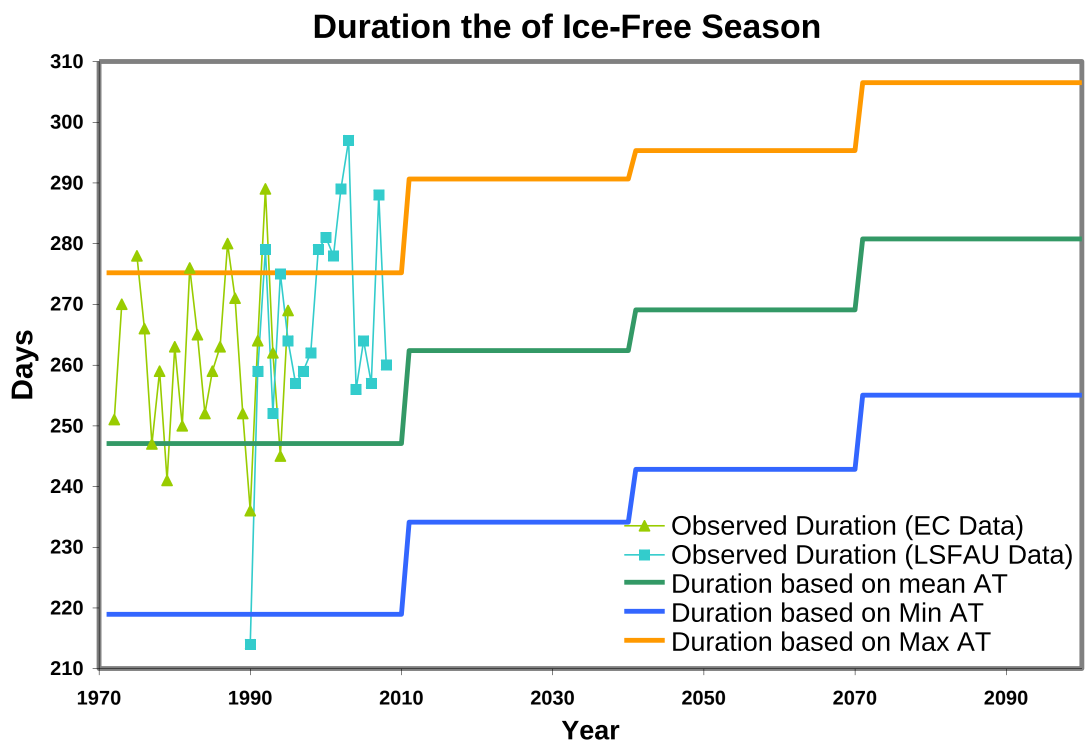
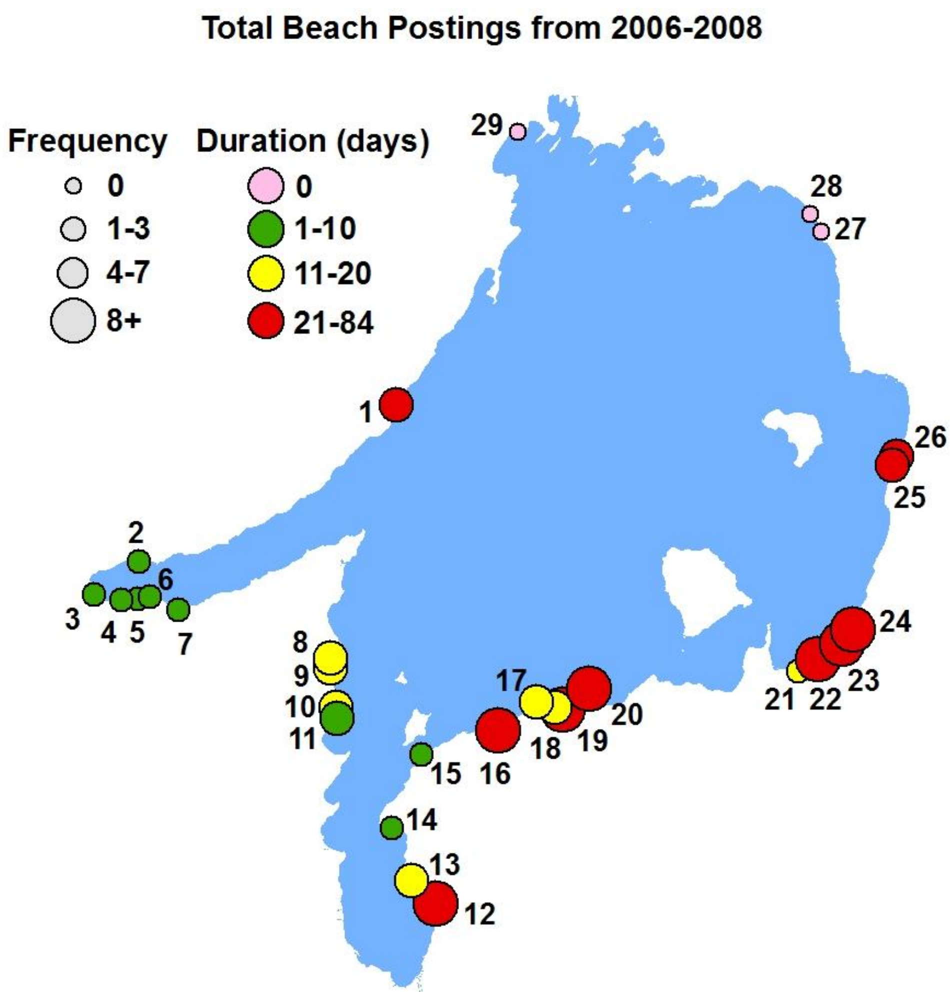


Figure 6: Total number of postings and the total number of days that beaches were closed from 2006 to 2008. During this time, most beaches had at least one posting or closure; only three beaches at the north end of the lake remained posting-free. (Young et al, 2010)



1 Memorial Park Beach
2 Johnson's Beach
3 Barrie Centennial Park Beach
4 Minet's Point Beach
5 Gabel Place
6 Tyndale Beach
7 Wilkin's Beach
8 Leonard's Beach
9 Glenwood Beach
10 Alcona Beach North
11 Alcona Beach South
12 Claredon Beach
13 Keswick Beach
14 Balfour Beach
15 Island Grove Beach
16 Willow/Paradise Beach
17 Willow Wharf Dock
18 Franklin Beach
19 De La Salle Beach
20 Jackson's Point Beach
21 Holmes Point Beach
22 Peninsula Motel Beach
23 Port Bolster Beach
24 Thorah Centennial Beach
25 Beaverton Beach South
26 Beaverton Beach North
27 The Steps
28 Lagoon City Beach
29 Kitchener Beach