PAPER 4

RAPID ASSESSMENT OF THE IMPACTS OF CLIMATE CHANGE (RAICC): BUILDING PAST AND FUTURE HISTORIES OF CLIMATE EXTREMES

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ABSTRACT: Climate change will result in a set of diverse and regionally-specific impacts on natural ecosystems and human societies. Canadian municipalities can play an important and vital role in addressing climate change especially in mitigating or adapting to existing or future climate change impacts. Municipalities need direction on the priority that should be given to climate change in their community. This study focuses on developing an integrated approach to setting this priority called the Rapid Assessment of the Impacts of Climate Change (RAICC, pronounced as race), and is applied to the Regional Municipality of Halton, Ontario, Canada. The five step RAICC approach includes building a history of climate extremes, selecting a model for climate futures, building a future of climate extremes, linking climate indices to environmental prediction and then conducting a relative risk assessment of the impacts. Results from applying the approach to the Halton Region show that a changing climate is an important issue to Halton, and its importance will increase over the 21st century. Climate observations show increases in temperature and decreases in precipitation over the past 28 years. Future climate modelling projects continued increases in temperatures for Halton Region on average 3.8°C by the year 2100, mostly in minimum temperatures. Also, the climate models show that changes to precipitation levels eventually level off by mid-century with a slight increase by the year 2100. A literature review was conducted in order to identify climate change environmental prediction thresholds (sensitivities triggered at certain climate thresholds above which result in significant changes that may require some form of human interventionist adaptation) for ten economic and ecological sectors of Halton Region. The changes in risks/opportunities are assessed together with the model uncertainty to provide a relative risk assessment on the impacts of climate change at Halton Region. This study concludes that the built environment, agriculture and tourism are those eco-sectors in Halton Region requiring priority focus, more in-depth study and subsequent action. RAICC is a tool designed to be illustrative of the changes that may occur as a result of a changing climate rather than a prescriptive tool that defines the scope and totality of changes that may occur. All scientific tools selected for the application RAICC met all of the criteria of accessibility, transferability, acceptability in the scientific discipline, ease-of-use and the ability to be used in the Canadian context.

Keywords: climate change, impacts, adaptation, rapid assessment

1. Introduction

Climate change will result in a set of diverse and regionally-specific impacts on natural ecosystems and human societies. A growing literature suggests that while climate mitigation strategies are necessary to reduce greenhouse gas emissions from anthropogenic sources, those alone are unlikely to be sufficient. As studies have shown, the impacts of climate change from previous emissions of greenhouse gases over the past 150 years will have to be confronted by all countries including Canada. Therefore, pursuing a complementary strategy of enabling countries to adapt to climate change and negate many of the expected adverse impacts is equally, if not more, urgent (Adger and Kelly, 1999; Burton *et al.*, 2002).

Canadian municipalities can play an important and vital role in addressing climate change (Robinson, 2000). Approximately 80 percent of Canadians live in municipalities with populations greater than 10,000 people (Hough, 1995). A review of the literature shows that the specific delegation of municipal responsibility varies by province in Canada. Generally speaking, in Canada, municipalities: have at least partial control over land use through zoning and official plan documents; issue building permits and development approvals; control parking supply and prices; hold responsibility for roads and public transit; oversee parks and recreation services; play a regulatory and management role in power and gas utilities; and are considered the most accessible level of government from a resident's perspective. Other advanced municipal services include providing local health advisories, adequate housing, programs for seniors, social welfare payment services, emergency services and sewer, water and waste services (see Halton Region, 2007 for an example). These responsibilities enable municipalities to take action toward reducing greenhouse gas emissions as well as adapting to the impacts of climate change (Federation of Canadian Municipalities, 1996).

Robinson (2000) concluded that efforts to increase municipal response to climate change must consider that smaller municipalities are less likely to be willing or able to respond to climate change and efforts should be tailored accordingly. The number one factor limiting a municipality's response to climate change is their capacity, that is, trained staff, information, tools and financial resources. Many municipalities remain at first principles wondering whether climate change is an issue important to their region; that is, what the specific risk of climate change will be for their region. They also wonder what priority should be given to climate change, and what aspect of their economy and ecology needs to be focused on for further study and action. And Ontario municipalities want this information now as provincial legislation requires them to review potential natural and anthropogenic hazards and risks within a tight timeframe (Ontario Emergency Management Act, 2003).

There are many expert tools in climate change science (software, websites, statistics, models, indices, archives, networks and processes) that can equip municipalities in answering this question. Although many methodologies exist for climate change impact assessment (see UNEP, 1998), there is no approach available to put climate change science expert tools together in an integrated fashion for this task. This paper is about developing an integrated approach that is fast and simple; builds on existing expert tools; is linked to the climate change impacts scientific literature; and allows for risk assessment. And most importantly, this approach is applied as a demonstration of the products that emerge from such an approach. This approach is named the Rapid Assessment of the Impacts of Climate Change, or RAICC (pronounced race) and is shown graphically in Figure 1. The development of RAICC is an attempt at navigating through the great deal of climate change information available to community decision-makers. RAICC tries to place the disparate information sources of climate change information in a coherent and systematic form, in an attempt at improving the management of climate change information.

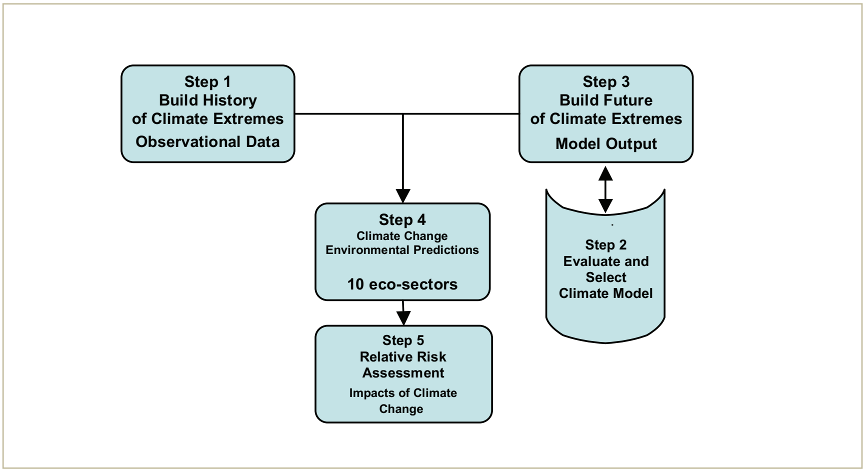

FIGURE 1
Rapid Assessment of the Impacts of Climate Change (RAICC)

The approach to rapidly assess the risks to climate change uses 5 major steps: *Step 1 - Building a History of Climate Extremes.* In this first stage of the approach, a climate history of temperature, precipitation and extremes (as measured by climate indices developed by Gachon *et al.*, 2005) is built for a region using an analysis of observational records. *Step 2 – Selecting a Climate Model for Future Scenarios.* In the second stage, global and regional climate models are evaluated for their ability to model future climate change, and then a model is selected based on criteria provided by the Intergovernmental Panel on Climate Change for climate change impact studies. *Step 3 - Building a Future of Climate Extremes.* In the third stage, a climate future is built for a region from scenarios of future climate change for the next 100 years using the same temperature and precipitation extremes as measured by climate indices developed by Gachon *et al.* (2005). *Step 4 – Identifying Climate Change Environmental Predictors.* Comprehensive climate change impact studies examine many economic sectors and various aspects of the natural environment – referred to here as "eco-sectors" - including forests, fisheries, energy, transportation, agriculture, tourism, human health, water quality, biodiversity and the built environment. Each of these sectors is sensitive to extremes of temperature and precipitation at some level. These sensitivities are triggered at certain climate thresholds above or below which result in significant changes that may require some form of human interventionist adaptation. These are identified in this step through a literature review, and are referred to as environmental predictors. *Step 5 – Ranking the Relative Risks of Climate Change to the Region.* The final step uses an accepted process (known as the Hazard Identification and Risk Assessment - HIRA - process) (Emergency Management Ontario, 2004) amended to identify priority eco-sectors at risk from climate change relative to other eco-sectors at risk from climate change. This allows managers to target areas for further intensive study and, in further steps, develop prioritized response plans for humans to intervene and adapt to future climate change.

Each of these steps utilizes at least one of a set of expert tools (software, websites, statistics, models, indices, archives, networks and processes) used for various aspects of climate change science, and are applied and integrated for the first time in the overall RAICC approach. These tools include: the National Climate Data and Information (NCDI) Archive; the Gachon Indices of Climate Extremes (GICE); the Canadian Climate Change Scenarios Network (CCCSN); the Canadian Global Climate Model (CGCM) 3.1; the Canadian Regional Climate Model (CRCM); and the Hazard Identification and Risk Assessment (HIRA) process. All of these tools are to be integrated and applied in this paper as an approach to rapidly assessing the impacts of climate change on the Halton Region of Ontario, Canada.

2. The Regional Municipality of Halton (Halton Region)

The Regional Municipality of Halton, hereinafter known as the Halton Region, is located in southern Ontario, Canada and encompasses the municipalities of Oakville, Burlington, Halton Hills and Milton (Figure 2). As part of Canada's Niagara Escarpment Biosphere Reserve, Halton Region has been designated by the United Nations' Education, Science and Cultural Organization's (UNESCO)

Man and the Biosphere (MAB) programme as one of the "world's important ecosystems expressing the balance between biological conservation and human development." It is part of a global network of 531 Biosphere Reserves in 101 countries (UNESCO, 2007). Biosphere Reserves are used to share knowledge on how to manage natural resources in a sustainable way; to co-operate in solving natural resource issues; to conserve biological diversity; to maintain healthy ecosystems; to learn about natural systems and how they are changing; and to learn about traditional forms of land-use. Biosphere reserves are test areas for demonstrating ideas, tools, concepts, and knowledge of resource conservation, sustainable development as well as climate change. It is the role of the biosphere reserve to serve as a mechanism for enhancing local, regional, and multi-jurisdictional cooperation that is most needed in the area (Ravindra, 2001).

FIGURE 2
Halton Region of Ontario, Canada and its four municipalities of Oakville, Burlington, Halton Hills and Milton.

These objectives are met through each Biosphere Reserve's management structure, or "round table" of local communities, farmers, foresters, fishermen, research scientists, government decision-makers, and other agency representatives. What make these "round tables" unique are their connection to a national network of Biosphere Reserve communities and the links to the World Network promoting areas where sustainable development is an applied concept.

Since 1972, UNESCO has designated 15 biosphere reserves in Canada (Figure 3): Mont St. Hilaire (Quebec, 1978); Waterton (Alberta, 1979); Long Point (Ontario, 1986); Riding Mountain (Manitoba, 1986); Charlevoix (Quebec, 1989); Niagara Escarpment (Ontario, 1990); Clayoquot Sound (British Columbia, 2000); Redberry Lake (Saskatchewan, 2000); Lac St. Pierre (Quebec, 2000); Mount

Arrowsmith (British Columbia, 2000); South West Nova (Nova Scotia, 2001); Thousand Islands – Frontenac Arch (Ontario, 2002); Georgian Bay Littoral (2004); Manicouagan Uapishka (2007) and Fundy (2007).

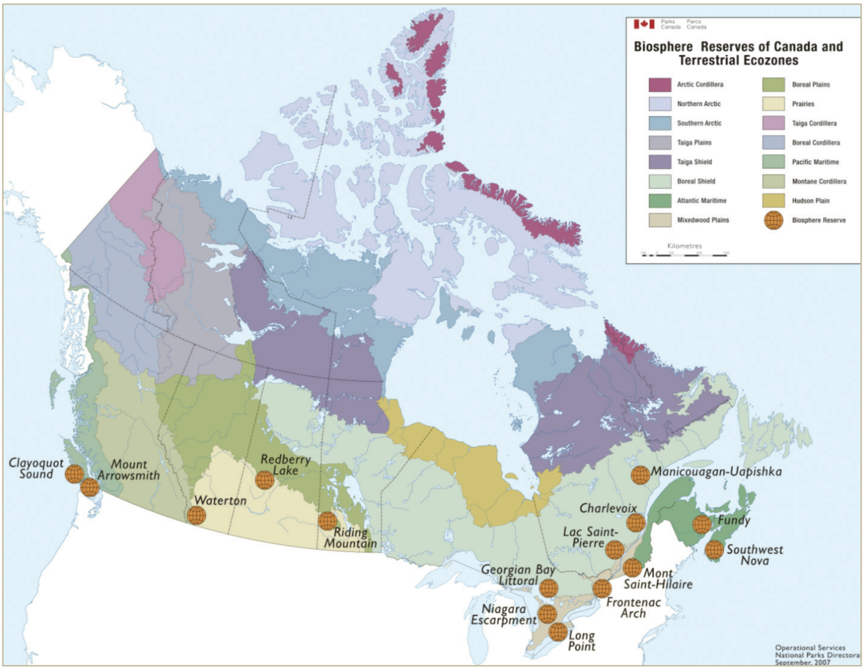

FIGURE 3
Canada's 15 Biosphere Reserves as designated by the United Nations' Education, Science and Cultural Organization's (UNESCO) Man and the Biosphere (MAB) programme.

The southern Ontario portion of the Niagara Escarpment stretches 725 kilometres from Queenston (near Niagara Falls) to Tobermory (Figure 4) and runs through the Halton Region. The total protected area of the Escarpment is 1,837 km^2, representing almost two percent of the total land area of southern Ontario. The Niagara Escarpment has over 60 waterfalls (including Niagara Falls) and also contains the greatest concentration of cold-water streams in the southern Ontario region, involving 7 different watersheds.

The Niagara Escarpment Biosphere Reserve is a region accorded special attention by the research community regionally, nationally and internationally (Fenech *et al.*, 2004a). Given its unique topography, the Niagara Escarpment

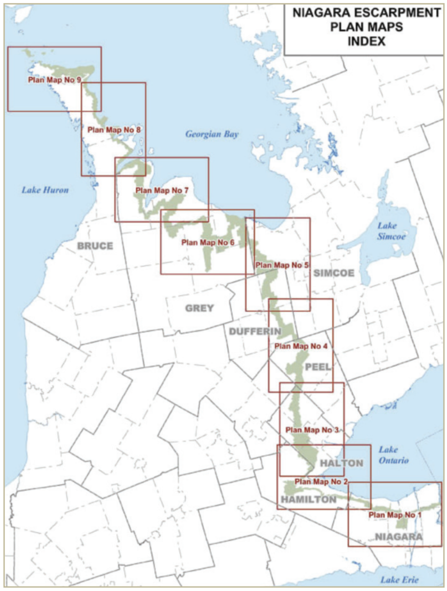

FIGURE 4
The Niagara Escarpment and Halton Region (lower right of map) in southern Ontario

supports an especially high diversity of plant and animal species (Coalition on the Niagara Escarpment, 1998). The southern extent of the Escarpment is within the Carolinian, or deciduous forest region, while the north of the Niagara Peninsula is in the Great Lakes-St. Lawrence forest region. Many plant species found on the Niagara Escarpment are regionally, and even globally significant. The Niagara Escarpment also supports a wide variety of wildlife – 36 species of herptiles (herbivores and reptiles), 55 mammal species, and over 300 species of birds.

Public concern about protecting the Niagara Escarpment began to emerge in the early 1960s primarily in response to mineral resource extraction. The government responded with the enactment of the Niagara Escarpment Protection Act, 1970 and the Pits and Quarries Control Act, 1971 which served to restrict aggregate extraction along the escarpment. In 1973, the Niagara Escarpment Planning and Development Act was enacted to: "provide for the maintenance of the Niagara Escarpment and land in its vicinity substantially as a continuous natural environment, and to ensure only such development occurs as is compatible with that natural environment" (Government of Ontario, 1990). The Act established the Niagara Escarpment Commission and required it to develop a land-use plan that would achieve several important objectives for the escarpment including protecting unique ecological and historic areas, and providing adequate opportunities for outdoor recreation and public access.

A process that began in the mid-1970s culminated in the 1985 Ontario government's approval of the Niagara Escarpment Plan of land-use policies, development criteria and open space systems (Government of Ontario, 1994). All lands within the Niagara Escarpment Plan area were placed into one of seven land use designations - natural (protected in a natural state to protect ecological significance), protection (landforms of visual or environmental significance that have been altered by existing land uses and act as a buffer for natural), rural (another buffer acting as a transitional zone between the natural, and the protected and human use), recreation (ski centres, cottage areas or resorts), mineral extraction (aggregate resource extraction areas), minor urban (villages and hamlets) and urban (larger towns and cities). About 92 percent of the Plan area has been designated as natural, protection or rural area.

The southern portion of the Niagara Escarpment runs through Halton Region, the area selected for this study. Halton covers over 967 square km, including a 25-km frontage onto Lake Ontario. There was a human population in Halton Region of about 439,000 in 2006. Halton Region is located west of the City of Toronto, Ontario, Canada, and is strategically located in Ontario's economic heartland. It has a diversified economic base featuring advanced manufacturing, automotive, metal processing, knowledge-based industries, tourism, professional services, and scientific and technical services.

The town of Oakville and the city of Burlington make up the largely urban area in the south of Halton Region, while the towns of Milton and Halton Hills to the north are significantly more rural despite the presence of growing urban areas. The town of Georgetown, where much of the regional government is located, is somewhere in between these urban and rural settlements in terms of overall development. Urbanization in Brampton to the east in neighbouring Peel Region has made urban areas in the Greater Toronto Area uninterrupted all the way to the City of Toronto. Halton region experienced a human settlement growth rate of 17.1% between the 2001 and 2006 census, giving it one of the highest growth rates in the country. Despite the unprecedented growth in residential development in Halton, agriculture and protected lands along the Niagara Escarpment are still the predominant land uses.

Halton Region's natural environment is diverse and dominated by the Niagara Escarpment that runs through it. The forests of the Region are of two types (separated approximately by the route of Ontario's Highway 401): the northern limit of the Southern Deciduous Forest, which once covered most of the mid-eastern United States, passes through Halton although urban growth and agriculture have restricted this forest type to major stream valleys; while the Great Lakes-St. Lawrence Forest, which originally covered most of southern Ontario, is found in the northern three-quarters of Halton. Predominant species include Sugar Maple (*Acer saccharum*), Beech (*Fagus sylvatica*), White Pine (*Pinus strobus*), and Yellow Birch (*Betula alleghaniensis*). Forest animals that disappeared after European settlement included Marten (*Martes martes*), Fisher (*Martes pennanti*), Wolverine (*Gulo gulo*), Timber Wolf (*Canis lupus lycaon*), Canada Lynx (*Lynx canadensis*), Wapiti (*Cervus canadensis*), Wild Turkey (*Meleagris gallopavo*), and Passenger Pigeon (*Ectopistes migratorius*). Halton is drained by two major stream basins - Twelve Mile Creek and Sixteen Mile Creek. These have their headwaters above the Escarpment and drain southeast into Lake Ontario. Until the building of mill dams in the 1850s, both streams were rich salmon (*Salmo salar*) fisheries. The Lake Ontario shoreline forms the southern boundary of Halton. Halton Region was selected for this study due to its unique natural environment and pressing economic growth and development.

3. RAICC Step One: Building a History of Climate Extremes

3.1 Climate and Biosphere Reserves

Climate can be thought of as an average of the weather over a period of years or decades. It describes the characteristic weather conditions to be expected in a region at a given time of year, based on long-term experience. By international convention, weather observations are commonly averaged over a period of 30 years to produce the statistics that describe the climate "normals" (see Phillips and McCulloch, 1972; Gates, 1973; Watson, 1974; Janz and Storr, 1977; Wahl *et al.,* 1987; Auld *et al.,* 1990). These averages are helpful for providing "average" temperatures and precipitation, or when comparing one location to another, but they do not provide the necessary information to assist communities in planning for climate change adaptation.

For example, as part of the Canadian Biosphere Reserves Association's (CBRA) Climate Change Initiative (CCI) designed to present climate change information to Biosphere Reserve communities to allow local organizations to understand climate change and adapt to potential impacts, Hamilton *et al.* (2001) examined climate observational records from Biosphere Reserves across Canada including Waterton Lakes, Riding Mountain, Niagara Escarpment, Long Point, and Kejimkujik (a candidate Biosphere Reserve that was designated as the Southwest Nova Biosphere Reserve in 2001). Annual average temperature and precipitation series were generated from daily temperature and precipitation values. Long term trends were identified over the period of the instrumental record leading to the following results.

In general, data from the interval 1900 to 1998 showed lower temperatures in the 1920's (cooler), higher (warmer) temperatures from the early 1940's into the early 1950's, and lower (cooler) temperatures into the 1970's, and subsequent higher temperatures (warmer). At many stations, 1998 was the highest (warmest) in the instrumental record. The 20th century warming was shown as

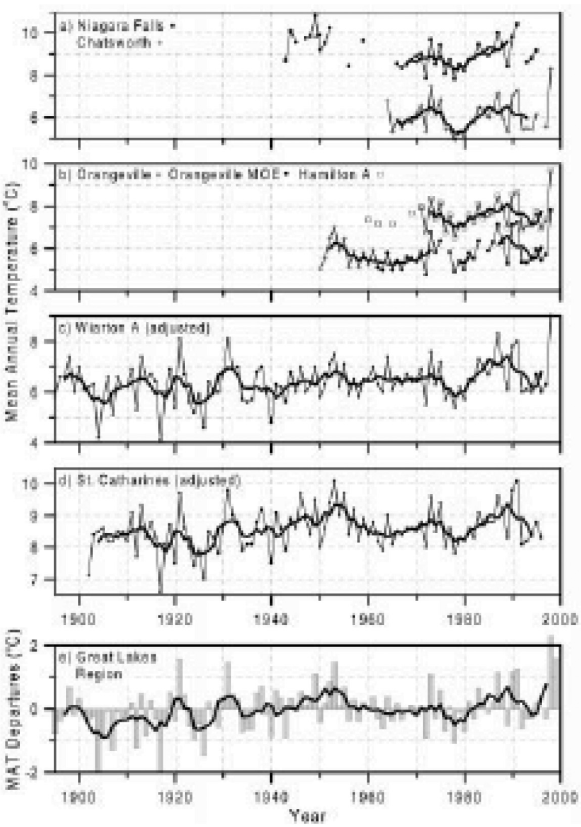

FIGURE 5

Mean annual temperature for stations representing Niagara Escarpment Biosphere Reserve, and departures for the Great Lakes Region.

approximately 1.0°C in the Riding Mountain area and 0.6°C at Long Point, Niagara Escarpment (see Figure 5 for example), and Waterton Lakes. There was a slight cooling in the Kejimkujik area over the past half century. Precipitation data showed increasing trends in the Kejimkujik, Long Point, Niagara Escarpment, and Waterton Lakes areas with no long term trend in the Riding Mountain area.

Managers at the Biosphere Reserves in Canada were perplexed when presented with this data and information. They viewed such information on climate normals and trends as unable to assist them in preparing for future climate change, and the necessary adaptations that might follow (Fenech and Liu, 2007).

Informal discussions were conducted with environmental managers at Biosphere Reserves in Canada and China – those responsible for local agriculture, local tourism, park management, or biodiversity conservation. The question was asked: "How do you make preparations about the threats from future climate (climate change)?" Most viewed the threat of climate change, or their own vulnerability, was to climate extremes – high and low temperature extremes (hot and cold), and high and low precipitation extremes (wet and dry). They also believed that they had good experience with extreme weather over the past decades that they could learn from how they adapted in the past (if reminded of the specific years). The unknown was when and how often extreme weather was going to occur – the frequency of extremes. Scientists are unable to answer the "when" question at this time, but there is some scientific ability to provide guidance on answering the question of "how often." It was clear from the discussions that communities such as Biosphere Reserves need climate information on extremes of climate so that they can determine how they have adapted in the past to these extremes, and how to best plan for these in the future.

3.2 Indices of climate extremes

There have been an increasing number of new environmental indices being proposed in the literature since Ott's seminal book in 1978. Environmental indices can be defined as "a condensed description of multi-dimensional environmental states by aggregating several variables (or indicators) into a single quantity" (Ebert and Welsch, 2004). Such a description may be useful whenever an aggregation of individual variables is impossible usually due to a lack of information, or when there is no association between individual variables and anticipated responses.

The basic purpose of environmental indices is to allow comparisons of states of the environment across time or space (Adriannse, 1993). Indices are used to summarize and present a complex set of multivariate (several variables at the same time) changes so that the results can be easily understood and used in policy decisions made by non-specialists in the field. Despite their increasing use in natural resource disciplines, researchers and public decision makers continue to express concern about the validity of indices to capture and communicate multidimensional, and sometimes disparate, characteristics of research data and stakeholder interests (Hoag *et al.,* 2005).

The greatest tension, however, is between the many environmental indices proposed in recent years and the lack of external criteria for choosing among them. For climate, many have developed their own indices of climate extremes (ClimDex, 2001; Frich *et al.,* 2002; European Climate Assessment, 2007; Klein Tank *et al.,* 2003; Kiktev *et al.,* 2003; Stardex, 2007; Bonsal *et al.,* 2001; and Klein Tank *et al.,* 2002) which now total over 400. The World Meteorological Organization's Commission on Climatology (CCl) expert team has narrowed the total down to 27 core indices based on daily temperature values or daily precipitation amount, but this is still a large number to calculate and communicate. Some of the indices are based on fixed thresholds that are of relevance to particular applications (for example, a drought index), and are the same for all stations; while other indices are based on thresholds that vary from location to location.

In order to select the most appropriate for this study, a literature search found a paper on the application of indices of climate extremes to Canada and other climate-similar regions. Gachon (2005) selected 18 indices for extreme temperature and precipitation for Canadian regions using the following criteria:

- the indices must represent regional Canadian climate conditions;
- the indices must be relevant to climate change impact studies; and
- the indices must be adapted to the main characteristics of climate conditions at the regional scale.

Gachon (2005) describes these 18 indices as "providing a good mix of information – precipitation indices characterize the frequency, intensity, length of dry spells, magnitude and occurrence of wet extremes while temperature indices refer to variability, season lengths and cold and warm extremes in terms of magnitude, occurrence and duration." These are referred to in this paper as the Gachon Indices of Climate Extremes (GICE) and formulae for calculating the indices are presented in Table 1.

Note that the Gachon Indices are selected for Canadian Regions similar to the climate of Quebec such as the province of Ontario. For other Canadian provinces, as well as for other countries, other indices may be selected or the indices may be revised in order to meet regional climate conditions. For example, application in tropical countries will require the selection of indices of climate extremes that recognize the low temperature variability and wet and dry seasons typical of tropical regions.

TABLE 1
Gachon Indices of Climate Extremes for Impact Studies of Climate

INDEX	DEFINITION	UNIT	TIME SCALE
Precipitation			
Frequency	Percentage of wet days (Threshold=1 mm)	% days	Season
Intensity	Simple daily intensity index : sum of daily precip/ number of wet days	Mm/wet d	Season
Extremes	Maximum number of consecutive dry days (<1 mm)	days	Season
Magnitude and Occurrence	Maximum 3-days precipitation total	Mm	Season
	90th percentile of rainday amount ((Threshold=1 mm)	Mm/days	Season
	Percentage of days Prec>90th percentile (61-90 based period)	% days	Season
Temperature			
Daily variability	Mean of diurnal temperature range	°C	Season
	Percentage of days with freeze and thaw cycle (Tmax>0°C, Tmin<0°C)	% days	Month
Season length	Frost season length :Tday<0°C more than 6 d.and Tday>0°C more than 6 d.	days	Year
	Growing season length :Tday>5°C more than 6 d. and Tday<5°C more than 6 d.	days	Year
Extremes cold & hot	Sum of sequences > 3 days where Tmin< daily Tmin normal - 5°C	days	Winter
	Sum of sequences > 3 days where Tmax> daily Tmax normal + 3°C	days	summer
Extremes Magnitude and Occurrence	10th percentile of daily Tmax	°C	Season
	90th percentile of daily Tmax	°C	Season
	10th percentile of daily Tmin	°C	Season
	90th percentile of daily Tmin	°C	Season
	Percentage of days Tmax>90th percentile (61-90 based period)	% days	Season
	Percentage of days Tmin<10th percentile (61-90 based period)	% days	Season

3.3 Climate observational data for past climate extremes

The Gachon Indices of Climate Extremes (GICE) that are used to provide an understanding of climate changes to communities across temperate regions are based on the two most common meteorological observations - temperature and precipitation. For the indices to be useful in understanding extremes, observations of the maximum and minimum temperatures as well as precipitation should be available on a daily basis, with a record length of at least thirty years of data in order to conduct trend analyses. Basic climate observations of temperature and precipitation are taken around the world using common methodologies and standards established by the World Meteorological Organization (WMO, 1983). Temperature and precipitation observations are recorded across Canada by automated weather stations and volunteer climate observers whose locations are shown in Figure 6 (Durocher, 2007).

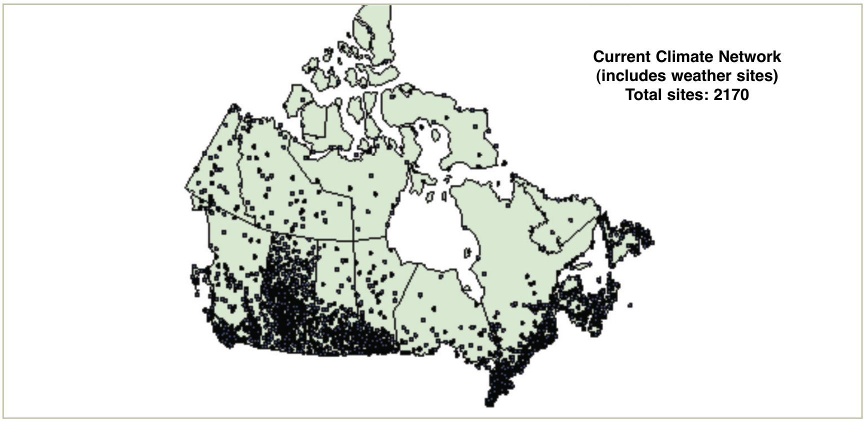

FIGURE 6
Canadian Climate Network as of 2007.

An automatic weather station is a cluster of climate sensors connected to a data logger. Sensors are usually positioned by international standards and protocols on a two meter mast; and the station powered by a solar panel and battery. Sensors often used on automatic weather stations include: air temperature; relative humidity; rainfall; solar radiation; wind speed and direction; and barometric pressure. These stations can be designed as automated bioclimate monitoring stations (see Figure 7) adding sensors to measure meterological variables throughout the forest canopy and in the soil (Fenech *et al.,* 1995).

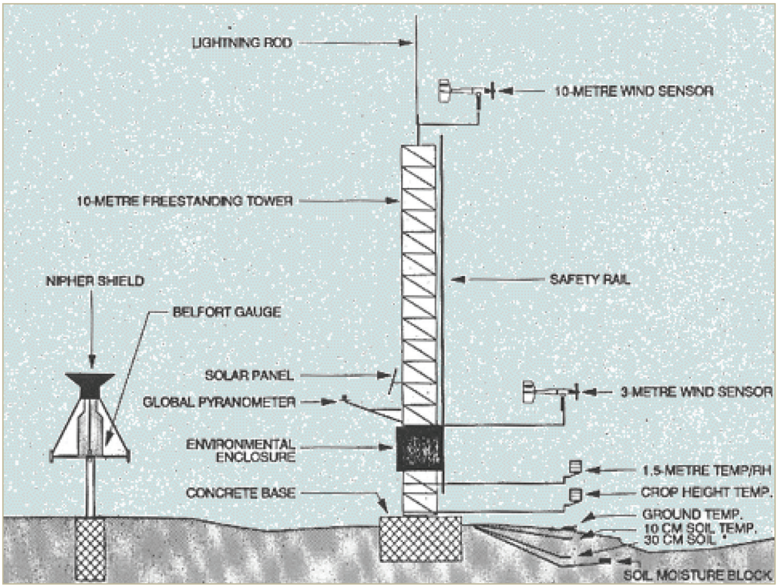

FIGURE 7
Bioclimate instrumentation to measure a profile of temperature, humidity, wind, precipitation and solar radiation throughout the forest canopy and temperature into the soil.

In addition to the automatic machines, a network of more than two thousand volunteer climate observers from every province and territory in Canada records maximum and minimum temperature readings and precipitation readings twice daily. These measurements are reported to Environment Canada using an automated telephone entry system, and since 2000, via the Internet. The new system has resulted in a reduction in expenses (for manual data entry, postage and handling), automated quality assurance, and data availability from observation to archive in minutes rather than months. Canada's National Climate Data and Information (NCDI) Archive houses more than seven billion observations collected across Canada over the past century and a half, many of which are from volunteer climate observers (NCDI Archive, 2007).

3.4 Selecting a climate station for Halton Region

Canada's National Climate Data and Information Archive (2007) contains official climate and weather observations for Canada, and is operated and maintained by Environment Canada. The Archive provides direct access, through a website, to climate and weather values in the database of Canadian climate stations. The website can be used to obtain weather values for a particular hour, day, month or year, plus an almanac (daily averages and extremes) (Table 2). *Note that all data parameters and time intervals are not available for all possible stations; it depends on what was observed at each site.* Data can be downloaded as XML or as a CSV (comma delimited) file; hourly data can be downloaded for a period of 1 month at a time, daily data for a period of 1 year at a time, and monthly data for the entire period of record.

TABLE 2

Climate data parameters available at Canada's National Climate Data and Information Archive website (2007).

Hourly	Daily	Monthly	Almanac
Temperature	Maximum Temperature	Mean Maximum Temperature	Average Maximum Temperature
Dew Point Temperature	Minimum Temperature	Mean Temperature	Frequency of Precipitation
Relative Humidity	Mean Temperature	Mean Minimum Temperature	Frequency of Precipitation
Wind Direction	Heating Degree Days	Extreme Maximum Temperature	Highest Temperature
Wind Speed	Cooling Degree Days	Extreme Minimum Temperature	Lowest Temperature
Visibility	Total Rainfall	Total Rainfall	Greatest Precipitation
Station Pressure	Total Snowfall	Total Snowfall	Greatest Rainfall
Humidex	Total Precipitation	Total Precipitation	Greatest Snowfall
Wind Chill	Snow on Ground	Snow on Ground on Last Day	Most Snow on Ground
Weather	Direction of Maximum Gust	Direction of Maximum Gust	
	Speed of Maximum Gust	Speed of Maximum Gust	

To select a climate station in Halton Region for the climate data analysis, a customized search query was made at Environment Canada's National Climate Data and Information (NCDI) Archive (2007). Milton township was selected as the geographic mid-point of Halton Region by viewing a map of the area. A search was made by location coordinates with a proximity of 25 kilometers to Milton's latitude and longitude (43° 30′ North latitude, and 79° 53′ West longitude) for default years from 1840 to 2007. The search returned 56 climate stations within 25 kilometers of Milton as shown in Figure 8. Each of the stations was evaluated for its length of record as a minimum of 30 years is recommended by the IPCC (2001a). This returned eleven potential locations (Aldershot, Brampton, Brampton

MOE, Burlington TS, Georgetown, Georgetown WWTP, Hamilton RBG, Millgrove, Oakville Southeast WPCP, Port Credit and Valens). Of these eleven, each was evaluated for its location to determine if it was located within the Regional Municipality of Halton, our study area. This returned five potential locations whose length of records were reviewed once again as longer climate records are more desirable - Aldershot (1947-1977), Burlington TS (1951-1999), Georgetown (1882-1966), Georgetown WWTP (1962-2007), and Oakville Southeast WPCP (1970-2001). Georgetown WWTP was selected from these five as the most appropriate location for the study due to its length of record within the memory of environmental and economic managers (city planners) of the Halton Region (many of whom reside in Georgetown itself at the municipality's offices), and was selected to represent the Halton Region. Note that the Georgetown weather station was not combined with the Georgetown WWTP station due to their significant elevation differences.

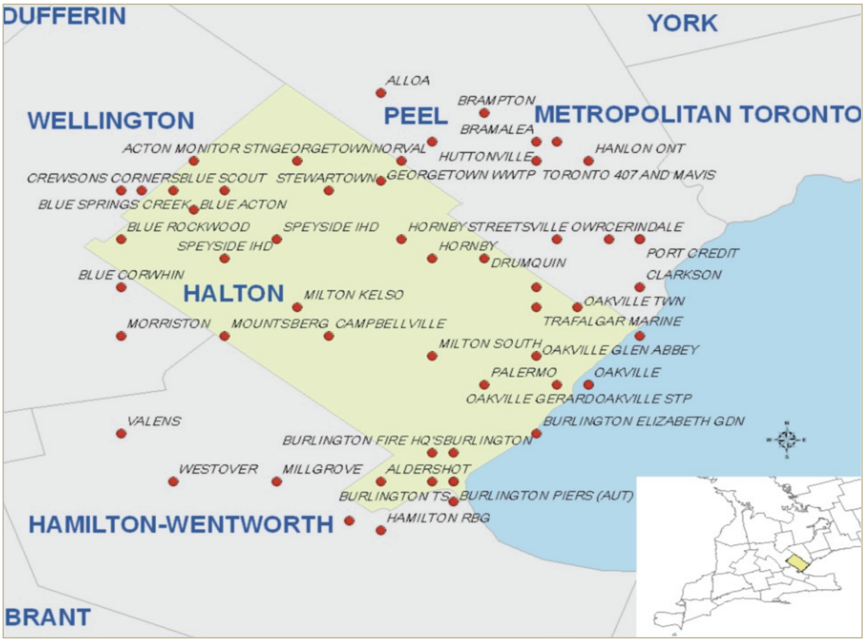

FIGURE 8
56 climate stations within 25 kilometers of Milton returning data from the National Climate Data and Information Archive.[1]

1 Consider the red dots in the blue lake to be shoreline sites.

Returning to the customized search query at the NCDI Archive (2007), a query was made for "Georgetown WWTP" by station name for default years from 1966 to 2007. Using the *Bulk Data* option in the *Navigation Options* available at the bottom of the *Daily Data Report for Georgetown WWTP,* the climate data was downloaded from the NCDI Archive onto a personal computer. These data were imported into a spreadsheet software (Microsoft © Excel 2003), and stripped down to the daily temperature and precipitation records, and studied for completeness. Large gaps of missing data values for temperature (1967-1978) and precipitation (1967-1968) were recognized, and the offending time periods (years or seasons) removed from the data analysis.

3.5 The Climate of Halton Region 1980-2007

The Georgetown WWTP station database was analyzed for climate trends, and shows an increase in the annual mean temperature of 1.54° Celsius from 1980 to 2007 (Figure 9).

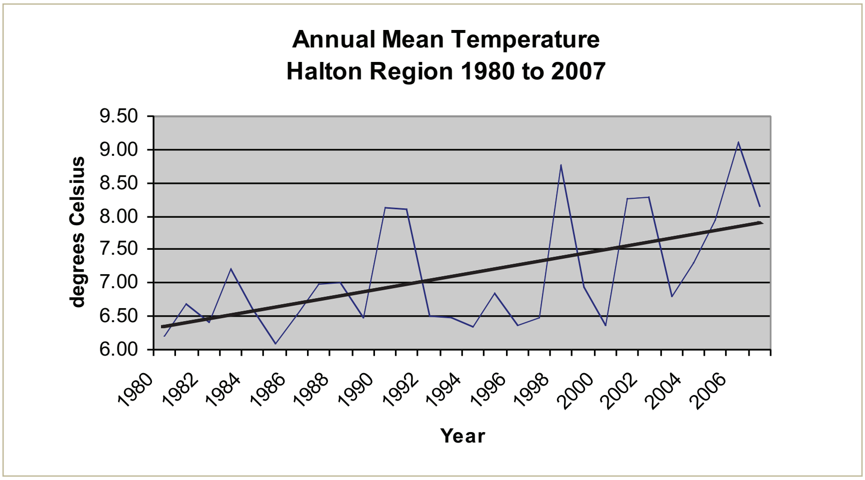

FIGURE 9
Mean annual temperature at Halton Region 1980-2007.

R	0.32
Standard Error	0.74
Observations	27
p-value	0.01

Alternatively, the annual mean precipitation has decreased from 1980 to 2007, on average by 0.55 millimeters per day (Figure 10).

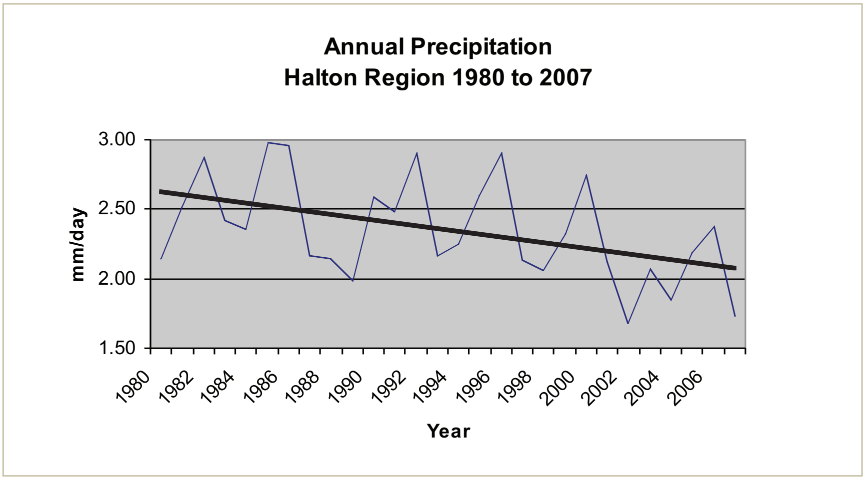

FIGURE 10
Mean annual precipitation at Halton Region 1980 to 2007

R	0.27
Standard Error	0.33
Observations	27
p-value	0.04

The analysis of the observation data concludes that the climate of Halton Region has shown an increase in temperature (mainly maximums) and a decrease in precipitation over the past 30 years that, given their magnitude, constitute significant changes. However, this does not necessarily mean that climate change has impacted on the Halton Region. Changes in temperature and precipitation over the observational record may have resulted from other factors such as land-use change. This is particularly relevant for the Halton Region as it is one of the fastest growing municipalities in Canada in terms of human settlement and industrial growth. This type of urbanization has been shown to increase minimum temperatures by as much as 3.9°C over 125 years (see Urquizo *et al.*, 2002) between an urban site (Toronto, Ontario) as compared to a rural site (Beatrice, Ontario) at latitudes similar to the Halton Region.

3.6 A History of Climate Extremes at Halton Region 1980-2006

The climate of Halton Region as shown above is insufficient to assist environmental managers in preparing for future climate change, and the necessary adaptations that might follow. However, the threat of climate change, or the vulnerability of the Region, is to climate extremes – extreme hot, cold, wet and dry – so a history of climate extremes is to be written as the first step in the RAICC process. Environmental managers have good experience with extreme weather over the past decades, and they can learn from how they adapted in the past (if reminded of the specific years). This is a process known as *adaptation through learning* and is detailed in Fenech and Liu (2007).

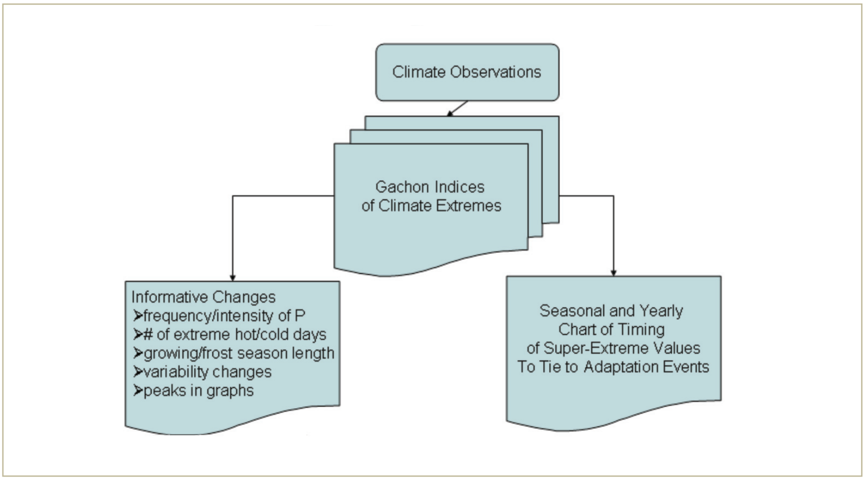

FIGURE 11
Building a History of Climate Extremes

A history of climate extremes is a storyline of climate vulnerability that is understandable to environmental managers built using climate extreme indices – in this case, the Gachon Indices of Climate Extremes (GICE). Figure 11 shows a graphical description of building a history of climate extremes. First, the Indices are calculated using the climate data from the observational record. Second, the trends in extreme heat, cold, wetness and dryness that have occurred over the observational record are described with the indices charts as background. These may include: changes in the frequency and intensity of precipitation; changes in the number of extreme hot and cold days; changes in the length of the growing season and frost season; changes in the climate variability such as freeze/thaw cycle or diurnal temperature range; and identification of any peaks in the graphs that correspond to known extreme weather events impacting the region (for example, Hurricane Hazel). Third, values that are outside of the distribution of the mean value of the index plus or minus two times the standard deviation are transferred to five timelines that highlight the annual and seasonal timing of "extremes" in the climate extremes of heat, cold, wet, dry and variability. For illustrative purposes, two figures are shown in applying the history of climate extremes approach to the climate observational record at Georgetown.

- Over the years 1980 to 2007, it has been raining or snowing 7 percent less often per year in Halton Region (-2% in Winter, -7% in Spring, -10% in Summer and -7% in Autumn) (Figure 12).

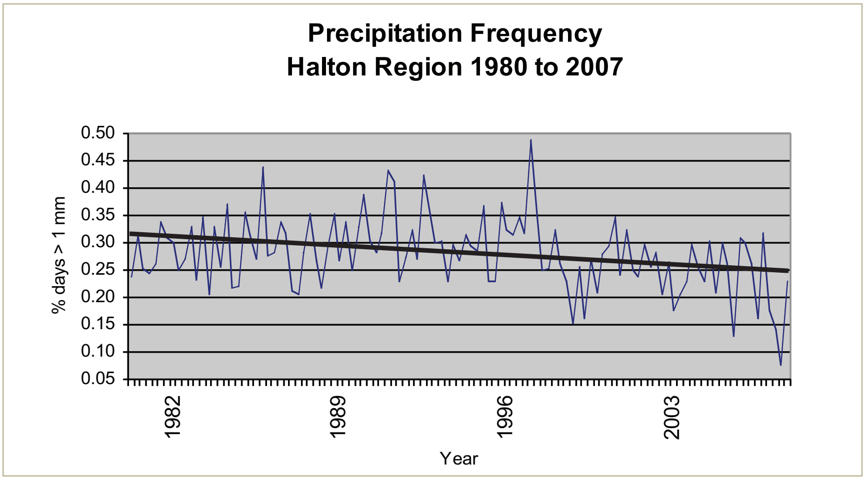

FIGURE 12
Frequency of Annual Precipitation at Halton Region 1980-2007.

R	0.21
Standard Error	0.03
Observations	26
p-value	0.01

- The growing season of Halton Region has increased by over 3 weeks (23 days) (Figure 13) as is consistent with recent studies globally on the impact of climate changes on the lengthening of the growing season (Huntington, 2007).

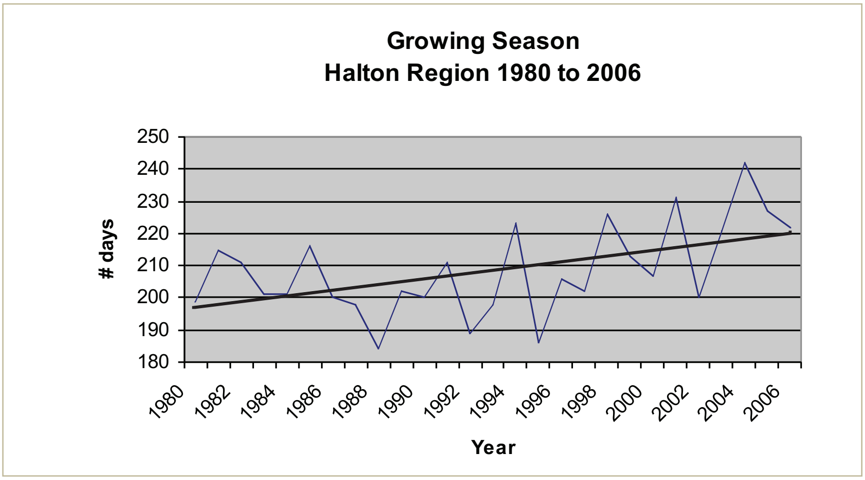

FIGURE 13
Length of growing season at Halton Region 1980-2006.

R	0.21
Standard Error	12.49
Observations	27
p-value	0.01

As indicated above, in Step 3 of building a history of climate extremes, the outlier values in the indices are targeted if they fall outside the normal distribution represented by the mean plus or minus two times the standard deviation. Table 3 provides the values for each of the Gachon Indices of Climate Extremes (GICE) above or below which represent a *super-extreme* value to be identified. All Gachon Indices of Climate Extremes for Halton Region derived from observation records are shown in Appendix II.

TABLE 3
Threshold Values for Gachon Indices of Climate Extremes

Gachon Indicator	Mean + 2 X standard deviation Season				Mean – 2 X standard deviation Season			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Pfrequency (%days)	44	39	39	41	15	17	14	18
Pintensity (mm)	10.27	10.64	13.18	12.44	4.53	5.54	5.21	4.96
Dry Days	21	23	21	22	4	2	4	3
3-day Maximum P (mm)	64.78	61.36	89.06	77.66	7.79	19.59	12.34	13.43
90th Percentile Rainday (mm)	10.87	10.96	12.54	14.75	2.44	3.73	2.43	1.90
%days 90th Percentile	17	16	15	17	3	3	3	3
Tdiurnal (°C)	10.82	14.09	15.02	13.19	7.25	10.61	12.50	9.49
Frost season (days)		139				68		
Growing season (days)		237				180		
Extreme Cold (days)		36				0		
Extreme Heat (days)		40				0		
10th Percentile Tmax (°C)	-2.21	3.70	23.54	7.65	-12.08	-1.82	17.91	1.30
90th Percentile Tmax (°C)	9.57	27.74	33.79	28.31	2.25	18.12	27.04	20.59
10th Percentile Tmin (°C)	-12.02	-6.04	8.59	-2.31	-26.05	-13.62	4.33	-6.79
90th Percentile Tmin	1.40	11.96	19.69	13.47	-3.02	4.44	14.59	9.06
%days 90thPer Tmax	98	20	38	27	51	0	0	0
%days 10thPer Tmin	22	19	21	19	0	0	0	3

	Ja	Fe	Mr	Ap	My	Oc	Nv	De	Ja	Fe	Mr	Ap	My	Oc	Nv	De
freeze/thaw (days)	21	20	25	22	10	17	23	23	0	1	11	6	0	2	10	4

All values identified as super-extreme are shown in Table 4. These are then transferred to five timelines as a calendar presented in Table 5 that indicate the annual and seasonal timing pattern of climate super-extremes in hot, cold, wet, dry and variability (more and less). Many observations about Halton Region's climate can be made from Table 4 including:

- the late 1990s and 2000s are a time of hot super-extremes;
- there are more hot or wet super-extreme years than cold or dry super-extreme years;
- all super-extreme categories (hot, wet, cold, dry, variability) appear to be independent from one another with none occurring in the same season

and year. This is true for both complementary super-extreme categories (hot and dry, wet and cold) or opposite super-extreme categories (hot and cold, wet and dry). None appear to be linked with variability (neither more nor less);

- sometimes super-extreme events occur for two consecutive seasons thus perhaps prolonging their impacts (hot Summer and Autumn 2005; wet Spring and Summer 2000; cold Autumn 1993 and Winter 1994; cold Summer and Autumn 1986; wet Summer and Autumn 1985) and perhaps indicating a persistence in the climate system;
- sometimes super-extremes in one season are followed by the opposite super-extremes in another season (wet Winter to dry Spring 1999; dry Autumn 1998 to wet Winter 1999); and
- sometimes super-extremes occur in the same season two years in a row (hot summers 2005 and 2006; cold Autumns 1986 and 1987; wet Autumns 1985 and 1986), or follow an alternating cycle such as the super-extreme wet Winter seasons for 1995, 1997, 1999 and 2001.

By showing environmental managers at the Halton Region how the climate has changed in the past in these intriguing ways, the question can be asked as to how the natural environment as well as the economy have been impacted by the extreme changes, or how humans have intervened to help the natural environment or the economy adapt to these changes. In the case of Halton Region, the past climate highlights years of consecutive super-extreme seasons within the memory of all regional managers. These super-extreme seasons may have required intervention from environmental managers to save agricultural crops, host an influx of visitors to natural areas, preserve endangered species habitat, or ensure the quality of groundwater. This knowledge, taken together with scenarios of future climate change showing a similar future of extreme hot years in the future, can identify some adaptation measures that might be taken to ensure that an adaptation infrastructure is in place, or that alternative management of the Halton Region occurs. In other words, what lessons did the Region learn from the past extreme climate events that can be drawn on with advanced knowledge about the future to minimize the negative impacts and maximize the benefits from climate change?

TABLE 4
Super-Extreme GICE (Gachon Indices of Climate Extremes) Values

Precipitation	Temperature	Variability
Wetter More Often 1997 Winter; 1992 Summer; 1991 Spring; 1985 Autumn More intense 1999 Winter, Autumn; 1986 Autumn; 1982 Summer 3day max 2001 Winter; 2000 Spring, Summer; 1995 Winter; 1986 Autumn; 1981 Autumn 90thPercentile Rainday 1997 Winter; 1985 Summer, Autumn %days90thPercentileP 1991 Spring **Drier** Less Often 2005 Summer; 1999 Spring Dry Days 2007 Summer; 1999 Spring; 1998 Autumn; 1992 Winter; 1989 Summer; 1988 Winter %days90thPercentileP 1980 Winter	**Hotter** Short Frost Season 2000 Longer Growing Season 2004 Zero Days Extreme Cold, 2007, 2002, 1998 Many Days Extreme Heat, 2005 Tmax10thPercentile, 2005 Summer Tmax90thPercentile, 2002 Autumn; 1991 Spring; 1988 Summer Tmin10thPercentile, 2002 Winter Tmin90thPercentile, 2007 Winter; 2006 Summer; 2000 Autumn; 1991 Spring %days90thPercentileTmax, 2005 Summer, Autumn; 2002 Autumn; 1998 Spring; **Colder** Long Frost Season 1996 Many Extreme Cold Days, 1994 Tmax10thPercentile, 1994 Winter; 1984 Spring Tmax90thPercentile, 1997 Spring Tmin10thPercentile, 2003 Spring; 1986 Summer; 1984 Autumn Tmin90thPercentile, 1993 Autumn; 1980 Winter %days10thPercentileTmin 2002 Spring; 1994 Winter; 1987 Autumn; 1986 Autumn	**More variable,** Tdiurnal range increasing, 1998 Autumn Freeze-thaw increasing, 2005 May; 2002 January; 1997 April; 1994 March; 1990 January; 1989 January; 1986 December **Less variable** Tdiurnal, 2006 Winter; 1980 Spring Freeze-thaw decreasing, 2007 March, October, November

TABLE 5
Super-Extreme GICE (Gachon Indices of Climate Extremes) Values

Super-Extreme Hot Values				Hot	Super-Extreme Cold Values				Cold
	Winter	Spring	Summer	Fall		Winter	Spring	Summer	Fall
1980					1980				
1981					1981				
1982					1982				
1983					1983				
1984					1984				
1985					1985				
1986					1986				
1987					1987				
1988					1988				
1989					1989				
1990					1990				
1991					1991				
1992					1992				
1993					1993				
1994					1994				
1995					1995				
1996					1996				
1997					1997				
1998					1998				
1999					1999				
2000					2000				
2001					2001				
2002					2002				
2003					2003				
2004					2004				
2005					2005				
2006					2006				
2007					2007				

TABLE 5

Super-Extreme GICE (Gachon Indices of Climate Extremes) Values cont...

Super-Extreme Wet Values				Wet	Super-Extreme Dry Values				Dry
	Winter	Spring	Summer	Fall		Winter	Spring	Summer	Fall
1980					1980	■			
1981				■	1981				
1982			■		1982				
1983					1983				
1984					1984				
1985			■	■	1985				
1986				■	1986				
1987					1987				
1988					1988	■			
1989					1989			■	
1990					1990				
1991		■			1991				
1992			■		1992	■			
1993					1993				
1994					1994				
1995	■				1995				
1996					1996				
1997	■				1997				
1998					1998				■
1999	■			■	1999		■		
2000		■	■		2000				
2001	■				2001				
2002					2002				
2003					2003				
2004					2004				
2005					2005			■	
2006					2006				
2007					2007			■	

TABLE 5
Super-Extreme GICE (Gachon Indices of Climate Extremes) Values cont...

	Super-Extreme Variability		More	Less
	Winter	Spring	Summer	Fall
1980				
1981				
1982				
1983				
1984				
1985				
1986	Dec			
1987				
1988				
1989	Jan			
1990	Jan			
1991				
1992				
1993				
1994		Mar		
1995				
1996				
1997		Apr		
1998				
1999				
2000				
2001				
2002	Jan			
2003				
2004				
2005		May		
2006				
2007		Mar		Oct, Nov

4. RAICC Step 2 – Selecting a Climate Model for Future Projections

A more detailed description of selecting a climate model for future projections is available in this collection of papers by Fenech, Comer and Gough (2007) titled Selecting a *Global Climate Model for Understanding Future Scenarios of Climate Change.*

There is a wide selection of climate models available to provide scenarios of future climate change. All are mathematical models that simulate the functioning of the global climate system varying in size (computer space), scope (atmosphere, ocean, sea-ice and land-surface components), scale (horizontal spacing and grid size) and complexity (parameterization schemes). The models range (from largest to smallest attributes) from Global Climate Models (GCMs) to Regional Climate Models (RCMs) to downscaled models (DCMs). Our present understanding of the climate system and how it is likely to respond to increasing concentrations of greenhouse gases in the atmosphere would be impossible without the use of global climate models (GCMs) (Environment Canada, 2002). GCMs are powerful computer programs that use physical processes to replicate, as accurately as possible, the functioning of the global climate system.

Twenty-four GCMs used in the IPCC's 4th Assessment Report (Table 6) were examined for their past and future projections of climate. These 24 models represent eighteen modelling groups around the world who performed a set of coordinated, standard climate experiments. The model output, analyzed by hundreds of researchers worldwide, forms the basis for much of the current IPCC assessment of model results.

TABLE 6
GCMs used in the IPCC's Fourth Assessment Report (AR4)

CENTRE	MODEL
Bjerknes Centre for Climate, Norway	BCM2.0
Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	CGCM3T47
Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	CGCM3T63
Centre National de Recherches Meteorologiques, France	CNRMCM3
Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia	CSIROMk3.0
Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia	CSIROMk3.5
Max Planck Institute für Meteorologie, Germany	ECHAM5OM

TABLE 6

GCMs used in the IPCC's Fourth Assessment Report (AR4) cont...

CENTRE	MODEL
Meteorological Institute, University of Bonn Meteorological Research Institute, Germany	ECHO-G
Institute of Atmospheric Physics, Chinese Academy of Sciences, China	FGOALS-g1.0
Geophysical Fluid Dynamics Laboratory (GFDL), USA	GFDLCM2.0
Geophysical Fluid Dynamics Laboratory (GFDL), USA	GFDLCM2.1
Goddard Institute for Space Studies (GISS), USA	GISSAOM
Goddard Institute for Space Studies (GISS), USA	GISSE-H
Goddard Institute for Space Studies (GISS), USA	GISSE-R
UK Meteorological Office, United Kingdom	HADCM3
UK Meteorological Office, United Kingdom	HADGEM1
National Institute of Geophysics and Volcanology, Italy	INGV-SXG
Institute for Numerical Mathematics, Russia	INMCM3.0
Institute Pierre Simon Laplace, France	IPSLCM4
National Institute for Environmental Studies, Japan	MIROC3.2 hires
National Institute for Environmental Studies, Japan medres	MIROC3.2
Meteorological Research Institute, Japan Meteorological Agency, Japan	MRI-CGCM2.3.2
National Center for Atmospheric Research (NCAR), USA	NCARPCM
National Center for Atmospheric Research (NCAR), USA	NCARCCSM3

When beginning any impact assessment, choosing which climate model and scenario to use is an important question that should be considered early on in the process. The scatterplot tool at the Canadian Climate Change Scenarios Network (CCCSN) website is used primarily for the selection of useful scenarios. Scatterplots of various model scenarios will assist in identifying the range of values that are projected. For any climate change impact assessment, the selection of a representative range of scenarios is required. For example, a 'dry and warm', 'dry and warmer', 'wet and warm' and 'wet and warmer' scenarios could encompass a range of possible future outcomes. It is important to note that although the CCCSN scatterplot interface allows the user to enter a specific latitude/longitude or location (in this case for Halton Region) for which the information is required, the information that is returned is for the model grid box that contains the required location.

Figure 14 shows the range of possible future climate outcomes using both mean temperature and precipitation. A box has been added to show a tighter range of possibilities and arrows have been added to show drier to wetter (horizontal arrows) and warm to warmer (vertical arrows). These values are anomalies from the baseline that is represented by the red ■. As Comer (2007) suggests, even this "box" of models represents a large range, therefore the selection of a model or ensemble of models that reflects the range of changes is critical.

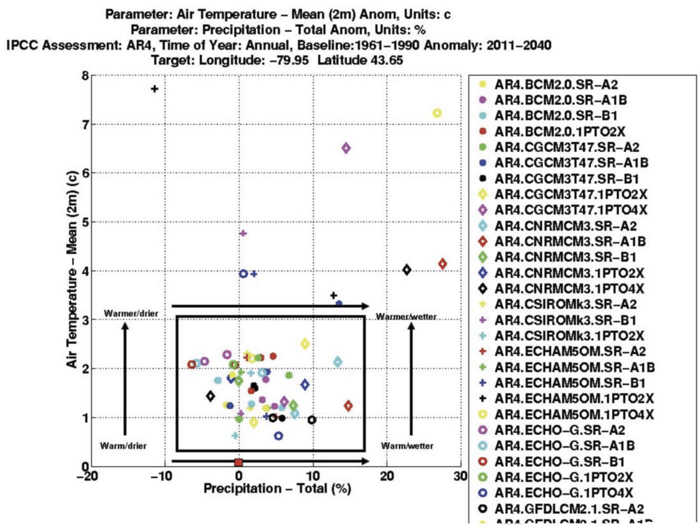

FIGURE 14
Range of future climate scenarios for Halton Region. Box and arrows added by authors.
■ represents baseline values (1961-1990).

The IPCC Data Distribution Centre (2007) suggests a list of five criteria that should be met by climate scenarios if they are to be useful for impact researchers and policy makers. The Canadian Global Climate Model (CGCM3) was selected from the 24 GCMs as the climate model for this study based on these criteria. Many climate change studies are based on the assumption that models that simulate better consistency with the observed changes (past) will provide more reliable projections of future climate change. The Canadian Global Climate Model 3.1 was validated with the observation data from Halton Region by downloading a dataset of modelled values for the years 1980 to 1999. The model presents an inherent bias of overall mean temperature values 0.27°C (almost 4%) lower than the observations, while standard deviations (variability) are similar. In order to maintain the variability of the model output yet bring the model output closer to the observed values, the inherent bias was removed from the mean temperature as well as the maximum and minimum temperatures and the total precipitation.

There are many limitations to using GCM output in local impact studies. A number of methodologies have been developed for deriving more detailed regional and site scenarios of climate change for impact studies. These downscaling techniques are generally based on GCM output and have been designed to bridge the gap between the information that the climate modelling community can currently provide and that required by the impacts research community (Wilby and Wigley, 1997). The literature presents downscaling techniques as generally divided into spatial (deriving local scenarios from regional scenarios) and temporal (deriving daily data scenarios from monthly or seasonal information) classes (Giorgi and Mearns, 1991; Robock *et al,* 1993; Hewitson and Crane, 1996; Wilby *et al.,* 1997; Murphy, 1999; IPCC, 2001b).

Our modified model output that removes the inherent bias of the selected GCM, however, is able to provide daily climate variables necessary for the application of climate indices to future climate changes.

5. RAICC Step 3 - Building a Future of Climate Extremes

5.1 The Future Climate of Halton Region

Using the CGCM3 model output, a similar approach as building a history of climate extremes was used for building a future of climate extremes. First, the Gachon Indices of Climate Extremes are calculated using the output from the modelled data (all 3 future scenarios). Second, the trends in extreme heat, cold, wetness and dryness that have occurred over the observational record are described with the indices charts as background. Third, the “super-extreme” values in the indices are identified in five timelines to highlight the annual and seasonal timing of climate extremes in heat, cold, wet, dry and variability. When examining overall climate trends, the model projects increases in overall temperature below the increasing observation trend from the past 29 years. All three model scenarios diverge from the observation trend at 2046 and result in an average increase of 3.8°C by 2100 (Figure 15).

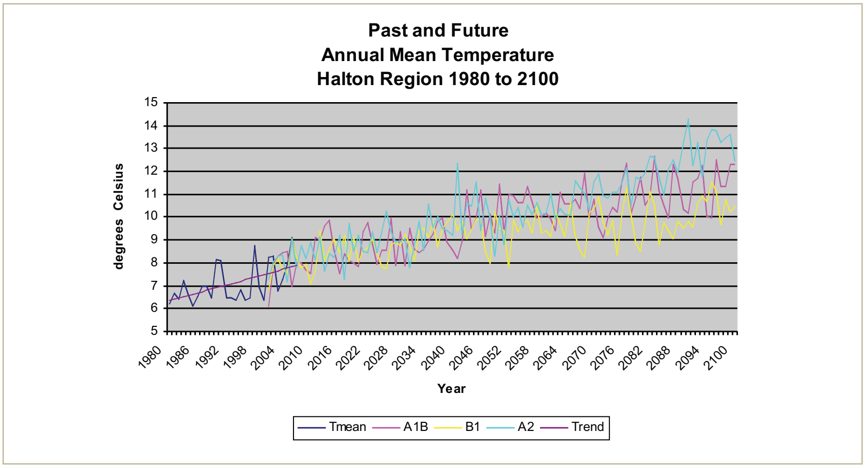

FIGURE 15
Observation and modelled mean temperature values for Halton Region 1980 to 2100.

The model also projects a slight increase (0.32 mm/day) in total annual precipitation for Halton Region (Figure 16) above the observation trend from the past 29 years.

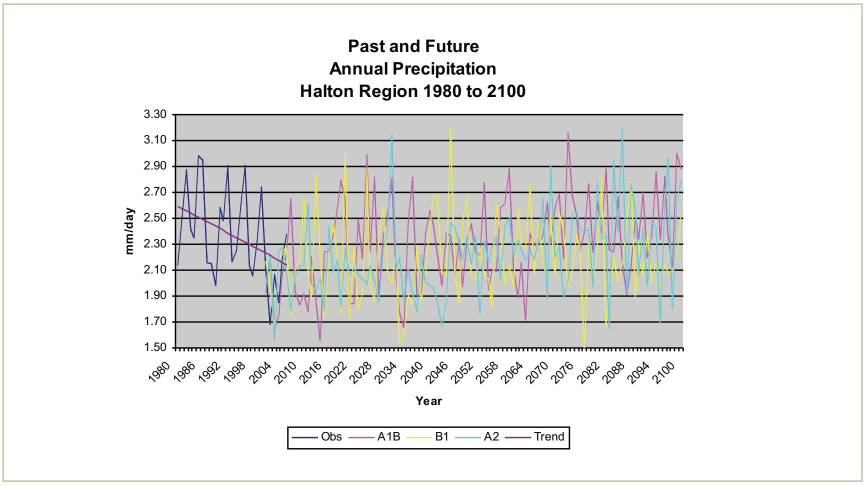

FIGURE 16
Observed and modelled precipitation values for Halton Region 1980 to 2100.

The Gachon Indices of Climate Extremes are calculated for Halton Region using the global climate model in order to develop a "future of climate extremes". An illustrative figure from these results follow.

- The model projects extreme hot days to increase, on average, by 32 days by the year 2100 (Figure 17).

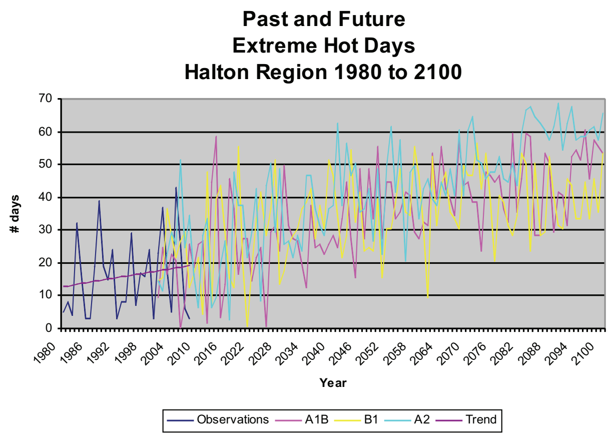

FIGURE 17
Observation and modelled extreme hot days for Halton Region 1980 to 2100.

- The model projects extreme cold days to decrease significantly to almost zero, on average, by the year 2100, a drop of over 17 days (Figure 16).

In step 3 of building a future of climate extremes, the outlier values in the indices are targeted if they fall outside the normal distribution represented by the mean plus/minus two times the standard deviation. There is a dramatic increase in hot and wet super-extreme values with smaller increases in cold and dry super-extremes. This is consistent with what the climate models of future change are revealing. Super-extremes of variability, both more and less, also appear to be on the rise.

6. RAICC Step 4 - Identifying Climate Change Environmental Predictors.

Step 4 of RAICC considers 10 economic and ecological sectors of Halton Region, named in this study as eco-sectors. These include: forestry, fisheries, agriculture, built environment, human health, tourism, transportation, water quality, energy, and biodiversity. RAICC focuses on 10 eco-sectors representing a broad variety of groups and activities based on article counts and percentages (of the total climate change adaptation dataset) of a literature review. Table 7 shows the article counts and percentages of total climate change adaptation literature for given categories.

TABLE 7
Article counts and percentages of total climate change adaptation literature for given categories

Climate Change Adaptation Category	Number of Articles (%) per category
Agriculture	233 (19.9%)
Water	194 (16.6%)
Forestry	87 (7.4%)
Health	59 (5.1%)
Built Environment (Infrastructure)	50 (4.3%)
Wildlife/Ecosystem Services	31 (2.7%)
Tourism	18 (1.5%)
Energy	17 (1.5%)
Fisheries	12 (1.0%)
Transportation (Emergency Services)	12 (1.0%)
Service Sector	1 (0.1%)

A literature review on the impacts of climate change was conducted for each of the 10 eco-sectors, and the climate-sensitive aspects were examined. Factors sensitive to temperature and precipitation were selected. These sensitivities are triggered at certain climate thresholds above which result in significant changes that may require some form of human interventionist adaptation. These are named "environmental predictors". These predictors were examined using data from Halton Region's past observations and future modelling. This provided an understanding of past changes in the climate-sensitive aspects of this eco-sector, as well as how these sensitivities are to change over time according to future modelling. The tourism sector is presented in this paper as an example. (A more detailed description of all 10 eco-sectors is available in this collection of papers by Fenech (2007) titled *Environmental Prediction: Using Future Projections of Climate Change to Understand Local Impacts and Adaptation)*

Tourism is one of the world's biggest industries. It is also the fastest growing. World tourism grew by a record 260% between 1970 and 1990 (Hale and Altalo 2002). The recreation and tourism sector is a diverse group of businesses and their clients that includes the airline industry, travel agents, tour operators, car rental companies, convention organisers and resorts, to name just a few. For many regions tourism is the most important source of income. There are other regions where the potential economic returns from the development of tourism are enormous but are as yet untapped. In these places it is generally accepted that climate is an important part of the region's tourism resource base, but the role of climate in determining the suitability of a region for tourism or outdoor recreation is often assumed to be self-evident and, therefore, to require no elaboration. Relatively little is known, other than in very general terms, about the effects of climate on tourism or the role it plays. And even less is known about the economic impact or significance of climate on commercial prospects for tourism.

Most climate impact studies from recent years have been conducted on the demand for domestic and international tourists (see Berrittella *et al.,* 2006; Perry, 2006; Amelung and Viner, 2006; Agnew and Palutikof, 2006; Gossling and Hall, 2006). The recent studies on specific aspects of the tourism industry have focused on skiing (Scott *et al.,* 2007a, 2006; Bicknell and Mcmanus, 2006; Diolaiuti *et al.,* 2006); nature-based tourism, that is, hiking, bird-watching (Scott *et al.,* 2007b); outdoor event planning (Jones *et al.,* 2006); and the golf industry (Scott and Jones, 2006). The climate impacts on golf are selected for this study as future golf course development has been identified as an important land-use planning issue in the Halton Region over the next 25 years (Regional Municipality of Halton, 2000).

The golf industry is one of the largest recreation sectors in North America and one that is strongly influenced by weather and climate (Scott and Jones, 2006). There are almost 6 million golfers in Canada (Royal Canadian Golf Association, 2006) playing almost 25 million rounds of golf in Ontario alone. Golf accounts for $15 billion of goods and services in Canada. Scott and Jones assessed the impact of weather on golf in the Greater Toronto Area (GTA) because it has one of the highest concentrations of golf courses in Canada. A private, regulation 18-hole course (par 72; maximum 7,043 yards) centrally located in the GTA was selected for the analysis. The course tended to operate at about 90 percent capacity during the peak season with green fees averaging about CAN$80 per 18-hole game, which is claimed by the authors to be in the low to mid-range of the green fees charged by other premium golf courses in the study area.

Numerous championship events including the Ontario Open and a variety of LPGA Tour events have been played at this course.

Scott and Jones (2006) found that daily rounds increased with temperature (18°C) and declined at a critical temperature (28°C). This makes sense as at some critical maximum temperature, the number of rounds played would be influenced by heat-related discomfort and eventually physiological heat-stress. The maximum and minimum temperatures that golfers find comfortable are likely to differ from region-to-region, so application of this threshold in regions of different climate should be cautioned. They also found that precipitation played a role in influencing daily golf participation declining 19.3% when 2.5 millimeters of rain occurred and 35.3% when between 2.5 and five millimeters occurred. Game day heavy precipitation greater than 10 millimeters was found to be an important factor as well, often leading to no rounds being played as well as day-before heavy precipitation greater than 20 millimeters.

The Scott and Jones (2006) model of the impact of temperature and precipitation on rounds of golf in the GTA can be described numerically as follows:

Premium Golf Days = Annual sum of days where daily T_{mean}*>18°C and* T_{mean}*<28°C, * 80.7% where* P_{daily} *>0 and <2.5mm, *64.7% where* P_{daily} *>2.5mm and <5mm, *0 where* P_{daily} *>10mm, and *0 where previous day's* P_{daily} *>20mm*

A look at past and future premium days for golf at Halton Region (Figure 18) reveals an upward trend from the observations due mainly to the decrease in frequency of days with precipitation. The model projects the trend to continue for similar reasons although the scenarios show a leveling off, on average, by mid-century and through the year 2100 for a total gain of 18 days on average per year.

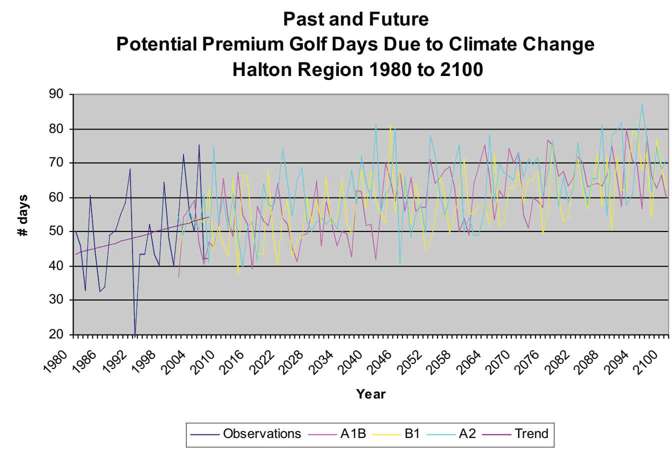

FIGURE 18
Observed and modelled premium golf days at Halton Region 1980 to 2100.

7. RAICC Step 5 - Ranking the Relative Risks of Climate Change

Provincial legislation (Ontario Emergency Management Act, 2003) requires that municipalities in Ontario undertake a Hazard Identification and Risk Assessment (HIRA) process to identify priority risks to infrastructure and public safety giving rise to emergencies in their communities. The purpose of the new legislation is "to improve and promote the sustainable management of hazards and to encourage communities to achieve acceptable levels of risk." According to Emergency Management Ontario's Guidelines for Provincial Emergency Management Programs in Ontario (Emergency Management Ontario, 2004), a realistic risk based program, properly resourced and including funding for staff training and exercises, will save lives and money. The legislation requires that all Ontario Municipalities and Ministries identify and assess various hazards and risks to public safety that may give rise to an emergency situation. Auld *et al.* (2006) have considered the application of the HIRA process to the risk of climate change.

The HIRA process recognizes that each municipality has different and distinct hazards and risks. The risk assessment determines how often and how severe the effects could be and is generally understood as being a function of probability and consequences (impacts and vulnerability). The managing provincial agency, Emergency Management Ontario (EMO), provided a HIRA template for municipalities that is based on the probability of a hazard occurring and the consequence of an event or risk. The risk characteristics were ranked and scored according to the following guidance (Emergency Management Ontario, 2004): *1. Frequency or Probability: 2. Consequences: and 3. (Optional) Response Capabilities.*

A relative risk ranking to climate change at Halton Region can be achieved by modifying the HIRA approach, and applying it to the Halton Region as the final step in the Rapid Assessment of the Impacts of Climate Change (RAICC) approach. In other words, a quick study of the eco-sectors most sensitive to climate change can be assessed, and given a relative ranking to one another based on the work conducted above in this chapter and in previous chapters. In the Rapid Assessment of the Impacts of Climate Change approach, the characteristics of the HIRA are revised to include:

1. Change in Risk/Opportunity: The change of the risk/opportunity as defined by the index selected for each eco-sector was valued relative to how the modelled future of change related to the observations. The change in the risk/opportunity was ranked for percentage changes in ascending order - zero to 10% (very low), 10.1 to 20% (low), 20.1 to 30% (medium), 30.1 to 40% (high) and greater than 40% (very high); and

2. Model Uncertainty: The uncertainty of the climate change model was evaluated by comparing the observation record to the back projection of the climate model for the years 1980 to 1999 at Halton Region. The uncertainties were ranked using a Confidence Index (CI) (Fenech *et al.,* 2007) as a measure of how faithful the model is in reproducing the mean values. The CI is a measure of the absolute difference between the observed and model means divided by the observed standard deviation. The model uncertainty was ranked for CI values in ascending order – zero to 0.5 (very low), 0.51 to 1 (low), 1.1 to 1.5 (medium), 1.51 to 2 (high), greater than 2 (very high).

These rankings are presented in this paper for the first time and may require further revision and testing.The results of the assessment are shown in Table 8. As a fast, preliminary assessment of the impacts of climate change on Halton Region, the table shows that further, more in-depth study is required on the built environment, agriculture and tourism as those eco-sectors most affected by climate change with the least amount of uncertainty in the findings. Many caveats must be included with these conclusions. First, the selection of climate station to represent the Halton Region was based on data availability (parameters and length) and not representativeness. Second, the climate data for the climate model selected (as well as the climate models evaluated for selection) is representative of the center of the cell selected, not of the exact location of the climate station representing Halton Region. Third, the selection of eco-sectors is not exhaustive; the study could have examined the impacts of climate change on air quality, water quantity, *et al.* Fourth, a series of indices could be selected and examined for each eco-sector, not a single one to be representative of the eco-sector as in this study. However, the Rapid Assessment of the Impacts of Climate Change (RAICC) approach, in spite of all the caveats, has provided a first step in the consideration of climate change impacts in the Halton Region.

TABLE 8
Relative Risk/Opportunity Assessment of Climate Change: Halton Region Eco-Sectors

Change (Δ) in Risk (-)/ Opportunity (+)	Measured as % change				
Very High Δ in Risk/Opportunity (>40)	Biodiversity (-)	Forests (-)	Energy (Cooling) (-)	Agriculture (+)	Built Environment (+)
High Δ in Risk/Opportunity (30 to 40)					Tourism (+)
Medium Δ in Risk/Opportunity (20 to 30)			Energy (Heating) (-)		Human Health (-)
Low Δ in Risk/Opportunity (10 to 20)				Water Quality (-)	Fisheries (-)
Very Low Δ in Risk/Opportunity (0 to 10)	Transportation (-)				
	Very High Model Uncertainty (>2.0)	High Model Uncertainty (1.51 to 2.0)	Medium Model Uncertainty (1.1 to 1.5)	Low Model Uncertainty (0.51 to 1.0)	Very Low Model Uncertainty (0 to 0.5)
	Model Uncertainty	measured by Confidence Index (CI)			

8. Conclusions

RAICC is a tool designed to be illustrative of the changes that may occur as a result of a changing climate rather than a prescriptive tool that defines the scope and totality of changes that may occur. RAICC can be described as a basic climate model – one that examines only first-order impacts, that is, those that are direct measures (for example, in biological production things such as yield, differences between area planted and area harvested). The second-order impacts arise, for example, from the effects of yield decreases through the network of social and economic relationships. In the use of the basic climate model, the analyst must make many choices such as defining terms, bounding the study area, choosing indices and categorizing impacts (SCOPE, 1985). These study elements can be generalized in the basic climate model as climate events, exposure units, and impacts or consequences.

The use of the basic impact model is criticized for its literal determinist implications (SCOPE, 1985), and for its use of climate as a major determinant of human events. While there are many examples of such usage, most analysts use it not for simplistic thinking but as a simplifying assumption. This model does not seek to ignore societal interaction, but to hold it constant in order to examine the climatic contribution to impacts in isolation from societal influence. When societal interaction and human response are added to the basic impact model the analyst has to grapple with other new problems including how to characterize society, social organization, and societal change and variation? how to study and describe human response, adjustment and adaptation? and how to examine the interaction between society and nature, social change, and climatic change? These other factors are important and valid concerns when conducting climate vulnerability studies. Yet, in the context of a basic climate model, RAICC considers the impacts of climate factors alone, held in isolation from other societal factors. Once again, this is for illustrative purposes to understand the impacts of climate solely.

For climate change impact assessment, a variety of analytical methods can be adopted ranging from qualitative descriptive studies, through more diagnostic and semi-quantitative assessments, to quantitative and prognostic analysis (Carter *et al.*, 1994). Any single impact assessment may contain elements of one or more of these types. In fact, each approach has it own advantages and weaknesses, and a good strategy may be to use a combination of approaches in different parts of the assessment or at different stages of the analysis (UNEP, 1998). Four general methods have been identified by Carter *et al.* (1994): experimentation, impact projections, empirical analogue studies and expert judgement.

The first involves testing hypotheses through cause and effect relationships through direct experimentation. In the context of climate impact assessment, however, experimentation has only a limited application (Carter *et al.*, 1994). While it is not possible physically to simulate large-scale systems such as the global climate, experiments can be conducted where the scale of impact is manageable, the exposure unit is measurable and the environment controllable. Good examples are the carbon dioxide chamber studies where the growth and response of plants are examined in a contained box where the atmosphere may be manipulated. The second are impact projections which use an array of mathematical models to extrapolate into the future. First-order effects of climate are usually assessed using bio-physical models (Carter *et al.*, 1994). The third method is the use of empirical analogues where past observations of the interactions of climate and society in a region can be of value in anticipating future impacts. The most common method employed involves the transfer of information from a different time or place to an area of interest to serve as an analogy. Four types of analogy can be identified: historical event analogies, historical trend analogies, regional analogies of present climate and regional analogies of future climate. A fourth method - expert judgement – is a useful method of obtaining a rapid assessment of the state of knowledge concerning the effects of climate on given exposure units. This method solicits the judgement and opinions of experts in the field through a literature review, a review of comparable studies, and the experience and judgement of experts is used in applying all available information to the current problem.

The RAICC approach is a twist on three of the methods - impact projections, historical event analogies and expert judgement – in that it also uses back-projection into the past, and assesses the first-order impacts relative to one another, while utilizing expert knowledge and judgement in the identification and assessment of appropriate tools and models to be selected in the analysis. RAICC uses global climate models for scenarios of future climate change because they are the most quantifiable. Where feasible, it is desirable to use models where the variables can be expressed in quantitative terms, so that a variety of tests can be carried out (for example, sensitivity tests), and so that results can be expressed in more precise terms (UNEP, 1998).

The objective of RAICC was to develop a rapid, transferable, step-by-step relative-risk assessment approach grounded in expert climate tools and the scientific literature for studying the impacts of climate change at the local level. In the context of other climate impact approaches reviewed, Table 9 shows that many of the approaches meet several of the criteria (except the rapid) yet none of the approaches meet the full list of criteria while the RAICC approach does.

TABLE 9
Criteria for Approaches Applied to 14 Climate Impact Studies

Climate Impact Study	Rapid	Transferable	Step-by-Step	Relative Risk Assessment	Expert Science Tools	Grounded in Science Literature
1. SCOPE, 1985	☒	☑	☒	☒	☑	☑
2. Carter *et al.*, 1994	☒	☑	☒	☒	☑	☑
3. UNEP, 1998	☒	☑	☒	☒	☑	☑
4. ACIA, 2004	☒	☒	☒	☒	☑	☑
5. AIACC, 2007	☒	☑	☑	☑	☑	☑
6. UKCIP, 2003	☒	☑	☑	☑	☑	☑
7. EC, 1998	☒	☑	☒	☒	☑	☑
8. US Global Change Program, 2000	☒	☑	☒	☒	☑	☑
9. China Meteorological Administration, 2006	☒	☒	☒	☒	☑	☑
10. US Great Plains, 2001	☒	☑	☒	☒	☑	☑
11. US Northeast Climate Impacts Synthesis Team, 2007	☒	☑	☒	☒	☑	☑
12. London, 2002	☒	☑	☒	☒	☑	☑
13. New Zealand Climate Change Office, 2004	☒	☑	☑	☑	☑	☑
14. Aspen, 2007	☒	☑	☒	☒	☑	☑

Using the criteria of accessibility, transferability, acceptability in the scientific discipline, ease-of-use and the ability to be used in the Canadian context, all tools selected for RAICC met all of the criteria (see Table 10). Those tools not selected did not meet the criteria as fully as those selected. The implications of selecting these tools are many. For the National Climate Data and Information (NCDI) Archive, the data conforms to World Meteorological Organization (WMO) standards, but many of the climate variables available will not be available in other less developed countries. Only temperature (T) and precipitation (P) are used in the calculating of Gachon Indices of Climate Extremes (GICE) which all countries have access to, but other climate variables that may change as a result of climate change will be missed. The Canadian Climate Change Scenarios Network (CCCSN) provides access to future climate scenarios from all of the 19 Global Climate Models (GCMs) used in the 4th Assessment Report (4AR) of the Intergovernmental Panel on Climate Change (IPCC), but no other GCMs are available. The Canadian Global Climate Model (CGCM) 3.1 provides daily data for temperature (T) and precipitation (P) as well as backcasts for verification of model output to observational data, but the resolution is poor (at 312 kilometers by 240 kilometers) for impact studies. SCOPUS bills itself as the 'world's largest abstract and citation database of peer-reviewed literature', but the literature is biased towards Europe, Middle East and Africa (EMEA) with 52% of the database records and North America (NA) with 36% of the database records. The Hazard Identification and Risk Assessment (HIRA) approach is used universally, but it has never been applied to climate change.

TABLE 10
Criteria and Implications of Selection of Expert Tools

Expert Tool	Accessibility (internet)	Used in Canadian Context	Acceptibility in Climate Science Discpline	Ease of Use	Transferability (Global/ Canada/ Review)	Rapidity of Use	Implications of Selection
National Climate and Data and Information Archive (NCDI)	☑ tool	☑	☑	☑	Canada	☑	• data conforms to WMO standards • many climate variables available that will not be available in other countries
Gachon Indices of Climate Extremes (GICE)	☑ papers	☑	☑	☑	Review	☑	• selected as only T and P used in GICE which all countries have access to other climate variables missed
Canadian Climate Change Scenarios Network (CCCSN)	☑ tool	☑	☑	☑	Global	☑	• provides access to scenarios from all 24 GCMs used in IPCC 4AR • no other models available
Canadian Global Climate Model (CGCM) 3.1	☑ tool	☑	☑	☑	Global	☑	• provides daily data for T and P, backcasts ▪ resolution poor for impact studies
SCOPUS	☑ tool	☑	☑	☑	Global	☑	• 'world's largest abstract and citation database of peer-reviewed literature' • literature biased towards EMEA (52%), NA (36%)
Hazard identification and Risk Assessment (HIRA)	☑ papers	☑	☑	☑	Global	☑	• internationally utilized • never applied to climate change

The Rapid Assessment of the Impacts of Climate Change (RAICC) approach has been applied successfully to the Regional Municipality of Halton portion of the Niagara Escarpment Biosphere Reserve by providing a history of past climate extremes, a future of climate extremes and a relative risk assessment of the impacts of climate change. This has identified priority areas for further study and possible examination of adaptation options. In order to fully understand its transferability, and to further illustrate its importance, this approach should be applied in other localities such as municipalities or Biosphere Reserves. As a result of presentations of early work on this paper as well as earlier work commissioned by the Canadian International Development Agency (CIDA) (see Fenech *et al.,* 2004b), a commission has been offered to apply the RAICC approach to Biosphere Reserves in Canada and China, as well as at Iquitos, Peru as part of a partnership with the Smithsonian Institution on climate change and biodiversity. Its application will be limited by resources, mainly time and money. Application in these other locations may require some modification to the selection of climate extreme indices, the selection of the global climate model (GCM) used in the study, as well as the selection of eco-sectors and adaptation thresholds examined. These changes may be dependent on local climate conditions, availability of climate data, stakeholder demands, and scientific literature available.

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