PAPER
6

ENVIRONMENTAL PREDICTION: USING FUTURE PROJECTIONS OF CLIMATE CHANGE TO UNDERSTAND LOCAL IMPACTS AND ADAPTATION

ADAM FENECH[1] and STU MCNAIR[2]

[1]Environment Canada
[2]CSM Consulting, Toronto, Canada

ABSTRACT: This paper considers the impact of climate change on indicators in ten economic and ecological sectors of Halton Region including forestry, fisheries, agriculture, built environment, human health, tourism, transportation, water quality, energy, and biodiversity. A literature review on the impacts of climate change was conducted for each of the 10 eco-sectors, and one climate-sensitive indicator (factors sensitive to temperature and precipitation were selected) per eco-sector was examined for illustrative purposes. These sensitivities are triggered at certain climate thresholds, above or below which result in significant changes that may require some form of human intervention, so-called "adaptation thresholds". These thresholds were examined using data from Halton Region's past observations and future modelling. A relative risk ranking of eco-sectors sensitive to climate change was conducted by modifying Ontario's Hazard Identification and Risk Assessment (HIRA) approach, and applying it to the Halton Region.

Keywords: climate change, indices, environmental prediction, impacts, adaptation, risk ranking

1. Introduction

Environmental prediction is, in its simplest form, the application of knowledge to predict environmental responses. In centuries past, this meant careful observation of repeating patterns in order to predict their recurrence. Over time, verbal predictions gave way to graphical associations and then mathematical calculations. Until the 20th century and the advent of powerful digital computers, the amount of calculation required to apply mathematical methods to solve dynamic equations was prohibitive. Today, environmental prediction forecast systems are coupled in one way or another to a numerical weather prediction model bringing together economic, hydrologic, ocean, sea ice, air quality, forest fire, insect infestation and even disease propagation models with meteorological or climatological models to produce forecasts of new parameters of immediate value to Canadian decision-makers and the public. Existing capabilities allow the forecasting of flooding from storm surges, forest fire danger ratings, movement of ice edges in offshore drilling areas, energy utilization of ice breakers following different tracks through the ice, and wind energy potential for any location in the country. Potential applications are virtually unlimited.

The science of environmental prediction provides valuable input to decision-making even when applied to past data. Detailed knowledge of environmental interactions, scenario modelling and sensitivity analyses can establish links between planned and unplanned, anthropogenic and natural events and the resulting environmental responses. The ability to predict environmental responses resulting from a given set of initial conditions is at the heart of any environmental prediction system, no matter whether it is run as a backcast, a diagnosis, or a forecast. Modellers, however, are never completely satisfied with their models. There will always be something that could be done a little more accurately or a little more efficiently. Still, the goal of environmental prediction is to migrate the models to an operational environment where the emphasis is on applying the models and delivering results to relevant decision makers in an appropriate timeframe.

This study takes output from one global climate model and applies it to climate sensitive indicators to provide an example of past changes in the economy and ecology of Halton Region, as well as how these sensitivities are to change into the future. Ten sectors of Halton Region – including forestry, fisheries, agriculture, built environment, human health, tourism, transportation, water quality, energy, and biodiversity - were selected representing the large economic and ecological sectors of Halton Region. They are also similar to those reviewed in the climate change adaptation study conducted by Ouranos (2004), the applied research consortium in Quebec organizing the major scientific efforts needed to develop ways to reduce the impacts of climate change and to adapt to the changes (Bourque, 2006). A literature review on the impacts of climate change was conducted for each of the ten 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 "adaptation thresholds". These thresholds were examined using data from Halton Region's past climate observations and output from future modelling. A model projecting future changes in climate over the next one hundred years was selected using the five criteria established by the Intergovernmental Panel on Climate Change (IPCC Data Distribution Centre, 2007). Projections of climate from the Canadian Global Climate Model (CGCM3) were selected for this study using the three major greenhouse gas emission scenarios (A1B, B1, A2). Some examples of the application of this approach to ten eco-sectors in the Halton Region are provided below for illustrative purposes.

2. The Impacts of Climate Change on Eco-sectors of Halton Region

Table 1 below shows the indicators used to illustrate adaptation thresholds for ten eco-sectors in the Halton Region. The results from applying past climate data and future projections of climate change are shown for only five indicators in this paper.

TABLE 1

Indicators of Adaptation Threshold for 10 Halton Region Eco-sectors

Eco-sector	Indicator	Formula	Main Source
Tourism	Premium Golf Days	Annual sum of days where daily Tmean>18°C and Tmean<28°C, * 80.7% where Pdaily >0 and <2.5mm, *64.7% where Pdaily >2.5mm and <5mm, *0 where Pdaily >10mm, and *0 where previous day's Pdaily >20mm	Scott and Jones, 2006
Water Quality	Waterborne Disease Outbreaks	Annual sum of days where Pdaily > 90th percentile Ptotal, Tmin>0°C; and Annual sum of days where Pdaily > 2*standard deviation of Ptotal, Tmin>0°C	Curriero *et al.*, 2001 Auld *et al.*, 2001
Forests	Southern Pine Beetle	Annual sum of days where daily Tmin <-16°C	Ungerrer *et al.*, 1999
Built Environment	Pavement Damage Due to Frost Depth	Annual sum of 0°C – daily Tmean	Raymond *et al.*, 2003
Biodiversity	West Nile Virus	Annual sum of days where daily Tmean >30°C	Dohm *et al.*, 2001
Human Health	Salmonella Poisoning	Annual sum total of % where for every °C of daily Tmean > -10°C, *1.2%	Fleury *et al.*, 2006
Fisheries		Average 2-decade Tmean minus previous average 2-decade Tmean divided by 1.5°C * six percent	Burgmer *et al.*, 2007
Energy	Macro-invertebrate Change	Annual sum of days where Tmean >18°C (cooling); Annual sum of days where Tmean <18°C (heating)	Diaz and Quayle, 1980
Transportation	Cooling/Heating Degree Days	Annual sum of days where Pdaily > 0 mm, *2.4%	Keay and Simmonds, 2007
Agriculture	Road Accidents Corn Heat Units	(Ymax + Ymin) ÷ 2 where: Ymax = (3.33 x (Tmax-10.0))-(0.084 x (Tmax-10.0)2) (If values are negative, set to 0); Tmax = Daily maximum air temperature (°C); Ymin = (1.8 x (Tmin-4.4)) (If values are negative, set to 0); and Tmin = Daily minimum temperature (°C)	Brown and Bootsma, 1997

2.1 Tourism

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 1) 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.

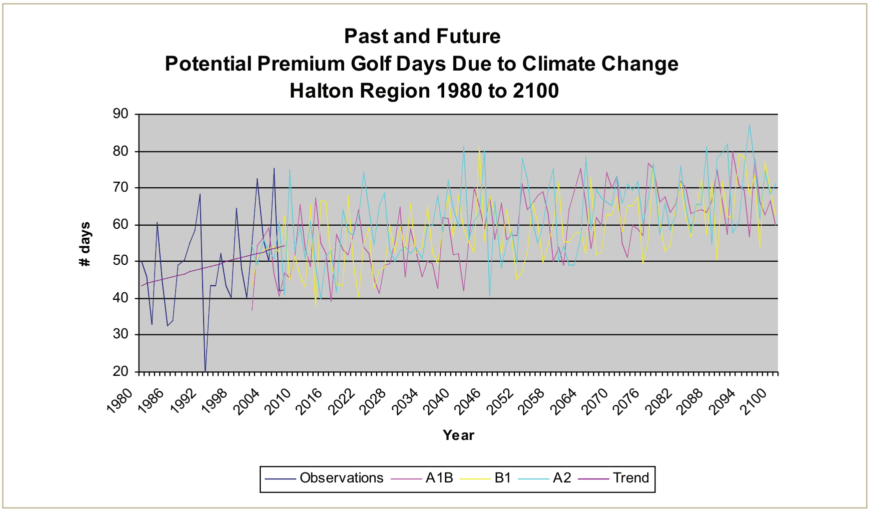


FIGURE 1
Observed and modelled premium golf days at Halton Region 1980 to 2100.

2.2 Forests

The southern pine beetle, *Dendroctonus frontalis,* reproduces by killing mature pine trees, and its populations frequently attain epidemic proportions devastating entire stands of trees (Turchin *et al.,* 1999, Ylioja *et al.,* 2005). It is by far the most important source of biotic disturbance in pine forests and is among the most economically and ecologically important sources of forest disturbance in North America (Ayres and Lombardero, 2000; Dale *et al.,* 2001). Based upon a composite historical record, the range of the southern pine beetle covers the southeastern United States, from southern New Jersey and Pennsylvania. The US state of Maryland experienced outbreaks for the first time in 2005, and Ohio reported outbreaks in 2001 (Wilent, 2005). As Alberta is threatened by the pine beetle outbreaks in British Columbia, Ontario may be threatened by the pine beetle ranges in the United States just south and east of the province.

Ungerer *et al.* (1999) predicted a northern expansion of southern pine beetle outbreaks should there be an increase of minimum winter air temperature. The authors selected thirty-three sites, aligned as three north–south transects through the eastern U.S. with daily climate records that exceeded 60 years. For a site to be included in the study, daily maximum and minimum temperature records had to be complete for the winter months (Nov.–Feb.) of at least 52 years (with no more than five consecutive years with missing temperature data). They concluded that their analyses clearly indicates that interannual variance in minimum temperature is a critical determinant of overwinter survival and the geographical distribution of *D. frontalis.*

Northerly *D. frontalis* populations are currently precluded occupying suitable pine habitat by low winter temperatures. However, *D. frontalis* has a very rapid and high dispersal (Turchin and Thoeny, 1993) so populations could respond within a few years to any change in winter mortality rates. All of the climate change scenarios evaluated by Ungerer *et al.* indicated the potential for relatively modest changes in climate to exert important effects on *D. frontalis.* The authors conclude this information is important to forest management decisions that are being made now (e.g. the selection of tree species and sites to be managed for timber) which depend upon assessing future risks from forest insects.

Most insects, including *D. frontalis*, are freeze-intolerant. The lower lethal temperature for freeze-intolerant animals is the temperature at which the body fluids crystallize when an animal is gradually cooled. Typically, exposure for even a few minutes to temperatures below the crystallization temperature causes irreparable tissue damage and death. Thus, mortality is expected in winters when temperatures drop below the lower lethal temperature at least once. Ungerer *et al.* (1999) showed that historical climate records can be used to estimate the proportion of winters when mortality occurs.

Winter mortality has been reported in natural populations of *D. frontalis* that experienced minimum air temperatures of temperatures of -12° to -18°C. Ungerrer *et al.* corroborated this with laboratory measurements using standard techniques. Using a programmable, low-temperature water bath, Ungerrer *et al.* cooled individual larvae, pupae, and adults of *D. frontalis* at 0.2°C per minute and recorded the temperature at which crystallization occurred (supercooling point or SCP). The supercooling point for each individual animal was evident as lethal air temperature for *D. frontalis*. Measuring eighty-seven adults, eighty-three larvae, and seventy-four pupae collected from the wild populations in the Kisatchie National Forest in Lousiana, Ungerer *et al.* concluded that adults were the most cold-tolerant stage (mean SCP±SD= -11.9±2.9°C) with larvae (-10.5±2.91°C) next and then pupae (-8.8±2.6°C). Allowing for intrapopulation variability, and adding 1°C to account for the insulating effects of the outer bark of trees, Ungerer *et al.* concluded that an air temperature of -16°C should result in mortality of > 90% of *D. frontalis* adults and virtually all of the larvae and pupae, and was used in their study as the lethal air temperature for *D. frontalis*. This value can be expressed numerically as:

Pine beetle (D. frontalis) killing days = Annual sum of days where daily T_{min} <-16°C

Examining the past and future days at Halton Region with temperatures able to kill the pine beetle and prevent it from expanding its population range shows a steady decline of over 10 days over the observation record. The model projects pine beetle killing days to decline another 20 days on average by the year 2100 (Figure 2).

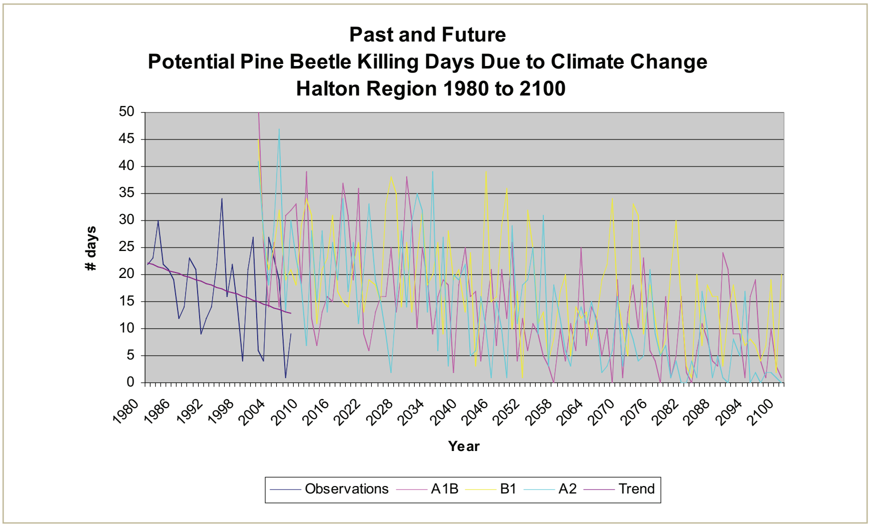


FIGURE 2
Observed and modelled pine beetle killing days at Halton Region 1980 to 2100.

2.3 Built Environment

Canada's geographical expanse coupled with limited transportation choices means Canadians rely heavily on private motor vehicles as their primary mode of transportation. With about 19 million registered vehicles, and approximately 21 million licensed drivers, Canadians are among the most mobile people in the world, and roads and highways are an important part of their daily lives. Canada's

National Highway System (NHS), which includes the Trans-Canada and other major roads, is approximately 900,000 kilometres in length, and is the backbone of Canada's transportation system. $17.6 billion was spent by all levels of government on roads (Transport Canada, 2007) during the fiscal year 2006/7. Despite this, the Canadian Automobile Association (2007) claims that Canada's roads and highways are inadequate and government spending is failing to keep up with the needs of Canadians; thereby affecting health and safety, the economy, trade, tourism and the environment. A 1988 study (Transport Canada, 1998) found that 38% of Canada's National Highways System and 22% of bridges are deficient and substandard. The savings associated with improved highway safety are estimated to be up to $15.3 billion (CAA, 2007).

Weather and climate factors interact with traffic, construction, structural and maintenance characteristics to influence road pavement deterioration and performance (Mills *et al.,* 2007). Climate has been identified as an important consideration in three processes: thermal cracking, frost heave and thaw weakening, and rutting. Few road deterioration models incorporate the number of freeze-thaw cycles despite its obvious importance in frost-related action (Haas *et al.,* 2004). Many models make use of a "freezing or frost index", which provides a measure of the air temperature throughout the freezing period. The freezing index, along with soil properties, can be used to predict the depth of frost penetration (CRRL, 2002), the extent of frost cracking (Joint CSHP/Quebec Bayesian Application Project, 2000) and the site effects in pavement deterioration models (Raymond *et al.,* 2003). The frost index[1] is calculated usually as an additive value (sum of 0°C minus the daily mean temperature) based on seasonal data. Early work (Brown, 1964) showed that there was a relationship between the index calculated in this way and the depth of frost penetration. The Frost Index is described numerically as follows:

Frost Index = Annual sum of 0°C – daily Tmean

As higher values for the Frost Index mean more pavement damage, the model projects a decrease in the depth of frost due to rising temperatures (Figure 3) by the year 2100 by, on average, over 50 percent.

---

[1] One limitation of the frost index is that it does not adequately capture the sequencing of weather events (Uzan, 2004). It is possible to obtain the same index value when a site experiences one long cold spell as when it experiences several short cold spells (Sherwood and Roe, 1986), despite the fact that these different weather scenarios have different implications for pavement performance.

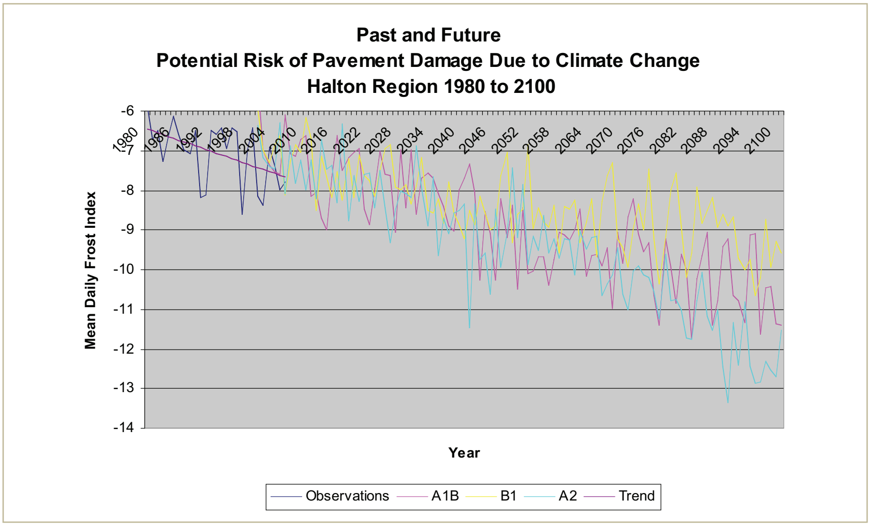


FIGURE 3
Observed and modelled risk of pavement damage due to climate as measured by daily frost index at Halton Region 1980 to 2100.

2.4 Biodiversity

The main factors causing current changes in biodiversity are land-use and climate change (Sala *et al.*, 2000; Donald *et al.*, 2001). Although the first effects of climate change can already be measured, more profound effects are expected in the future (Groom *et al.*, 2006). In the summer of 1999, the West Nile virus was recognized in the western hemisphere for the first time when it caused an epidemic of human encephalitis and meningitis in the metropolitan area of New York City, NY, USA, and resulted in thousands of dead birds across eastern North America. It has been proposed that temperature and other climate factors can be implicated in the spread and severity of the West Nile virus across North America (Chiotti *et al.*, 2002).

There was no West Nile virus recorded in 2000 for the dead birds that were tested in Ontario, Canada that year, a number totaling 2,288. By 2001, the percentage of infected dead birds tested reached high levels in Toronto, Peel and Windsor-Essex Health Regions (as defined by Health Canada). One year later in 2002, the West Nile virus appeared in infected dead birds tested across all of

Ontario except the Sudbury Health Region (Fenech and Chiotti, 2004). Studies have shown that ambient temperature increases the ability of mosquitoes to transmit the West Nile virus (Dohm and Turell, 2000; Dohm *et al.,* 2001; Nasci, 2001).

Dohm *et al.* evaluated the effect of incubation temperature (18, 20, 26, or 30°C) on the ability of *Culex pipiens L.* derived from specimens collected during the outbreak in New York in 1999 to transmit a strain of WN virus obtained from a crow that died during this outbreak. Although mosquitoes fed on the same viremic chickens, infection rates were directly related to subsequent incubation temperatures. In mosquitoes held at 30°C, the virus was recovered from nearly all mosquitoes tested, disseminated infections were detected as early as 4 days after the infectious blood meal, and 90% of all mosquitoes had a disseminated infection 12 or more days after the infectious blood meal. In contrast, for mosquitoes held at 18°C, disseminated infections were not detected until 25 days after the infectious blood meal, and even after 28 days, ~30% contained a disseminated infection. Results for mosquitoes held at 20 and 26°C were intermediate for both infection and dissemination rates. This led the authors to claim that the effect of environmental temperature should be considered when evaluating the vector competence of these mosquitoes and modelling risk of West Nile virus transmission in nature.

This has implications for bird species across North America. The American crow population declined by up to 45% since the arrival of the West Nile virus, and only two of the seven bird species with documented impact recovered to pre-West Nile Virus levels by 2005 (Ladeau *et al.,* 2007). The risk is described numerically as:

$$\textit{Potential Risk of West Nile Virus} = \textit{Annual sum of days where daily } T_{mean} > 30°C$$

All future model scenarios, following the observation trend, project a significant increase in the number of days (on average 36 days by the year 2100) of high risk of West Nile virus that threatens birds, humans and other mammals (Figure 4).

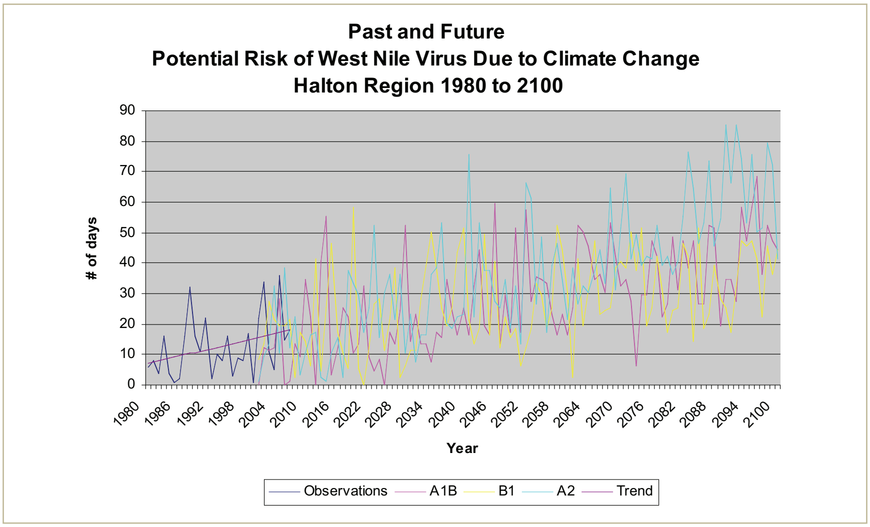


FIGURE 4
Observed and modelled risk of the West Nile virus transmission at Halton Region 1980 to 2100.

2.5 Agriculture

Crop Heat Units (CHU) are temperature-based units that are related to the rate of development of corn and soybeans. CHU are used to help farmers select the hybrids and varieties that are best suited to their climatic region. Crop heat units (CHUs) are based on a similar principle to growing degree days that were examined in a previous chapter. CHUs are calculated on a daily basis, using the maximum and minimum temperatures, yet the equation that is used is quite different and more patterned to crop development in Ontario. There are separate calculations for maximum and minimum temperatures. The maximum or daytime relationship uses 10°C as the base temperature and 30°C as the optimum because warm-season crops do not develop at all when daytime temperatures fall below 10°C, and develop fastest at about 30°C. The minimum or nighttime relationship uses 4.4°C as the base temperature and does not specify an optimum temperature because nighttime minimum temperatures very seldom exceed 25°C in Ontario. The nighttime relationship is considered a linear relationship (temperatures match growth rates), while the daytime relationship is considered a non-linear one (temperatures do not match growth rates) because crop development peaks at 30°C and begins to drop at higher temperatures.

Daily crop heat units are calculated by using the average of the two daily values, described numerically as follows:

Daily Corn Heat Unit = (Y_{max} + Y_{min}) ÷ 2 where: Y_{ma}x = (3.33 x (T_{max}-10.0))-(0.084 x (T_{max}-10.0)2) (If values are negative, set to 0); T_{max} = Daily maximum air temperature (°C); Y_{min} = (1.8 x (T_{min}-4.4)) (If values are negative, set to 0); and T_{min} = Daily minimum temperature (°C).

Hybrids or varieties are rated according to the CHU that are normally accumulated from planting the crop to physiological maturity (Brown and Bootsma, 1997). For example, corn hybrids are rated based on the CHU required to reach 32% kernel moisture and soybean varieties are rated on the CHU required to have 95% of the pods turn brown on a given variety. The historical accumulated CHU for growing corn in Ontario (for the nearest station to Halton Region) is 3210 CHU which acts as a baseline for our study.

The model projects values slightly higher than the observation trend at Halton Region showing the growth of warm season crops will gain another 1052 CHU, on average, by the year 2100 (Figure 5). Given that most of the warm-season

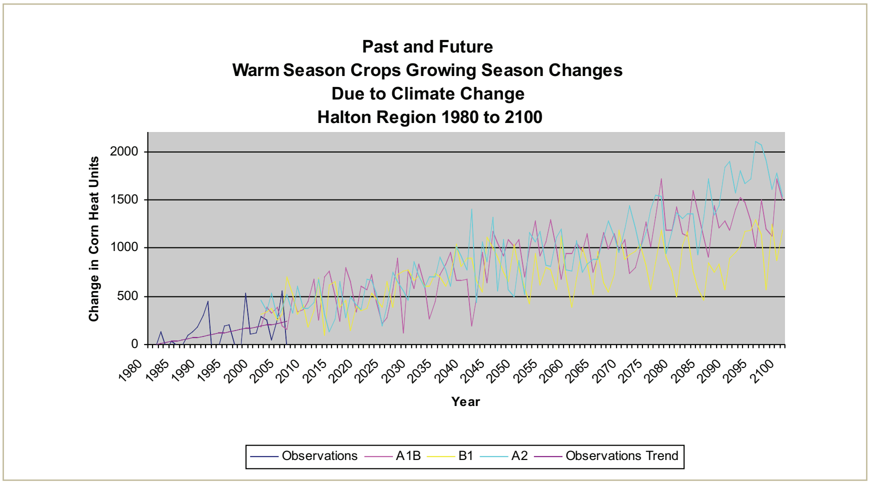


FIGURE 5
Observed and modelled growing season for warm season crops at Halton Region 1980 to 2100 above or below baseline of 3210 CHU.

crops have a wide range of maturities (Bootsma *et al.*, 2001), farmers in Halton Region will need to consider turning to a wide range of hybrids and varieties of crops over the next century.

3. Relative Risk/Opportunity Assessment 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: Hazards were assigned a rank from 1 to 4, with "1" reflecting a low occurrence rate and "4" reflecting frequent occurrence within the past 15 years. A ranking of "4" was used to indicate that an event was likely to occur within five years or had occurred within the past five years. The lowest score of "1" indicated that an occurrence of that specific risk had never been documented in the past 10 to 15 years or that the known relative frequency was low.

2. Consequences: The consequences or impacts from the hazards on the municipality were ranked from 1 (negligible) to 4 (severe). The degree of consequence was determined through expert opinion and consultation with experts. Negligible consequence is defined as damage with relatively lower impacts. A "high" consequence score reflects a likelihood of severe damage and consequences, which may include fatalities and the loss of essential services.

3. (Optional) Response Capabilities: Response capabilities could also be used to guide the assessment of consequences and ranked from 1 (excellent) to 4 (poor). Determining the municipality's response capability involved evaluating human, capital and technological resource capacity, including equipment, personnel, communications, technical support, training, experience and contingency plans. The process also included evaluating the ability of outside agencies to provide support. Higher weighting could be assigned to those emergencies that jurisdictions would have difficulty responding to because of limited response capability. This assessment criteria can be likened to assessing the adaptive capacity to climate change.

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. 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 above (five examples of the ten eco-sectors are shown in this paper). The characteristics of the HIRA are revised in this study 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 the Confidence Index (CI) 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). Note that these rankings are presented in this study for the first time and may require further revision and testing.

The results of the relative ranking risk assessment are shown in Table 2. 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, this approach, in spite of all the caveats, has provided a first step in the consideration of climate change impacts in the Halton Region.

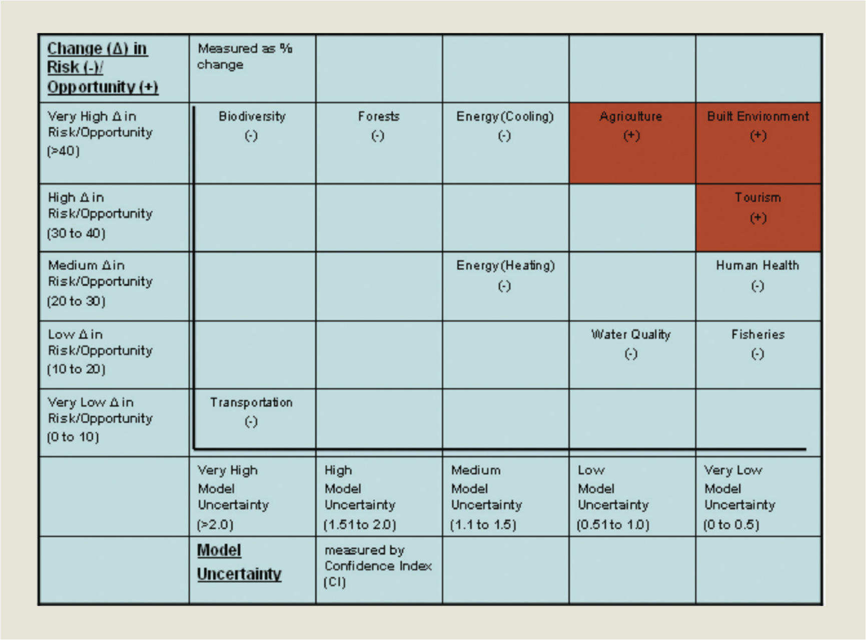
4. Conclusions

Specific economic and ecological sectors of Halton Region were examined including forests, fisheries, energy, transportation, agriculture, tourism, human health, water quality, biodiversity and the built environment as to their sensitivities to temperature and precipitation. An extensive literature review was conducted identifying climate change adaptation thresholds (sensitivities triggered at certain climate thresholds above which result in significant changes that may require some form of human interventionist adaptation) for each sector, and data from Halton Region observations and models were inputed to reveal the past and future changes in these thresholds. Results showed significant changes (as a percentage of total) in the frequency of the risk for the built environment, agriculture, forests, tourism, energy (cooling) and biodiversity.

The risk frequencies were assessed together with the model uncertainty in an amended version of the Government of Ontario’s Hazard Identification and Risk Assessment (HIRA) process 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 at Halton Region most affected by climate change with the least amount of model uncertainty (Table 2). The results provide the priority aspects of Halton Region’s economy and ecology that need to be focused on for more in-depth study and subsequent action.

TABLE 2

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)			

The caveats to these findings are many, and have been detailed throughout the study including the selection of climate station, the use of climate models, the selection of a climate model, the selection of eco-sectors, and the selection of adaptation thresholds. Each provides its own reasons to be wary of the conclusions of this study. However, the best science available at this time in the given resources has been applied to the approach for illustrative purposes only, and resulted with conclusions that represent just a first step in the consideration of climate change impacts in the Halton Region.

Overall, this study has been an attempt at navigating through the great deal of climate change information available to community decision-makers. It places 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. Most importantly, it provides one means of rapidly assessing climate change impacts at the local level.

References

Agnew, M.D. and J.P. Palutikof. 2006. Impacts of short-term climate variability in the UK on demand for domestic and international tourism. *Climate Research* 31 (1), pp. 109-120.

Amelung, B. and D. Viner. 2006. Mediterranean tourism: Exploring the future with the tourism climatic index. *Journal of Sustainable Tourism* 14 (4), pp. 349-366.

Auld, H., D. Maciver, J. Klaassen, N. Comer and B. Tugwood. 2006. Planning for atmospheric hazards and disaster management under changing climate conditions. In Fenech, A., D. MacIver, H. Auld and T. Brydges (eds). *Building the Adaptive Capacity to Climate Change in the Americas*. Environment Canada.

Ayres, M. P. and M. J. Lombardero. 2000. Assessing the consequences of climate change for forest herbivores and pathogens. *Science of the Total Environment* 262:263–286.

Berrittella, M., A. Bigano, R. Roson, and R.S.J. Tol. 2006. A general equilibrium analysis of climate change impacts on tourism. *Tourism Management* 27 (5), pp. 913-924.

Bicknell, S. and P. Mcmanus. 2006. The canary in the coalmine: Australian ski resorts and their response to climate change. *Geographical Research* 44 (4), pp. 386-400.

Bootsma, A.; Gameda, S.; McKenney, D.W. 2001. Adaptation of agricultural production to climate change in Atlantic Canada. *Final Report for Climate Change Action Fund Project A214*. Agriculture and Agri-Food Canada, Eastern Cereal and Oilseed Research Centre, Ottawa. **res2.agr.ca/ecorc/clim/index_e.htm**

Bourque, A. 2006. Adapting to global climate change using a regional approach: the Ouranos Consortium. In Fenech, A., H. Auld and D.C. MacIver. 2006. *Building the Adaptive Capacity to Climate Change in the Americas*. InterAmerican Institute for Global Change Research (IAI).

Brown, D.M. and Bootsma, A. 1997. Crop Heat Units for Corn and Other Warm Season Crops in Ontario. *Factsheet.* Queen's Printer for Ontario. Toronto, Ontario, Canada.

Brown, W.G. 1964. Difficulties associated with predicting depth of freeze or thaw. Canadian Geotechnical Journal Vol. 1. p. 215-226.

CAA (Canadian Automobile Association). 2007. Infrastructure. **www.caa.ca/publicAffairs/public-affairs-infrastructure-e.cfm**

Chiotti, Q., A. Fenech and M. Liebowitz. 2002. The threat of West Nile virus in Ontario: out of the blue or predictable? *Presentation at the 2002 Canadian Association of Geographers Annual Meeting, Special Session on Integrated Mapping Assessment Project (IMAP).* University of Toronto. May 30, 2002.

CRRL (Cold Regions Research and Engineering Lab). 2002 Army MSSR. **www.msrr.army.mil/index.cfm?top_level=ORG_A_1000136&taxonomy=ORG**

Dale, V. H. *et al.* 2001. Climate change and forest disturbances. *BioScience* 51:723–734.

Diolaiuti, G., C. Smiraglia, M. Pelfini, M. Belò, M. Pavan and G. Vassena. 2006. The recent evolution of an Alpine glacier used for summer skiing (Vedretta Piana, Stelvio Pass, Italy). *Cold Regions Science and Technology* 44 (3), pp. 206-216.

Dohm, D.J. and Turell, M.J. 2000. Effect of incubation at overwintering temperatures on the replication of West Nile virus in New York *Culex pipiens* (Diptera: Culicidae). *Journal of Medical Entomology:* Vol. 38, No.3 pp.462-464.

Dohm, D.J., O'Guinn, M.L. and Turrell, M.J. 2001. Effect of environmental temperature on the ability of *Culex pipiens* (diptera: Culicidae) to transmit West Nile virus. *Journal of Medical Entomology.* Vol. 39, No. 1, pp. 221-225.

Donald, P.F., R.E. Green and M.F. Heath. 2001. Agricultural intensification and the collapse of Europe's farmland bird populations. *Proceedings of the Royal Society of London Series B* Vol. 26. p.25–29.

Emergency Management Ontario. 2004. *Guidelines for Provincial Emergency Management Programs in Ontario.* Government of Ontario, Queens Park, Toronto, Ontario, 2004.

Fenech, A. and Q. Chiotti. 2004. The effect of climate on the West Nile virus in Ontario, Canada. In Fenech, A., R. Hansell, D. MacIver and H. Auld (eds). *Integrated Mapping Assessment (IMAP).* Environment Canada. Toronto, Ontario, Canada.

Gössling, S. and C.M. Hall. 2006. Uncertainties in Predicting Tourist Flows Under Scenarios of Climate Change. *Climatic Change* 79: 3-4, December 2006.

Groom, M.J., G.K. Meffe and C.R. Carroll. 2006. *Principles of Conservation Biology. 3rd edition.* Sinauer, Sunderland, Massachusetts.

Haas, R., L.C. Falls, D. MacLeod and S. Tighe. 2004. Climate impacts and adaptations on roads in Northern Canada. *Cold Climates Conference.* Regina, Saskatchewan. 18p.

Hale, M. and M. Altalo. 2002. *Current and potential uses of weather, climate and ocean information in business decision-making in the recreation and tourism industry.* Science Applications International Corp, McLean, Virginia.

IPCC Data Distribution Centre. 2007. *Criteria for Selecting Climate Scenarios.* **www.ipcc-data.org/ddc_scen_selection.html**

Joint CSHRP/Quebec Bayesian Application Project. 2000. *The Development of Models to Predict Pavement Performance in Frost Conditions: 7. Cracking Model.* **www.cshrp.org/products/bayesian/PQ/pqh4.htm**

Jones, B., D. Scott, D. and H.A. Khaled. 2006. Implications of climate change for outdoor event planning: A case study of three special events in Canada's National Capital Region. *Event Management* 10 (1), pp. 63-76.

LaDeau, S., A.M. Kilpatrick and P.P. Marra. 2007. West Nile virus emergence and large-scale declines of North American bird populations. *Nature* Vol. 447:10. p.1038.

Mills, B.N., S.L. Tighe, J. Audrey, J.T. Smith, S. Parm and K. Huen. 2007. *The Road Well Travelled: Implications of Climate Change for Pavement Infrastructure in Southern Canada.* Environment Canada. Toronto, Ontario, Canada.

Nasci, R., Savage, H., White, D., Miller, J. Cropp, B., Godsey, M, Kerst, A. Bennett, P., Gottfried, K., and Lanciotti, R. 2001. West Nile virus in overwintering Culex mosquitoes, New York City, 2000. *Emerg Infect Dis* 7(4).

Ouranos. 2004. Adapting to Climate Change. **www.ouranos.ca/intro/climang5.pdf**

Perry, A.H. 2006. Will predicted climate change compromise the sustainability of Mediterranean tourism? *Journal of Sustainable Tourism* 14 (4), pp. 367-375.

Raymond, C., S. Tighe, R. Haas and L. Rothenburg. 2003. Development of Canadian asphalt pavement deterioration models to benchmark performance. *Canadian Journal of Civil Engineering* Vol. 30. p.637-643.

Regional Municipality of Halton. 2000. *Halton golf course study – An analysis of future participation for gold courses in the Greater Toronto Area and Hamilton-Wentworth region.* Region of Halton, ON: Halton Area Planning Partnership Project.

Royal Canadian Golf Association. 2006. *RCGA Golf Participation in Canada Survey.* Toronto, Ontario.

Sala, O.E. 2000. Biodiversity—global biodiversity scenarios for the year 2100. *Science* Vol. 287. p.1770–1774.

Scott, D. and B. Jones. 2006. The impact of climate change on Golf participation in the Greater Toronto Area: A Case Study. *Journal of Leisure Research* Vol 38, No. 3. p. 363-380.

Scott, D., G. McBoyle and A. Minogue. 2007a. Climate change and Quebec's ski industry. *Global Environmental Change* 17 (2), pp. 181-190.

Scott, D., B. Jones and J. Konopek. 2007b. Implications of climate and environmental change for nature-based tourism in the Canadian Rocky Mountains: A case study of Waterton Lakes National Park. *Tourism Management* 28 (2), pp. 570-579.

Scott, D., G. McBoyle, A. Minogue, and B. Mills. 2006. Climate change and the sustainability of ski-based tourism in eastern North America: A reassessment. *Journal of Sustainable Tourism* 14 (4), pp. 376-398.

Transport Canada. 2007. Government Spending on Transportation. **www.tc.gc.ca/pol/en/report/anre2007/2_gov_spending.html**

Transport Canada. 1998. A National Highway System BP-465E. *Science and Technology Division*. September 1998.

Turchin, P. and P. Thoeny, P. 1993. Quantifying dispersal of southern pine beetles with mark-recapture experiments and a diffusion model. *Ecolological Applications* 3, pp. 187–198

Turchin, P., A. D. Taylor and J. D. Reeve. 1999. Dynamical role of predators in population cycles of a forest insect: an experimental test. *Science* 285:1068–1071.

Ungerer, M. J., M. P. Ayres, and M. J. Lombardero. 1999. Climate and the northern distribution limits of *Dendroctonus frontalis* Zimmermann (Coleoptera: Scolytidae). *Journal of Biogeography* 26:1133–1145.

Wilent, S. 2005. Mountain pine beetles threaten Canadian, U.S. forests. *The Forestry Source*. May. **www.safnet.org/archive/0505_beetle.cfmi**

Ylioja, T., D. H. Slone and M. P. Ayres. 2005. Mismatch between herbivore behavior and demographics explains scale-dependence of host susceptibility in two pine species. *Forest Science* 51:522–531.