ADAPTING TO CLIMATE VARIABILITY AND CHANGE

IN ONTARIO

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Canada

Volume IV of the Canada Country Study: Climate Impacts and Adaptation

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ADAPTING TO
CLIMATE VARIABILITY AND CHANGE
IN ONTARIO

VOLUME IV

of

THE CANADA COUNTRY STUDY: CLIMATE IMPACTS AND ADAPTATION

Jamie Smith and Beth Lavender
Smith and Lavender Environmental Consultants

Heather Auld, David Broadhurst and Tim Bullock
Environment Canada, Ontario Region

March, 1998

Environment Canada Environnement Canada

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Authors: Jamie Smith and Beth Lavender, Smith and Lavender Environmental Consultants; Heather Auld, David Broadhurst and Tim Bullock, Environment Canada, Ontario Region.

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PREFACE

The Canada Country Study

Intent
The *Canada Country Study (CCS): Climate Impacts and Adaptation* is a national evaluation of the impacts of climate change and variability on Canada as a whole, including consideration of existing and potential adaptive responses. In presenting this national perspective, it draws upon studies of a number of regional, sectoral and cross-cutting issues, of which this volume is one.

The study was initiated by Environment Canada (EC) and is being lead by the Environmental Adaptation Research Group, a component of EC's Atmospheric Environment Service located in Downsview, Ontario. Among the participants are representatives of various levels of government, the university community, the private sector and non-governmental organizations.

In providing Canadians with a balanced, realistic picture of what climate change and variability means for Canada as a whole, the CCS effort builds upon a number of sectoral and regional impact studies that have been completed during the past decade.

The CCS will provide information to Canadian policy makers in the public and private sectors, socio-economic decision makers, the scientific community both domestically and internationally, non-governmental organizations, and the Canadian general public.

Structure
Work on the CCS is divided into two phases. Phase I began in the summer of 1996 and will conclude in the spring of 1998; it is focussed on an extensive review and assessment of all existing literature, the identification of knowledge gaps, and the development of recommendations for future research. The latter would be addressed in Phase II which has recently begun and will extend over approximately a five-year period.

In Phase 1, a number of summary reports will be published–a national policy makers summary, a national plain language summary, and six regional plain language summaries. In addition, the basis of these summaries–26 component studies and papers–are being published in 8 volumes as follows:
- Vol. I: British Columbia and Yukon
- Vol. II: Arctic
- Vol. III: Prairies
- Vol. IV: Ontario
- Vol. V: Québec
- Vol. VI: Atlantic
- Vol. VII: Sectoral (comprising 12 national papers on agriculture, built environment, energy, fisheries, forestry, human health, insurance, recreation and tourism, transportation, unmanaged ecosystems, water resources and wetlands)
- Vol. VIII: Cross-Cutting (comprising 8 national papers on changing landscapes, costing, domestic trade and commerce, extra-territorial influences, extreme events, integrated air issues, sustainability, and the two economies).

The Climate Background

Climate Change and Variability
Climate may be thought of as a description of the regularities and extremes in weather for a particular location. It is also, however, naturally variable; from our own experience, we know that one summer is often warmer than another, or one winter is colder or snowier than another. Such variability is a normal feature of a stable climate, and is related to changes in ocean currents or sea-surface temperatures, volcanic eruptions, alterations in the sun's output of energy, or other complex features of the climate system some of which are not yet fully understood.

Natural large-scale climate shifts (or climate changes, such as those that resulted in past ice ages or warm interglacial periods) are driven by long-term alterations in the position of the Earth with respect to the sun. Such alterations can be reflected in changes in the composition of the Earth's atmosphere, an important characteristic of which is the occurrence of certain greenhouse gases (such as carbon dioxide and methane). These gases keep the Earth's surface and atmosphere from cooling too rapidly and help to maintain surface temperatures within the range needed to support life.

Greenhouse gas concentrations have been observed to be lowest during periods of cold climate (ice ages) and highest during warm periods. This connection is of concern because human activities since the beginning of the industrial revolution over 200 years ago (mainly involving the burning of fossil fuels) have greatly increased the concentration of such gases in the atmosphere. Scientists expect to see a doubling of the atmospheric composition of carbon dioxide, for example, within the next century. The increase so far is already considered to have had a discernible effect on the Earth's climate, an effect which is expected to continue.

Models and Scenarios

In order to understand how the world's climate may respond, elaborate supercomputer models of the climate system are used. Known as general circulation models or GCMs, these models are used to simulate the type of climate that might exist if global concentrations of carbon dioxide were twice their pre-industrial levels. Although the models disagree about many of the details of a doubled carbon-dioxide climate, the results of the simulations all agree that the Earth would be warmer, on average (with more warming occurring towards the poles), and would experience overall increases in both evaporation and precipitation. These simulations of climate are referred to as "GCM-driven scenarios"–distinct from actual forecasts for the future–since they depict a possible future based on certain assumptions about atmospheric composition. The most recent report of the Intergovernmental Panel on Climate Change (IPCC - qui vive), issued in 1995, projects an increase in global surface temperature of 1 to 3.5°C over the next 100 years. This may be compared with the observed increase of 0.3 to 0.6°C over the past 100 years.

For its first Phase, the CCS does not follow a single climate scenario. It reflects the range of scenarios that have been used as a basis for the various papers and reports appearing in the scientific literature. In general, the main model scenarios used come from one of five GCMs which have been developed in Canada, the United States, or the United Kingdom.*

While there is an increasing level of comfort with the validity of GCM results at the global scale, such comfort decreases when we look at the regional scale. For Canada there are broad areas of agreement in model results including warming over much of the western and northern areas, but there is also some disagreement between models as to the location and magnitude of areas of surface temperature or precipitation change, particularly in eastern Canada. This disagreement is reflected in the words of uncertainty that appear at times in this volume of the *Canada Country Study.*

The International Context

International concern about the future of our climate has been building steadily over the past 20 years. One of the first important international conferences to look at the issue was held in Canada in 1988 - The Changing Atmosphere: Implications for Global Security. Also that year, the IPCC was established by the World Meteorological Organization and the United Nations Environment

* *CCC92 - Canadian Centre for Climate Modelling and Analysis 2nd Generation model*
GFDL91 - Geophysical Fluid Dynamics Laboratory model (US)
GISS85 - Goddard Institute for Space Studies model (US)
NCAR93 - National Center for Atmospheric Research model (US)
UKMO95 - UK Meteorological Office model

Programme with a mandate to assess the science of climate change, its environmental and socio-economic impacts, and possible response strategies. The IPCC subsequently published formal assessments in 1990 and 1995, with a third to follow in 2000 or 2001.

In 1992, the United Nations Conference on Environment and Development was held in Rio de Janeiro and resulted in consensus on a Framework Convention on Climate Change (FCCC). This Convention's objective is "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". It has now come into force and involves commitments to actions including emissions reductions, assistance to developing nations, reporting on emissions inventories, scientific and socio-economic research to reduce uncertainties, as well as education and training. Canada's domestic response to the FCCC has been its National Action Plan on Climate Change.

To date, as the objective of the FCCC would suggest, much of the international emphasis on response strategies for dealing with the impacts of climate change has focussed on reducing emissions of greenhouse gases. Respecting that climate change will be with us for a long time, a very important complement to such reductions is the need to understand the impacts of and to adapt to changing climate. The *Canada Country Study* is one of Canada's responses to recognizing the importance of impacts and adaptation.

Climate Impacts and Adaptation

The major concern arising from the climate change issue is the impact it may have on our environment, our economy, and therefore, on the way we live both now and in the future.

In Canada, we are accustomed to dealing with variations in climate both geographically and seasonally across the country. These variations have many impacts that can reverberate through natural and man-made systems, including water resources, vegetation and wildlife, agricultural practice, forestry and fisheries, energy supply and demand, buildings and roads, recreation and tourism, the insurance industry, and human health.

At present, there are many good examples of our ability to adapt to the range of climate conditions which we both collectively in our economy and as individuals in our everyday life are used to facing. If we depend upon wildlife species for sustenance, we follow them when migratory routes change; we plant different types of crops in different locations at different times of the year; we construct roads and buildings using designs that are compatible with ground that may or may not be characterized by permafrost or with differing snow and wind loads; we build ships and other marine platforms capable of withstanding expected wave heights and sea-ice conditions; we locate recreational facilities and events where they can benefit from appropriate climate conditions, such as sufficient snow for skiing or enough wind for sailing.

When thinking about adaptation as a way to respond to current climate and we then consider an on-going climate change and its impacts, we look for answers to the following questions so that our future planning can be done most effectively:

- What are the impacts of a changing climate and how will they affect me and my family through our lives?
- Are decisions being made today which will increase our vulnerability in the future because they are not taking such impacts into account?
- Will the approaches we use to adapt to the current climate still be workable in the future, or will new approaches be necessary to adapt to changes beyond our historical experience?
- Will the rate of changing climate allow enough time to adapt?
- Should society become more adaptable or flexible to changes in climate than it is now, and if so, how?

The *Canada Country Study* is aimed at helping to answer some of these questions.

PRÉFACE

L'Étude pancanadienne

Objet
L'Étude pancanadienne (EP) sur l'adaptation à la variabilité et au changement climatiques est une évaluation nationale des impacts du changement et de la variabilité climatiques sur l'ensemble du Canada, qui examine notamment les mesures actuelles et éventuelles d'adaptation. L'élaboration de cette perspective nationale fait appel à des études sur un certain nombre de questions régionales, sectorielles et intersectorielles, dont fait partie ce volume.

Cette étude a été entreprise par Environnement Canada (EC) et est dirigée par le Groupe de recherche en adaptation environnementale, composante du Service de l'environnement atmosphérique d'Environnement Canada, dont les bureaux sont à Downsview (Ont.). Parmi les participants à cette étude figurent des représentants de différents paliers de gouvernement, du milieu universitaire, du secteur privé et d'organisations non gouvernementales.

Afin de fournir aux Canadiens une image juste et réaliste de ce qu'impliquent le changement et la variabilité climatiques pour l'ensemble du Canada, l'EP a fait fond sur un certain nombre d'études d'impact régionales et sectorielles qui ont été réalisées dans la dernière décennie.

L'Étude pancanadienne fournira de l'information aux décideurs canadiens des secteurs public et privé, aux décideurs du domaine socio-économique, à la communauté scientifique nationale comme étrangère, aux organisations non gouvernementales, ainsi qu'à l'ensemble des Canadiens.

Structure
Les travaux de l'EP se divisent en deux étapes. L'étape I a été entreprise à l'été 1996 et prendra fin au printemps 1998; il s'agissait essentiellement de faire un examen et une évaluation approfondis de la littérature existante, de repérer les lacunes dans les connaissances, et d'élaborer des recommandations pour les recherches à venir. Ce dernier aspect sera l'objet de l'étape II, qui a commencé au début de 1998 et s'étendra sur environ cinq ans.

L'étape I débouchera sur la publication d'un certain nombre de rapports de synthèse, soit un résumé national à l'intention des décideurs, ainsi qu'un résumé national et six résumés régionaux de vulgarisation. De plus, les rapports généraux sur lesquels sont fondés ces résumés, soit un regroupement de 25 études et documents, seront publiés en huit volumes, comme suit :

- Vol. I : Colombie-Britannique et Yukon
- Vol. II : Arctique
- Vol. III : Prairies
- Vol. IV : Ontario
- Vol. V : Québec
- Vol. VI : Atlantique
- Vol. VII : Questions sectorielles
  (12 documents nationaux sur l'agriculture, le milieu bâti, l'énergie, les pêches, la foresterie, la santé humaine, les assurances, les loisirs et le tourisme, les transports, les écosystèmes naturels, les ressources en eau et les terres humides).
- Vol. VIII : Questions intersectorielles
  (8 documents nationaux sur la transformation des paysages, les frais, le commerce intérieur, les influences extra-territoriales, les phénomènes extrêmes, les questions atmosphériques intégrées, la durabilité et les deux économies).

Historique du climat

Changement et variabilité climatiques
On peut considérer le climat comme une description des constantes et des extrêmes des conditions météorologiques d'un endroit donné. Par contre, le climat est naturellement variable. Ainsi, nous en avons l'expérience, il arrive souvent qu'un

été soit plus chaud qu'un autre, ou un hiver plus froid ou plus neigeux qu'un autre. Cette variabilité est une caractéristique normale d'un climat stable, et tient aux fluctuations des courants océaniques ou des températures des eaux de surface de la mer, aux éruptions volcaniques, aux modifications de l'émission d'énergie par le Soleil, ou à d'autres caractéristiques complexes du système climatique dont certaines ne sont pas encore parfaitement comprises.

Les variations naturelles à grande échelle du climat (ou les changements climatiques, comme ceux qui se sont traduits par les glaciations et les périodes interglaciaires chaudes du passé) sont le résultat de modifications à long terme de la position de la Terre par rapport au Soleil. Ces modifications peuvent induire des changements dans la composition de l'atmosphère terrestre, dont l'une des caractéristiques importantes est la présence de certains gaz à effet de serre (comme le dioxyde de carbone et le méthane). Ces gaz protègent la surface et l'atmosphère de la Terre contre un refroidissement trop rapide et aident à maintenir les températures de surface dans la plage nécessaire au maintien de la vie.

On a observé que les concentrations de gaz à effet de serre étaient plus basses durant les périodes de climat froid (périodes glaciaires) et plus élevées durant les périodes chaudes. Cette relation est préoccupante car, depuis le début de la révolution industrielle, il y a plus de 200 ans, les activités humaines (surtout la combustion de combustibles fossiles) ont provoqué une forte augmentation de la concentration de ces gaz dans l'atmosphère. Selon les scientifiques, on pourrait assister, dans le prochain siècle, à un doublement de la concentration de dioxyde de carbone dans l'atmosphère. On considère que l'augmentation survenue à ce jour a déjà eu un effet perceptible sur le climat de la Terre, effet qui devrait se poursuivre.

Modèles et scénarios

Pour comprendre comment pourrait réagir le climat mondial, on utilise des modèles complexes du système climatique tournant sur superordinateur. Connus sous l'appellation de « Modèles de circulation générale » ou MCG, ces modèles servent à simuler le type de climat qui pourrait exister si les concentrations planétaires de dioxyde de carbone doublaient par rapport aux niveaux de l'ère préindustrielle. Bien que les modèles divergent sur nombre des détails d'un climat à double CO_2, l'ensemble des simulations confirment que le climat de la Terre serait généralement plus chaud (avec un réchauffement plus marqué près de pôles), et qu'il y aurait une augmentation globale de l'évaporation et des précipitations. Ces simulations du climat, appelées « scénarios issus des MCG », ne sont pas des prévisions comme telles, mais décrivent un futur éventuel fondé sur certaines hypothèses quant à la composition de l'atmosphère. Le plus récent rapport du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC - cf. infra), publié en 1995, prévoit un réchauffement de la surface du globe variant entre 1 °C et 3,5 °C au cours du prochain siècle; il convient de comparer ces valeurs avec le réchauffement de 0,3 °C à 0,6 °C observé au cours du dernier siècle.

Pour sa première étape, *l'Étude pancanadienne* sur le climat ne suit pas un scénario climatique unique. Elle prend plutôt en compte toute la gamme de scénarios sur lesquels se sont fondés les spécialistes pour préparer les différents documents et rapports parus dans la littérature scientifique. D'une façon générale, les principaux scénarios utilisés proviennent de l'un des cinq MCG mis au point au Canada, aux États-Unis ou en Angleterre.*

Bien que l'on ait de plus en plus confiance dans la validité des résultats fournis pas les MCG à l'échelle planétaire, cette confiance

* *CCC92 - Centre canadien de modélisation et d'analyse climatiques, modèle de 2e génération.*
GFDL 91 - Modèle du Geophysical Fluid Dynamics Laboratory (États-Unis)
GISS85 - Modèle du Goddard Institute for Space Studies (États-Unis)
NCAR93 - Modèle du National Center for Atmospheric Research (États-Unis)
UKMO9 - Modèle du Bureau météorologique du Royaume-Uni

s'érode lorsque l'on descend à l'échelle régionale. Pour le Canada, on constate de vastes secteurs de concordance entre les résultats des différents modèles, notamment le réchauffement du climat dans une grande partie de l'ouest et du nord; mais il y a également certaines divergences en ce qui concerne la localisation et l'ampleur des transformations qui toucheront les températures de surface et les régimes de précipitations, particulièrement dans l'est du Canada. L'incertitude exprimée à certains endroits dans le présent volume de *l'Étude pancanadienne* traduit ce désaccord.

Le contexte international

Au cours des 20 dernières années, l'avenir du climat mondial est devenu une préoccupation de plus en plus constante à l'échelle internationale. L'une des plus importantes conférences internationales sur cette question s'est déroulée au Canada en 1988 et s'intitulait « L'Atmosphère en évolution : implications pour la sécurité du globe ». Cette même année, le GIEC a été créé conjointement par l'Organisation météorologique mondiale et le Programme des Nations Unies pour l'environnement, avec le mandat d'évaluer les données scientifiques disponibles sur l'évolution du climat, les incidences écologiques et socio-économiques de cette dernière, et de formuler des stratégies de parade. Le GIEC a ensuite publié deux rapports d'évaluation en 1990 et 1995, et un troisième devrait suivre en l'an 2000 ou 2001.

En 1992 se tenait à Rio de Janeiro la « Conférence des Nations Unies sur l'environnement et le développement », dont les travaux ont permis d'en arriver à un consensus quant à une Convention-cadre sur les changements climatiques (CCCC). L'objectif ultime de la Convention est de « stabiliser les concentrations de gaz à effet de serre dans l'atmosphère à un niveau empêchant toute perturbation anthropique dangereuse du système climatique ». La Convention est maintenant en vigueur et comporte des engagements relatifs à certaines mesures comme la réduction des émissions, l'aide aux pays en développement, la préparation de rapports sur les inventaires d'émissions, l'exécution de recherches scientifiques et socio-économiques en vue de lever les incertitudes, ainsi que des activités d'information et de formation. En réponse à la CCCC, le Canada a mis au point son propre « Plan national d'action sur le changement climatique ».

À ce jour, conformément à l'objectif de la CCCC, la majorité des efforts déployés à l'échelle internationale pour élaborer les stratégies de parade face aux impacts des changements climatiques ont surtout porté sur la réduction des émissions de gaz à effet de serre. Étant donné que nous devrons composer longtemps avec les changements climatiques, il est important de comprendre leurs incidences et de nous y adapter, en plus d'effectuer ces réductions. *L'Étude pancanadienne* est l'une des réactions du Canada devant l'importance de ces incidences et de l'adaptation nécessaire.

Climat : Impacts et adaptation

Les impacts qu'il peut avoir sur notre environnement, sur notre économie et, par conséquent, sur notre mode de vie actuel et futur sont la principale préoccupation liée au changement climatique.

Au Canada, nous sommes habitués à composer avec les variations de climat qui se manifestent dans tout le pays, aussi bien d'une région à l'autre que d'une saison à l'autre. Ces variations ont de nombreux impacts, qui peuvent se répercuter sur les systèmes naturels et anthropiques, notamment les ressources en eau, la végétation et la faune, les pratiques agricoles, la foresterie et les pêches, la production et la consommation d'énergie, les bâtiments et les routes, les loisirs et le tourisme, l'industrie de l'assurance et la santé humaine.

Il y a déjà nombre de bons exemples de notre capacité d'adaptation à la diversité des conditions climatiques auxquelles nous devons faire face, aussi bien collectivement dans notre économie qu'individuellement dans notre vie quotidienne. Si notre subsistance dépend de la présence d'espèces sauvages, nous les suivons lorsqu'elles modifient leurs voies de migration; nous plantons des types de cultures différents selon les endroits et le moment de l'année; nous construisons les routes et les bâtiments différemment selon que nous sommes ou non sur du pergélisol, ou en fonction de différentes charges de neige et de vent; nous construisons des navires et des plates-formes marines qui peuvent résister aux hauteurs de vagues et aux conditions des glaces de mer prévues; nous aménageons les installations de loisirs et organisons les événements de manière qu'ils bénéficient de conditions climatiques favorables, comme assez de neige pour le ski ou assez de vent pour la voile.

Si l'on considère l'adaptation comme une façon de réagir face au climat actuel, et que l'on examine un changement climatique en cours et ses impacts, on doit répondre aux questions suivantes pour planifier l'avenir le plus efficacement possible :

- Quels sont les impacts du changement climatique, et de quelle façon viendront-ils se répercuter sur ma vie et celle de ma famille?
- Prend-on aujourd'hui des décisions qui viendront accroître notre vulnérabilité future parce qu'elles ne tiennent pas suffisamment compte de ces impacts?
- Les approches que nous utilisons pour nous adapter aux conditions climatiques actuelles seront-elles encore viables dans l'avenir, ou faudra-t-il en envisager de nouvelles pour nous adapter à des changements dépassant tout ce que nous avons connu?
- La vitesse à laquelle se produiront les changements climatiques nous laissera-t-elle le temps de nous adapter?
- Le société devra-t-elle devenir plus adaptable et plus souple qu'elle ne l'est maintenant face aux changements climatiques et, si oui, comment?

L'Étude pancanadienne a pour objectif de nous aider à répondre à certaines de ces questions.

EXECUTIVE SUMMARY

As the likelihood of climate change resulting from human activities increases, there is a growing need to estimate the magnitude of these changes, determine their impacts on the environment, our society and our economy, and identify the most effective strategies for adapting to the anticipated changes. This report summarizes the most recent literature describing the impacts of current climate and the potential effects of anticipated climate change on the environment and on those social and economic sectors in Ontario most likely to undergo significant changes.

Current Climate of Ontario

Ontario's climate varies widely from season to season and from one part of the province to another. In Northern Ontario, the climate is primarily continental, with cold winters and mild summers. Most precipitation falls in the form of summer showers and thunderstorms; winter snowfall amounts can be impressive, but usually contain less water. Precipitation amounts increase as one moves from northwest to southeast; a reflection of the increasing influence of moisture transported from the Great Lakes and the Gulf of Mexico. In Southern Ontario, the climate is highly modified by the influence of the Great Lakes. The addition of moisture from the Great Lakes in autumn and winter increases precipitation amounts, while the heat of the Great Lakes protects the region from the worst of winter's cold. In the spring and summer, the cooler waters of the Great Lakes act to moderate the oppressive heat of tropical air, which regularly approaches the area. The combination of uniform precipitation amounts year-round, delayed spring and autumn, and moderated temperatures in winter and summer makes Southern Ontario's climate one of the most suitable in Canada for both agriculture and human settlement.

Ontario experiences a variety of extreme weather events. In winter, Northern Ontario can have prolonged periods of extreme cold. Farther south, very heavy snow is a regular feature in the snowbelts to the lee of Lakes Superior and Huron, and Georgian Bay; major storms lash most parts of Ontario at least once or twice per year, with high winds and a mix of rain, freezing rain and snow. In spring, rapid snowmelt or ice jamming can lead to flooding of Ontario's rivers. Spring also marks the beginning of the tornado season in Southern Ontario, which has the highest frequency of tornadoes in Canada. In summer, thunderstorms can produce heavy downpours, hail, damaging winds and occasional tornadoes. Stagnant tropical air masses can bring poor air quality, heat waves and drought. In autumn, an early frost can damage crops, and remnants of hurricanes occasionally produce high winds and excessive rainfalls.

Impacts of Climate

Ontario's environment, society and economy are all affected by climate. The environment is well adapted to the current climate. Our economy and society have also adjusted, but as our knowledge of climate expands and our awareness of its impacts increases, further improvement is possible. The social and economic sectors most affected by climate include water resources, human health, the built environment, energy, transportation, tourism and recreation, forestry, agriculture, construction and finance. Some of the most significant impacts are listed below.

- The major climate-dependent regional air issues are: smog, fine particulates, acid rain, and hazardous air pollutants (HAPs). Local pollutant concentrations depend on: weather patterns, local and regional emission rates, and weather-dependent air chemistry. Concentrations of smog and particulates continue to exceed ambient air quality objectives on some days. Interannual climate variability affects the frequency of such weather-related extremes.

- Climate affects health directly, especially in summer through heat stress. Severe weather poses a hazard in all seasons. In addition, climate affects health indirectly by interacting with other atmospheric stressors.
- Variability in temperature and precipitation causes variations in lake levels and river flows, which affect hydroelectric power generation. Thunderstorms, freezing rain, high winds, freeze-thaw cycles and frozen ground affect the infrastructure of the energy distribution system. Wind patterns and cloud cover play a significant role in determining the feasibility of wind and solar energy. Daily and year-to-year fluctuations in energy demand are driven largely by temperature.
- The composition of terrestrial ecosystems is generally determined by temperature, water availability and soils. Aquatic ecosystems are affected by water temperature, the distribution of freshwater, and the hydrologic cycle. Past temperature changes of one degree have caused substantial changes in the home ranges of species.
- The boreal forest covers 82 percent of the total forested area in Ontario. Climate has direct (fire conditions and strong winds) and indirect (insects and disease) impacts on the health of existing stands and on restocking efforts. The forest industry is vulnerable to changes beyond the adaptive capability of trees, which are able to withstand most natural climate variability.
- Mean climate conditions and soils determine which agricultural products will be viable in a particular area. Year-to-year changes in productivity are governed largely by the interannual variability of climate.
- Up to four percent of building costs in Toronto are attributed to adaptation to current climate. Snow loading is a key determinant of structural strength. Temperature determines heating and cooling requirements. Precipitation amounts affect the design of dams, sewers, and other water management infrastructure. Freeze-thaw cycles, ultraviolet (UV) radiation and acid rain weather exterior surfaces. Severe weather events can damage or destroy structures. Snow and excessive rainfall affect operations on construction sites. Variations in temperature can cause building materials to expand and contract.
- The estimated total cost of damages (in 1989 dollars) for the major flood events recorded in Ontario between 1837 and 1989 is between $566 million and $1.5 billion.
- Extreme low lake levels can restrict the maximum cargo capacity of vessels, and can increase operating costs of ports and shipping channels. Temperatures and wind patterns affect ice conditions, which determine the operating season of the St. Lawrence Seaway. Colder winter temperatures require changes in fuels and lubricants and increase maintenance costs for aircraft and airports. Traction can be impaired by rain, snow and freezing precipitation. Snow removal and anti-icing costs comprise a large portion of road and airport operating budgets; some of the chemicals that are used damage vehicles, structures and ecosystems. Weather conditions have a major impact on flight operations, with consequences for profitability. Road and railway infrastructure can be damaged or rendered impassable by major winter storms, flooding and objects felled by wind. High winds are hazardous to shipping, and can prevent stacking of containers on trains.
- Each outdoor recreational activity has a set of climatic requirements and a level of sensitivity to fluctuations in climatic conditions; key climate variables are temperature, precipitation, sunshine and wind.

Future Climate of Ontario

For Ontario, results from some of the latest Global Circulation Model (GCM) simulations of climate, with an atmosphere containing twice the current amount of greenhouse gases, suggest an average annual warming of some 2° to 5°C by the latter part of the 21st century. Even if greenhouse gas amounts stabilize at that point, temperatures would continue to increase thereafter, with overall warming of 3° to 8°C possible. Increases will probably be greater in the winter than in the summer. These changes would significantly decrease the duration of the annual snow season and lengthen the growing season. They could increase the frequency and severity of extreme heat events in summer. It must be remembered, however, that even the most sophisticated GCMs do not incorporate the effects of important local climate controls, such as the Great Lakes. For this and other reasons, considerable uncertainty still exists about the application of GCM results on a regional scale.

Anticipated Impacts of Future Climate

While the greatest confidence is attached to projections of changes in temperatures, the most significant impacts are expected to result from the changes in other climatic conditions. These include changes in precipitation patterns, in soil moisture, and possibly in the frequency and intensity of severe weather events. Some of the key impacts of a changing climate are listed here.

- Changes in weather patterns may affect the frequency and intensity of pollution episodes. Air-water partitioning of HAPs may be affected by increased temperatures, and reduced frequency of lake turnover. Increased summertime temperatures could increase the volatilization of organic compounds, and the rates of chemical reactions, which could enhance the formation of ground-level ozone. However, these increases might be modulated by changes in cloud cover and precipitation frequency.
- Increased heat stress, and possible increases in the number or severity of episodes of poor air quality and extreme weather events could all have a negative effect on human health. A warmer climate may facilitate migration of disease-carrying organisms from other regions.
- Average water levels of the Great Lakes could decline to record low levels during the latter part of the 21st century. Water supply from both surface and groundwater sources is expected to decrease in Southern Ontario; the effect on water supply in Northern Ontario is unknown. Water demand is expected to increase during the summer months.
- Changes in the hydrologic cycle may result in more variability in water supply for hydroelectric power production. Energy demand is expected to increase in the summer and decrease in the winter.
- In the Great Lakes, the warming of waters in the summer is expected to cause fish species to shift northward. Many of the nearshore parts of the Great Lakes and stream waters will become too warm for salmonids in the summer, but will become optimal earlier in the spring and later in the autumn. Changes in wetlands and littoral areas may alter their efficacy as spawning and nursery areas. Some wetlands could shrink or disappear, others could move or expand, and new wetlands could be created. Increases in water temperature in the Great Lakes could reduce the frequency of overturning, which would seriously affect aquatic ecosystems.
- The cool temperate, moderate temperate and grassland regions are expected to expand northwards as the boreal forest retreats. Additional damage to forest ecosystems by pests and diseases, and increased frequency and intensity of fires may occur. Some moose and caribou habitat could be destroyed, leading to a decrease in the numbers of these animals. Species currently threatened with extinction face the greatest risk of extinction in a changing climate, while opportunities for successful

establishment of exotic species will be enhanced. Forest industry operating costs may increase because of a shorter winter harvesting season.

- Warmer temperatures and a longer growing season may increase opportunities for crop selection. Productivity in some areas may be limited by moisture rather than by temperature. Should climate variability increase, it would increase variability in productivity. Increased concentrations of carbon dioxide (CO_2) may improve yields and water utilization for some crop types.
- Decreased snow load may result in reduced cost of buildings and infrastructure. More frequent freeze-thaw cycles could increase weathering. The need for heating will be reduced, while demand for cooling will increase. Warmer winters will lengthen the construction season. In far Northern Ontario, degradation of permafrost may affect the stability of existing structures and the conditions for future construction.
- Changes in the frequency or intensity of extreme events would have consequences for the property insurance industry and possibly for disaster-relief agencies. Changes in human health could affect the health and life insurance and pension industries.
- Reduced ice on the Great Lakes is expected to increase the length of the shipping season. Dramatically lower lake levels would reduce the maximum capacity of vessels and could increase operating costs for ports and shipping channels. Changes in shipping conditions on the Great Lakes could affect demand for bulk shipment by rail. Changes in production of climate-sensitive commodities, such as agricultural products, could affect demand for rail and marine transport. The need for snow removal and aircraft de-icing could be reduced in Southern Ontario. Shorter seasons are anticipated for winter maintenance in Northern Ontario.
- Snow conditions are expected to be less reliable for outdoor winter recreation. Increased use of beaches and parks is possible as the annual period of favourable temperatures lengthens; this may be limited by beach aesthetics and water quality.

Adaptation to Climate Variability and Change

As we have seen, many aspects of Ontario's environment, economy and society are sensitive to climate variability and anticipated changes in climate conditions. One way Ontario could lessen the impacts of a changing climate is to reduce known vulnerabilities to current climate variability. In some cases, a changing climate could necessitate additional adaptive actions. Some adaptive strategies for climate sensitive sectors are suggested here.

- Increased use of energy-efficient cooling technologies and practices would reduce heat stress on humans. Adjustments in the health care system may be necessary to cope with new diseases.
- Water demand can be reduced through increased efficiencies of its delivery and utilization. Adjustment of shoreline ecosystems and facilities may be necessary to compensate for lower water levels.
- Energy conservation and efficiency measures should be encouraged. Water storage could be increased to reduce the variability of water supply for electricity production.
- Efforts to restore degraded habitats and preserve existing ecosystems should allow for expected changes in climate and their effects on optimum ranges of species. Where the establishment of exotic species is inevitable, it may be possible to select species that would be most beneficial to other components of the ecosystem.
- Preservation of existing tree stocks could be enhanced by increased public education and fire suppression, and improved pest and disease management. When

replanting, new strains or species more tolerant of expected conditions could be introduced. Practices may have to be tuned to optimize use of these resources.

- Crop types could be adjusted and new agricultural areas developed as climate changes. Crop insurance programs could be adjusted to encourage adaptation.
- Water control structures may need to be redesigned to handle greater variability of precipitation, including a possible increase in the intensity of extreme events. Building codes and land-use planning regulations may need to be revised.
- Improved knowledge regarding spatial patterns of, and trends in extreme weather events is necessary to improve estimates of future risk. The insurance industry could have more input into land-use planning to reduce exposure to future risks.
- Road weather information systems could be used more widely to optimize winter maintenance operations. Cleaner energy technologies would reduce emissions of pollutants. Increased use of communications technology could reduce the need for travel. More convenient public transit could encourage reductions in automobile usage. Shipping channels and ports may require increased dredging when lake levels are low.
- Operations at recreational facilities could be diversified to improve resilience to climate variability.
- Reducing emissions remains the best way to address air issues.

Areas Requiring Further Research

Information regarding climate change impacts, especially on regional scales, is still somewhat inexact. Although much more is known about the impacts of current climate variability, there remain gaps in our knowledge in this area, too. In order to better assess the relative magnitudes of climate impacts, and devise effective adaptation strategies, more research is required in all areas. Some of the key areas for future study are:

- climate and impacts modelling: increasingly accurate simulations of climate on regional and smaller scales, and better simulations of the hydrologic cycle, to improve our ability to quantify impacts of future climate;
- integrated air issues: the interaction of the various air issues with climate and with each other, as well as our understanding of their synergistic impacts on human and ecosystem health, and on economic sectors sensitive to atmospheric stresses;
- the impact of climate on water resources: on groundwater across Ontario, and also on surface waters in Northern Ontario;
- the climatology of severe weather and climate events: this should continue to be refined as more data becomes available, so that sectors sensitive to extreme events are better able to quantify risks;
- response strategy development: continued development will be possible as the scientific foundation continues to improve.

Accessible, high-quality environmental and socio-economic data is a requisite in order to detect climate change, to understand climate impacts, and to formulate and execute effective adaptation strategies.

Concluding Remarks

Adapting most effectively to a changing climate requires a knowledge of how climate will change and how the changes will affect the environment, society and the economy. However, changes in other key variables, such as technology, personal preferences and social values, will probably influence both the rate of climate change and our ability to adapt to it. For this reason, the unforeseeable future, the most prudent strategies to adopt today are so-called *no-regrets* strategies.

That is, regardless of what changes occur, these strategies will provide a net benefit to the environment, society and the economy. Examples of *no-regrets* strategies include more efficient use of energy and materials, and improving adaptation to current climate.

For Ontario, a changing climate will present challenges for some sectors, and opportunities for others. The present technology of climate prediction and our knowledge of climate impacts do not allow us to make confident estimates of losses and benefits. However, most expert opinion suggests that climate will continue to change, and that the costs of the impacts are likely to exceed the benefits from a warmer climate. Therefore, a sensible approach would be to: minimize anthropogenic forcing of climate change to the extent possible, without unduly disrupting the very environmental, social and economic systems we seek to preserve; and to improve our adaptation to current climate conditions in ways that will increase our ability to adjust to future changes.

The responsibility for action is broadly based: the scientific community must provide advice and information; governments must identify and eliminate barriers and disincentives to adaptation; and those in affected sectors must educate themselves about the risks and opportunities of a changing climate and act accordingly.

SOMMAIRE EXÉCUTIF

Plus il devient probable qu'il va y avoir un changement climatique dû aux activités humaines, plus il devient important d'estimer l'ampleur de ce changement, de déterminer ses impacts sur notre environnement, notre société et notre économie, et de trouver les stratégies les plus efficaces pour nous y adapter. Le présent rapport résume les travaux les plus récents décrivant les impacts du climat actuel et les effets possibles du changement climatique prévu sur le milieu et sur les secteurs sociaux et économiques de l'Ontario les plus susceptibles d'en subir des contrecoups marqués.

Le climat actuel de l'Ontario

Le climat de l'Ontario varie beaucoup d'une saison et d'une région de la province à l'autre. Le nord de l'Ontario connaît un climat surtout continental, avec des hivers froids et des étés doux. La plus grande partie des précipitations tombe sous la forme d'averses et d'orages d'été; les accumulations de neige en hiver peuvent être impressionnantes, mais déversent généralement moins d'eau. Les quantités de précipitations augmentent à mesure que l'on se déplace du nord-ouest vers le sud-est, ce qui reflète l'influence croissante de l'humidité arrivant des Grands Lacs et du golfe du Mexique. Dans le sud de l'Ontario, le climat est considérablement modifié par l'influence des Grands Lacs. L'humidité apportée par ceux-ci en automne et en hiver augmente les quantités de précipitations, mais la chaleur qu'ils libèrent protège la région des froids extrêmes de l'hiver. Au printemps et en été, les eaux plus fraîches des Grands Lacs amoindrissent la chaleur étouffante de l'air tropical qui remonte régulièrement vers la région. Cette combinaison d'une répartition uniforme des précipitations sur l'année, d'un printemps hâtif et d'un automne qui se prolonge et de l'adoucissement des températures en hiver et en été confère au sud de l'Ontario un des climats du Canada les plus propices à l'agriculture et au peuplement humain.

L'Ontario connaît divers types de phénomènes météorologiques extrêmes. En hiver, dans le nord de la province, il peut y avoir de longues périodes de très grand froid. Plus au sud, il tombe régulièrement de très fortes chutes de neige dans les régions situées sous le vent des lacs Supérieur et Huron et de la baie Georgienne; d'importantes tempêtes frappent la plupart des régions de l'Ontario au moins une ou deux fois par an, avec des vents forts et un mélange de pluie, de pluie verglaçante et de neige. Au printemps, la fonte rapide de la neige et les embâcles peuvent faire déborder les cours d'eau. Le printemps marque aussi le début de la saison des tornades dans le sud de l'Ontario, région où l'on enregistre la plus grande fréquence de tornades de tout le Canada. En été, les orages apportent des pluies torrentielles, de la grêle, des vents destructeurs et parfois des tornades. Avec la stagnation des masses d'air tropical, viennent une détérioration de la qualité de l'air, des vagues de chaleur et des sécheresses. En automne, les gelées hâtives peuvent endommager les cultures, et les tempêtes qui suivent les ouragans donnent parfois des vents forts et des pluies très abondantes.

Incidences du climat

Le climat influe sur l'environnement, la société et l'économie de l'Ontario. L'environnement s'est bien adapté au climat actuel. Notre société et notre économie ont fait de même mais, à mesure que nous connaissons mieux le climat et sommes plus sensibles à ses impacts, il devient possible d'apporter de nouvelles améliorations. Les secteurs économiques et sociaux les plus touchés par le climat sont les ressources en eau, la santé humaine, le milieu bâti, l'énergie, les transports, les loisirs et le tourisme, la foresterie, l'agriculture, la construction et la finance. On trouvera ci-après quelques-uns des impacts les plus significatifs.

- Les principales questions atmosphériques régionales liées au climat sont le smog, les particules fines, les précipitations acides et les polluants atmosphériques dangereux (PAD). Les concentrations locales de polluants dépendent de plusieurs facteurs : situation météorologique, taux d'émissions locaux et régionaux, et chimie de l'air régie par les conditions météorologiques. Les concentrations de smog et de particules continuent certains jours de dépasser les objectifs de qualité de l'air ambiant. La variabilité interannuelle du climat influe sur la fréquence de ces extrêmes liés aux conditions météorologiques.

- Le climat a un impact direct sur la santé, surtout en été, en raison du stress dû à la chaleur. Le mauvais temps est dangereux en toutes saisons. De plus, le climat influe indirectement sur la santé, via ses interactions avec les autres problèmes atmosphériques.
- La variabilité de la température et des précipitations entraîne des fluctuations des niveaux des lacs et des débits des cours d'eau, qui déterminent la production d'hydroélectricité. Les orages, la pluie verglaçante, les vents forts, les cycles de gel/dégel et le gel du sol ont une influence sur l'infrastructure du système de distribution d'énergie. Les régimes des vents et la nébulosité jouent un rôle significatif dans la détermination de la viabilité des filières énergétiques éolienne et solaire. Les fluctuations quotidiennes et interannuelles de la demande en énergie sont gouvernées en grande partie par la température.
- La composition des écosystèmes terrestres est généralement déterminée par la température, la disponibilité de l'eau et les sols. Les écosystèmes aquatiques sont régis par la température de l'eau, la distribution de l'eau douce et le cycle hydrologique. Par le passé, des changements de température de un degré ont substantiellement modifié les aires de répartition de certaines espèces.
- La forêt boréale occupe 82 % de la superficie forestière totale de l'Ontario. Celui-ci agit directement (via les incendies et les vents forts) et indirectement (via les insectes et les maladies) sur la santé des peuplements et sur les efforts de reboisement. L'industrie forestière est donc vulnérable à des changements qui dépasseraient la capacité d'adaptation des arbres, pourtant capables de faire face à la plupart des variations naturelles du climat.
- Les conditions climatiques moyennes et les sols définissent quels sont les produits agricoles viables dans une région donnée. Les variations d'année en année de la productivité sont régies en grande partie par celles du climat.
- Jusqu'à 4% des coûts de construction à Toronto sont attribués à l'adaptation au climat actuel. Le poids de la neige est un facteur déterminant sur la résistance des structures. La température, quant à elle, régit les besoins en chauffage et en climatisation. Les quantités de précipitations sont prises en compte dans la conception des barrages, des égouts et d'autres infrastructures de gestion de l'eau. Les cycles de gel-dégel, le rayonnement ultraviolet (UV) et les pluies acides attaquent les surfaces extérieures. Les épisodes de temps violent peuvent endommager, voire détruire, les structures. La neige et les pluies excessives affectent les travaux de construction. Les variations de température peuvent faire dilater et contracter les matériaux.
- Le coût total estimatif (en dollars de 1989) des dommages attribuables aux grandes inondations survenues en Ontario de 1837 à 1989 se situe entre 566 millions et 1,5 milliard de dollars.
- Si les niveaux d'eau des lacs sont trop bas, la capacité maximale de chargement des navires est réduite, ce qui peut entraîner une hausse des coûts d'exploitation des ports et chenaux de navigation. Les régimes des températures et des vents influent sur les conditions des glaces, qui déterminent l'ouverture de la Voie maritime du Saint-Laurent. Le froid hivernal exige de changer de carburants et de lubrifiants, d'où une augmentation des coûts de maintenance des aéronefs et des aéroports.

Les coûts de déneigement et de déglaçage représentent une part importante des budgets d'exploitation pour la voirie et les aéroports; en outre, certains des produits chimiques utilisés endommagent les véhicules, les structures et les écosystèmes. Les conditions météorologiques ont un impact considérable sur les opérations de vol, ce qui nuit à la rentabilité. L'infrastructure routière et ferroviaire peut être endommagée ou rendue impraticable par les fortes tempêtes d'hiver, les inondations et les objets abattus par le vent. De plus, les vents violents sont dangereux pour la navigation, et peuvent empêcher d'empiler les conteneurs sur les trains.

- Tous les loisirs de plein air requièrent des conditions climatiques bien précises et sont très sensibles aux fluctuations du climat; les paramètres clés sont la température, les précipitations, l'ensoleillement et le vent.

Le climat futur de l'Ontario

En ce qui concerne l'Ontario, les simulations effectuées à l'aide de certains des plus récents modèles de circulation générale (MCG), pour une atmosphère où la quantité de gaz à effet de serre est double des valeurs actuelles, suggèrent un réchauffement annuel moyen de 2 à 5°C d'ici la dernière partie du XXI^e siècle. Même si par la suite de serre, la quantité de gaz à effet deserre se stabilise, les températures continueraient de monter par la suite, et un réchauffement total de 3 à 8°C est envisageable. Les augmentations seront probablement plus élevées en hiver qu'en été. Ces changements raccourciraient significativement la durée de la saison de neige et allongeraient la saison de croissance. Ils pourraient aussi accroître la fréquence et la gravité des vagues de chaleur estivales. Il faut cependant se rappeler que même les MCG les plus sophistiqués ne prennent pas en compte les effets des grands facteurs d'influence locaux du climat, comme les Grands Lacs. C'est pour cette raison, et d'autres, qu'il persiste une incertitude considérable quant à l'application des résultats des MCG à l'échelle régionale.

Impacts prévus du climat futur

Alors qu'on peut accorder beaucoup de confiance aux projections de l'évolution des températures, il demeure que les impacts les plus marqués découleront des changements d'autres paramètres climatiques, comme ceux des régimes pluviométriques, de l'humidité du sol et, possiblement, de la fréquence et de l'intensité des épisodes de temps violent. On trouvera ci-dessous certains des impacts clés du nouveau climat.

- Les changements des régimes météorologiques peuvent influer sur la fréquence et la gravité des épisodes de pollution. La séparation air-eau des PAD peut être modifiée par le réchauffement et le ralentissement du renouvellement de l'eau dans les lacs. Avec des étés plus chauds, on pourrait voir une augmentation de la volatilisation des composés organiques, et une accélération des réactions chimiques, ce qui accentuerait la formation d'ozone troposphérique. Cependant, ces augmentations seraient atténuées quelque peu par les changements de la couverture nuageuse et de la fréquence des précipitations.
- L'augmentation du stress dû à la chaleur et, possiblement, celle du nombre ou de la gravité des épisodes de mauvaise qualité de l'air et de phénomènes météorologiques violents pourraient avoir des effets nocifs sur la santé humaine. Dans un climat plus doux, les organismes vecteurs de maladies pourraient plus facilement arriver d'autres régions.
- Les niveaux moyens de l'eau dans les Grands Lacs pourraient descendre à des minimums records pendant la seconde partie du XXI^e siècle. L'approvisionnement en eau de surface et en eau souterraine devrait baisser dans le sud de l'Ontario; on ne sait pas encore comment se comporterait l'alimentation en eau dans le nord de la province. La demande en eau, quant à elle, devrait augmenter en été.

- Les changements du cycle hydrologique devraient accentuer la variabilité de l'approvision-nement en eau pour la production d'hydroélectricité. La demande en énergie devrait monter en été et baisser en hiver.
- Dans les Grands Lacs, le réchauffement estival des eaux devrait pousser les espèces de poissons à se déplacer vers le nord. Dans nombre de zones littorales des Grands Lacs et des cours d'eau, les eaux deviendront trop chaudes pour les salmonidés en été, mais atteindront une température optimale plus tôt au printemps et la conserveront plus tard à l'automne. Les changements subis par les milieux humides et les secteurs riverains pourraient abaisser leur efficacité comme aires de fraye et d'alevinage. Certains milieux humides pourraient rétrécir ou disparaître, d'autres s'étendre ou changer de place, et de nouveaux se créer. L'élévation de la température de l'eau dans les Grands Lacs pourrait en réduire la fréquence de renouvellement, ce qui affecterait gravement les écosystèmes aquatiques.
- La forêt boréale devrait rétrécir à mesure que les régions de climats tempéré frais et tempéré modéré et la prairie gagneront vers le nord. Les écosystèmes forestiers pourraient subir des dommages du fait des ravageurs et des maladies, et connaître une augmentation de la fréquence et de l'intensité des incendies. Certains habitats d'orignaux et de caribous pourraient être détruits, ce qui entraînerait une baisse des populations de ces animaux. Ce sont les espèces présentement menacées qui courront le plus grand risque d'extinction dans le nouveau climat, alors que les espèces exotiques auront plus de chances de s'établir avec succès. Les coûts d'exploitation de l'industrie forestière pourront augmenter avec le raccourcissement de la saison hivernale de récolte.
- La hausse des températures et l'allongement de la saison de croissance pourront accroître les possibilités de sélection des cultures. Dans certaines régions, la productivité pourrait être limitée par l'humidité, plutôt que par la température. Si le climat devenait plus variable, la productivité ferait de même. L'augmentation des concentrations de dioxyde de carbone (CO_2) pourrait améliorer les rendements et l'utilisation de l'eau pour certains types de cultures.
- Une diminution de la charge due à la neige pourra entraîner une réduction des coûts des immeubles et infrastructures. Cependant, des cycles gel-dégel plus fréquents pourraient en accroître le vieillissement. Le besoin en chauffage sera réduit, et la demande en climatisation augmentera. Le réchauffement des hivers allongera la saison de construction. Dans l'extrême nord de l'Ontario, la dégradation du pergélisol peut affecter la stabilité des structures existantes et les conditions futures de construction.
- Des changements dans la fréquence ou l'intensité des phénomènes extrêmes pourraient avoir des conséquences sur l'industrie des assurances des biens et, éventuellement, sur les organismes de secours en zone sinistrée. Les changements imposés à la santé humaine pourraient avoir une incidence sur les industries des pensions et des assurances-maladie et assurances-vie.
- La réduction de la glace sur les Grands Lacs devrait prolonger la saison de navigation. Une baisse marquée des niveaux des lacs réduirait la capacité maximale de chargement des navires, ce qui pourrait entraîner une hausse des coûts d'exploitation des ports et chenaux de navigation. Les nouvelles conditions de navigation sur les Grands Lacs pourraient avoir un impact sur la demande en transport de vrac par chemin de fer. Une modification de la production de denrées sensibles au climat, comme les produits agricoles, pourrait aussi jouer sur les demandes en transports maritime et ferroviaire. Les besoins en déneigement et en déglaçage

des aéronefs pourraient être réduits dans le sud de l'Ontario. On prévoit aussi des saisons plus courtes pour la maintenance d'hiver dans le nord de la province.

- Les conditions de neige pour les sports et loisirs extérieurs d'hiver devraient être plus variables. Il est possible que l'on puisse utiliser davantage les plages et les parcs, avec un allongement de la période de températures propices, mais la qualité de l'eau et la beauté des plages pourraient y mettre une limite.

Adaptation à la variabilité et au changement climatique

Nous venons de le voir, nombre d'aspects de l'environnement, de la société et de l'économie de l'Ontario sont sensibles à la variabilité du climat et aux changements prévus des conditions climatiques. Une des voies qui s'offrent à l'Ontario pour atténuer les impacts d'un climat en évolution est de réduire les vulnérabilités connues à la variabilité climatique actuelle. Dans certains cas, le changement climatique pourrait exiger d'autres mesures d'adaptation. On propose ci-dessous quelques stratégies d'adaptation pour les secteurs sensibles au climat.

- Un recours accru à des technologies et à des pratiques éconergétiques de climatisation réduirait le stress imposé à la population humaine par la chaleur. Il faudra peut-être modifier les systèmes de soins de santé pour lutter contre de nouvelles maladies.
- On peut réduire la demande en eau par une meilleure distribution et une meilleure utilisation. Des ajustements des installations et écosystèmes riverains seront peut-être nécessaires pour compenser la baisse des niveaux d'eau.
- Il faudrait encourager les mesures d'économie de l'énergie et d'efficacité énergétique. Le stockage de l'eau pourrait aider à réduire la variabilité de l'approvisionne- ment en eau pour la production d'électricité.
- Les efforts déployés pour restaurer les habitats dégradés et préserver les écosystèmes actuels devraient tenir compte des changements climatiques prévus et de leurs effets sur les aires optimales de répartition des espèces. Il sera certes impossible d'empêcher des espèces exotiques de s'installer, mais on pourra peut-être choisir les espèces qui seront le plus bénéfiques aux autres éléments de l'écosystème.
- En accroissant l'éducation du public et la répression des incendies, ainsi que la lutte contre les ravageurs et les maladies, on pourrait améliorer la préservation des stocks actuels d'essences forestières. On pourrait, au reboisement, choisir de nouvelles souches ou espèces plus tolérantes des conditions attendues. Il faudrait aussi adapter les pratiques utilisées afin d'optimiser l'utilisation de ces ressources.
- Il faudrait choisir de nouveaux types de cultures et développer de nouvelles régions agricoles à mesure que le climat évolue. Les programmes d'assurance-récolte pourraient être modifiés pour encourager l'adaptation.
- On pourrait être obligé de modifier les structures de régulation des cours d'eau en fonction d'une plus grande variabilité des précipitations, et d'une augmentation possible de l'intensité des phénomènes extrêmes. Les codes du bâtiment et les réglementations visant l'utilisation des terres pourraient devoir être modifiés.
- Il faudra mieux connaître les distributions spatiales et les tendances des phénomènes météorologiques extrêmes pour mieux estimer les risques futurs. L'industrie des assurances pourrait devoir participer davantage à la planification de l'utilisation des terres pour réduire l'exposition à ces risques.
- On pourrait recourir davantage à l'information des systèmes météo routiers (RWIS) afin d'optimiser les opérations de maintenance hivernale. L'utilisation de

technologies plus propres aiderait à faire baisser les émissions de polluants. En se servant plus des technologies de communication, on peut réduire les besoins en déplacements. Des systèmes de transports en commun plus pratiques encourageraient la population à délaisser les automobiles. Les ports et chenaux de navigation peuvent exiger davantage de dragage lorsque le niveau des lacs est bas.

- Les installations de loisirs peuvent diversifier leurs activités pour être moins vulnérables au climat.
- La réduction des émissions reste le meilleur moyen de lutter contre les problèmes atmosphériques.

Secteurs exigeant de nouvelles recherches

Il persiste quelques inexactitudes dans l'information sur les impacts du changement climatique -- surtout à l'échelle de la région. Il demeure aussi des lacunes dans nos connaissances des impacts de la variabilité actuelle du climat, bien que ce sujet soit beaucoup mieux compris. Pour mieux évaluer les ampleurs relatives des impacts du climat, et mettre au point des stratégies d'adaptation efficaces, il faudra encore effectuer beaucoup de recherches. Parmi les secteurs clés que devront viser ces recherches figurent les suivants :

- modélisation du climat et de ses impacts : des simulations de plus en plus précises du climat à l'échelle de la région et même à des échelles plus petites, et de meilleures simulations du cycle hydrologique sont nécessaires pour améliorer notre capacité de quantifier les impacts du climat futur;
- questions atmosphériques intégrées : il faudra étudier les interactions des diverses questions atmosphériques entre elles et avec le climat, et améliorer notre compréhension de leurs impacts synergiques sur la santé des populations humaines et des écosystèmes, ainsi que sur les secteurs de l'économie sensibles aux stress atmosphériques;
- impact du climat sur les ressources en eau : sur les eaux souterraines pour tout l'Ontario et sur les eaux de surface du nord de la province;
- climatologie des épisodes météorologiques et climatiques violents : cet aspect doit être raffiné à mesure que de nouvelles données sont disponibles, de manière que les secteurs sensibles aux phénomènes extrêmes puissent mieux quantifier les risques;
- élaboration de stratégies de réponse: on pourra continuer cette élaboration à mesure que la base scientifique s'améliorera.

Il faudra avoir accès à des données environnementales et socio-économiques de grande qualité pour détecter le changement climatique, comprendre les impacts du climat, et formuler et mettre en place des stratégies d'adaptation efficaces.

Conclusion

Pour s'adapter le plus efficacement possible à un climat en évolution, il faut savoir comment se fera cette évolution et de quelle manière les changements influeront sur l'environnement, la société et l'économie. Cependant, des modifications à d'autres variables clés, comme la technologie, les préférences personnelles et les valeurs sociales, affecteront probablement la vitesse du changement climatique et notre capacité à nous y adapter. C'est pourquoi, dans un avenir prévisible, les stratégies les plus prudentes à adopter aujourd'hui sont celles que l'on dit « sans reproche ». En d'autres termes, quels que soient les changements qui se produisent, ces stratégies se traduiront par un avantage net pour l'environnement, la société et l'économie. On pense par exemple à l'utilisation plus efficace de l'énergie et des matériaux, et à une meilleure adaptation au climat actuel.

En Ontario, un changement du climat présentera des défis à certains secteurs, mais ouvrira de nouvelles avenues à d'autres. La technologie actuelle de prévision du climat et notre connaissance des impacts de celui-ci ne nous permettent pas de faire des prévisions catégoriques des pertes et avantages. Cependant, de l'avis de la plupart des experts, le climat va continuer à changer, et les coûts des impacts vont probablement dépasser les avantages offerts par un climat plus chaud. L'approche la plus raisonnable serait donc de réduire au minimum les influences de l'activité humaine sur le changement climatique, sans perturbation indue des systèmes environnementaux, sociaux et économiques que nous tentons ainsi de préserver;et d'améliorer notre adaptation aux conditions climatiques actuelles de manières qui nous permettent de nous ajuster aux changements à venir.

La responsabilité de ces gestes repose sur de nombreuses épaules : la communauté scientifique doit fournir des avis et des informations; les gouvernements doivent repérer et éliminer tout ce qui freine l'adaptation ou y fait obstacle; les intervenants des secteurs touchés doivent se tenir au courant des risques et des avantages d'un climat en évolution et agir en conséquence.

1.0 INTRODUCTION

The social, cultural and economic development of Ontario has been shaped largely by the province's geography, its natural resources, and its climate. The natural environment and its resources are well-adapted to the current climate. Our society and industry have also taken steps to adapt to the climate, but areas remain where we could make further improvements.

It is expected that the concentration of greenhouse gases in our atmosphere will double over the next century. However, we are less certain about what the consequences of this increase will be for the climate of Ontario. Mean temperatures in this region have increased over the last century, particularly in winter, and all indications are that this trend will continue. These changes would shorten the snow season and decrease the extent of the snowpack, but would increase the length of the growing season. The frequency and severity of summer heat waves could increase. As the warming progresses, the water supply from both surface and groundwater sources in Southern Ontario is expected to decline. There could also be changes to precipitation patterns, and to the frequency and severity of winter storms, thunderstorms, hail, tornadoes and hurricanes.

The effects of climate change on the environment, society and the economy may be both positive and negative. How society and industry prepare for, and adapt to, a changing climate will determine the overall effect on Ontario. One way to prepare for a changing climate is to improve the adaptation to present climatic conditions.

This volume is the fourth in the series of six regional and two national studies published in Phase I of the *Canada Country Study: Climate Impacts and Adaptation.* The study examines the impacts of, and adaptation to, current and future climates from an Ontario perspective. The full scope of the national assessment is presented in the preface to this volume. The work has been funded by Environment Canada.

1.1 Ontario Region Report

The Ontario volume of the *Canada Country Study* represents the results of an extensive literature review, as well as discussions with professionals and academics associated with several key sectors. Although attempts were made to be as comprehensive as possible, the size and scope of this study did not allow for an exhaustive treatment of the subject. If this synthesis has overlooked any significant contributions, the authors apologize in advance for these omissions.

The volume begins with an examination of the physical, socio-economic and climatic conditions within in the province of Ontario. It assesses the impact of the current climate and its variability on key sectors of the economy, the human population and the ecosystem, and then explores the implications of a changed climate for these areas. The report concludes by surveying the adaptation capacity of selected sectors, with an emphasis on the situation within the province of Ontario.

The Ontario volume is structured as follows:

Chapter 1.
Introduction to the Ontario volume.

Chapter 2.
A description of the physical and socio-economic resources within the province.

Chapter 3.
Details of the current climatic conditions in Ontario, including its variability and recent trends.

Chapter 4.
Impacts of current climate on the following sectors: water resources, human and ecosystem health, the built environment, and industries such as energy, transportation, tourism and recreation, forestry, agriculture,

construction and finance. This chapter also examines the relationship between climate and regional air issues. These areas do not represent all of Ontario's social or economic sectors, but were selected on the basis of their significance to the social, environmental and economic well-being of the province.

Chapter 5.
A survey of future climate scenarios for Ontario. The chapter examines the impacts and opportunities arising from these scenarios with respect to the same sectors addressed in Chapter 4.

Chapter 6.
A survey of the research and application of adaptive measures in five key areas: water resources, human and ecosystem health, the built environment, industry and regional air issues. The study also reviews Ontario's adaptation capacity with respect to each of these sectors.

Chapter 7.
A summary of the knowledge gaps and research priorities for Ontario in the areas of climate variability and change, impacts and adaptation.

2.0 REGIONAL CONTEXT

Ontario covers approximately 1.1 million km^2 in east-central Canada. The province is bordered principally by the water bodies of the Hudson and James bays to the north, and the St. Lawrence River and Great Lakes to the south.

This chapter describes the physical resources of the three terrestrial ecozones within the province, focusing on their physiography, soils and vegetation. In addition, it explores the evolution of Ontario's resource economy and provides a sketch of its current socio-economic resources.

2.1 Physical Resources

Ontario contains portions of three major terrestrial ecozones (Figure 1): the Boreal Shield, which extends across the province in a broad crescent from the Manitoba border to the upper Ottawa Valley; the Hudson Plains to the north of the Shield; and the Mixedwood Plains to the south (Ecological Stratification Working Group 1995). The Boreal Shield rests on the uplifted broad dome of the Canadian Shield, and the other two ecozones are, for the most part, situated on the surrounding, flatter lowlands known as "Borderlands" (Bostock 1970).

To assess potential impacts of future climate change in Ontario, we must understand the forces that have shaped the present-day physiography of the province. This, in turn, will help us understand how climate might influence and/or be influenced by future land-use changes.

In the past, climate and geological events combined to shape the large-scale topography of Ontario, and climate and topography continue to influence regional and local variations in soils and vegetation. Soils and vegetation are important in the context of climate change because both these ecosystem components store and release carbon and nitrogen, which, in the forms of carbon dioxide, methane and nitrous oxide, are three of the principal greenhouse gases. Thus, by examining the geology, soils and vegetation, we can gain some insight into the potential effects of climate change on the release or sequestering of carbon and nitrogen in vegetation biomass and soil organic matter. These processes could have an impact on climate change scenarios.

The next section outlines the role of glaciation in shaping the landscape of Ontario. This is followed by descriptions of soils and vegetation in the province's three ecozones. Throughout these sections, the influence of physiography on settlement and land-use practices in the province will be shown.

2.1.1 Glaciation

The landscapes of the province have been shaped and reshaped over the past three to four billion years by an array of geological processes, including volcanism, sedimentation, faulting, mountain building, erosion, burial, uplift, weathering and glaciation. Of these processes, the dominating factor controlling present-day physiography of Ontario has been the effect of the Pleistocene Ice Age (Thurston 1991). In four successive cold periods of the Pleistocene, ending 10,000 to 15,000 years ago, vast masses of ice moved across Ontario scraping off much of the unconsolidated material and breaking off pieces of the bedrock itself. These ice sheets then rode over the top of the debris, further crushing and moulding the entrained fragments. The most recent glaciation, known as the Wisconsinan glaciation, left a distinct pattern of surficial deposits and glacial landform features of fundamental importance to the composition and distribution of the province's soils, and the density and diversity of vegetation in Ontario (Clayton et al. 1977; Thurston 1991).

Many of the province's freshwater lakes, including the Great Lakes, were shaped into their present forms by the ice sheets that scoured and carved the bedrock. There are roughly 250,000 freshwater lakes within Ontario's boundaries,

Figure 1. Ecozones of Ontario. (Source: Ecological Stratification Working Group 1995)

representing one-quarter of Canada's freshwater resources. The Great Lakes (Superior, Michigan, Huron, Erie and Ontario) cover 246,000 km^2 and store 20 percent of the world's freshwater supply.

This glacial legacy has influenced land use and human settlement patterns in the province since aboriginal peoples first settled along the numerous rivers and lakes of Northern Ontario and developed agricultural communities on arable lands, especially in Southern Ontario.

2.1.2 The Boreal Shield

Most of Ontario is dominated by the Precambrian or Canadian Shield, which is an uplifted, broad dome of ancient, resistant igneous and metamorphic rocks (granite, granite gneiss, granodiorite and quartz diorite). Once a mountainous area, the crystalline Precambrian bedrock of the Shield was planed down during long periods of erosion (Clayton et al. 1977). The Wisconsinan ice advance further modified the surface topography of the Shield by rounding and levelling rock ridges, scouring out hollows and depositing a shallow layer of stony, sandy till, most of which was carried outside the periphery of the Shield. Extensive areas were completely denuded of soil material, leaving bare and sterile bedrock plains.

The main legacy of the periods of glaciation for the landscape of the Shield, was the disruption of the pre-existing drainage. This left the surface covered with an enormous number of freshwater lakes, occupying basins scooped out by glacial quarrying, moraine-dammed depressions and erratic river systems (Clayton et al. 1977). The Shield influences drainage patterns throughout Ontario because a myriad of river systems flow off the Canadian Shield to the lowlands, draining north and east into Hudson and James bays, or south into the Great Lakes and the St. Lawrence River.

Most of the Shield's landscape is not well-suited for agriculture because the soils are too thin and acidic. There are, however, sizeable tracts of intrazonal soils that have reasonably good agricultural potential. Most of these soils have developed on waterlaid clays and other sediments. As the glaciers melted, fine sediments were laid down to create the plains and clay belts that are important features of the Shield region of Northern Ontario. The Great Clay Belt, centred on the town of Cochrane, spans approximately 50,000 km^2, and the Little Clay Belt, located west of Lake Timiskaming, covers 4,000 km^2. These areas of clay, which contain variable amounts of till and other materials, are characterized by their gentler relief, a general absence of rock outcrops and the presence of good forest and agricultural development. The intervening uplands, with a greater abundance of rock outcropping, shallow soils and variable sediments are mainly mining areas with some forestry and recreation. The problems of poor soil drainage, poor soil structure and high clearing costs are not easily overcome; however, over 1,000 km^2 have been developed for agricultural purposes in the clay belts of Ontario (Warkentin 1968).

Volcanic and intrusive rocks occur throughout the Shield in many areas in Northern Ontario. These deposits have made Northern Ontario one of the most productive mining areas in the world (Reeds 1972).

The boreal forest, which covers most of the Shield, includes more than 40 forest types; however, the dominant species are conifers, especially white and black spruce. Tamarack are found at wet sites, and jack pine and broadleaf species such as aspen, balsam poplar and white birch dominate in fire-swept areas. Balsam fir is also widely distributed. On the southern fringe of the Boreal Shield, the variety of tree species increases. In addition to all the species common to the boreal forest, white and red pine, eastern hemlock, yellow birch and many other deciduous tree species are found.

A great proportion of the Boreal Shield sustains reasonably productive forest cover. Non-productive growth occurs on stony or shallow soils. Production is also low on very dry or rapidly drained jack pine sites associated with coarse-textured Podzols and Brunisols, where forest growth is usually sparse and stunted. Where peat cover is present, growth is frequently limited by excess moisture or prolonged periods with frozen or very cold ground.

In Southern Ontario, the Boreal Shield region is characterized by protruding rock knobs and intermittent pockets of sand, silt and clay. This region covers about one-third of the total area of Southern Ontario and is primarily a recreational and forested area with no large urban settlements (Reeds 1972).

On the whole, the Shield region in Ontario is characterized by shallow soils, rich mineral deposits, extensive forests, sparse agricultural settlement and dispersed urban centres (Reeds 1972).

2.1.3 The Hudson Plains

These lowland plains were formed from the flat to gently dipping Paleozoic sedimentary sequences of limestones, shales and sandstones that originated as marine sediments of marl, clay and sand. Prior to glacial erosion and scouring, these Paleozoic sediments covered much of the Canadian Shield (Clayton et al. 1977).

The Hudson Plains, which slope gently towards James and Hudson bays, are dominated by swamps. The bedrock, which outcrops infrequently, is generally overlaid by a succession of unconsolidated deposits well-displayed on the steep banks of nearly all rivers.

Deep peat, composed of incompletely decomposed organic matter, covers nearly all the land surface. Peat remains frozen under an insulating cover of sphagnum moss so that spring and early summer conditions are very wet. Many forms of bogs and fens occur, and in some parts of the Plains there are pockets characterized by numerous small lakes, which serve as important breeding grounds for Canada geese (Judd and Spiers 1964).

The lignite deposits and peat bogs of the Hudson Plains provide a potential fuel source and fertilizer for horticultural applications (Thurston 1991). However, these deposits currently act as carbon sinks, and disturbing these ecosystems could release substantial amounts of carbon to the atmosphere as carbon dioxide or methane (Gates 1993).

Vegetation patterns along the coasts of Hudson and James bays are transitional between the tundra region to the north and the true boreal forest region to the south. Here, open tundra frequently occupies the interfluvial regions, whereas the main forests are confined to valleys and better-drained ridges.

The tundra areas are characterized by the absence of tall woody species; any tree species present adopts dwarfed forms. Vegetation communities consist chiefly of lichen-moss, which is found under harsh climatic conditions, and grass-sedge, which dominates under less severe conditions. Dwarf shrubs grow in both of these communities.

As weathering is slow in these cold climates, the soils associated with tundra vegetation are shallow and weakly developed (Reeds 1972). Soil drainage is often so poor that profile development is hindered. The problems of soil drainage, low fertility and a completely inadequate growing season mean agricultural development remains minimal.

The forests within this transition zone are mainly unproductive coniferous stands, dominated by stunted black spruce. However, the mixed pattern of open scrub forest and tundra vegetation provides shelter for wildlife habitat and has a limited productivity for woodland grazing.

In contrast to the vegetation farther north, the southern portion of the Hudson Plains is covered by boreal forest, which has a remarkably uniform cover of spruce forest with wide ranging species of plants and animals (Judd and Spiers 1964).

2.1.4 The Mixedwood Plains

South of the Canadian Shield, the impelling geological processes were quite different, resulting in a distinct pattern of landforms and land uses. Glacial erosion and deposition during the Pleistocene Ice Age left a wide range of glacial and glacial lacustrine deposits covering almost the entire Mixedwood Plains (Clayton et al. 1977).

During the retreat of the Wisconsinan glacier, extensive lowland areas were submerged beneath glacial lakes for a time. These areas are now clay or sand plains. Sand plains are found around Lake Erie, west of Lake Simcoe and in Eastern Ontario. Clay plains, which have flattish relief and predominantly heavy-textured soils, occur in the Toronto region, in the Niagara Peninsula and in Southwestern Ontario (Reeds 1972).

Limestone plains, from which much of the unconsolidated overburden was removed and where shallow and excessively stony soils have developed, flank the Shield in Eastern and Central Ontario. Till plains, characterized by drumlin fields and eskers, vary in relief from gently undulating to strongly rolling, and occupy extensive areas in western and central portions of Southern Ontario. The morainic regions have hummocky surfaces, uneven slopes and materials ranging from stony tills to sands and gravels. Bogs and marshes occupy old lagoons along former shorelines, parts of spillways or depressional areas in the moraine systems.

Possibly the most striking topographic feature in Ontario is the Niagara Escarpment, which extends from Niagara Falls to the northern tip of Bruce Peninsula and Manitoulin Island. The escarpment was formed from differential erosion of the hard, Silurian dolomite and the softer, underlying shales. Fossils found throughout the various strata provide a record of climate and life in prehistoric times; the valleys carved by ancient rivers and modified by glacial erosion provide some clues to understanding the region's geological past (Thurston 1991).

Except in a few well-known marginal areas, the deep overburden found in the Mixedwood Plains stands in striking contrast to the scanty, discontinuous, sandy mantle on the harder rocks of the Boreal Shield. The depth of the overburden, the gentle slopes and the high content of limestone and clay are responsible for the development of some highly productive and durable soils in Southern Ontario. In contrast to the land-use patterns of the Shield-dominated regions of Northern Ontario, the Mixedwood Plains are characterized by intensive agriculture, greater density of transportation facilities and a concentration of manufacturing and urbanization (Reeds 1972).

In the southern portion of the Mixedwood Plains, there exists a unique forest region containing a number of species of deciduous trees that are not found anywhere else in Canada (Judd and Spiers 1964). The deciduous forest of Southern Ontario is often referred to as a beech-maple forest; however, this area contains several other species of equal importance. The dominant trees are sugar maple, beech, white elm, basswood and red and white oak. Most southern species, including sassafras, black walnut, the tulip tree and the pawpaw reach their northern limit in this forest region, and thereby distinguish it from other deciduous or mixed forests in Ontario. Unlike the vegetation patterns in the remainder of the Mixedwood Plains, few conifers are found in the deciduous forest.

As a result of extensive cultivation, settlement and industrialization, very little natural deciduous forest remains today, and the relationship of the present vegetation to the original is largely inferential (Judd and Spiers 1964). Most of the historical deciduous forest area is populated, and the forest vegetation has been largely reduced to farm wood lots, hedge rows and remnant stands on non-arable soils. Both natural and cultured vegetation have been further modified by the rapid encroachment of urban and industrial development into rural areas (Clayton et al. 1977). For a detailed overview of the patterns of human settlement and their impact on the province's natural resources, readers are referred to Gentilcore (1972).

The remainder of the Mixedwood Plains contains a wide variety of tree species, including many of those found in the Boreal Shield, and a number of other deciduous species. The drier sites are dominated by eastern white cedar, red maple and elms. Black spruce and tamarack are found in the moist and wet sites, which are similar to cooler boreal conditions. Growth on organic and some of the colder peaty soils is largely unproductive, but under milder temperature regimes, these soils can support reasonably productive growth.

The clearing of forest lands for agricultural purposes, together with past and present forestry operations, has diminished and modified the forest resources in this area. A number of forest reserves have been established to protect these resources, as well as to accommodate the increasing demands of recreation and development.

In summary, Ontario's landscape has been shaped by an array of geological processes spanning more than three billion years. However, humanity now acts as the strongest physiographic control. In the past 150 years, humans have tunnelled into and tilled this province's soils, modified the vegetation patterns and constructed highways, pipelines, railways, water dams and urban environments that have significantly changed the face of the Ontario landscape.

2.2 Socio-economic Resources

Ontario has a diverse modern economy, with strong manufacturing, resource, financial and service sectors. The early development and expansion of this economy were, however, heavily dependent on the resource sector. In the first half of the 19th century, agriculture and forestry were the sustaining industries in the region and helped fuel the emergence of the manufacturing and service sectors. The scope and success of these resource industries were largely dependent on the underlying geography, the quality and distribution of soils, and the climatic controls within the region.

2.2.1 The Evolution of Ontario's Resource Economy

The 19th century saw the transformation of what we know as Southern Ontario from forest to predominantly grassland and farmland. The relatively flat land and productive soils, coupled with the long growing season and adequate rainfall, combined to produce the most favourable conditions for agricultural production in British North America. By the mid-19th century, Upper Canada (roughly corresponding to the Ontario portion of the Great Lakes Basin) had emerged as the major exporter of agricultural produce for the colonies (Gentilcore 1990). Spurred by the expansion of commercial agriculture, urbanization in the area proceeded faster than in any other part of the colonies. The rapidly growing population base in the region increased the demand for a whole range of goods and services.

The latter half of the 19th century was a period of transition for the Ontario economy. The relative importance of resource harvesting gradually declined, and manufacturing and service industries emerged. Despite this trend, as late as 1890, agriculture was still the dominant sector of the Ontario economy, accounting for 30 percent of the province's production. That same year forestry operations accounted for 7 percent of production, half of its 1850 total. However, the influence of this sector extended beyond timber harvesting. If the contribution of related forest products such as square timbers, boards and firewood were included, the output of the forestry sector would be double. At that time, the growing manufacturing and service sectors accounted for 25 and 15 percent of provincial production respectively (Head 1990).

Although the Ontario economy had undergone some significant adjustments in the late 1800s, the pace of change, if anything, accelerated in the new century. Tremendous advances in technology led to improved methods of resource extraction and new end-uses for those resources. For example, innovative techniques were introduced to efficiently extract base metals from complex ores. The development of a process to produce newsprint from spruce pulp opened the door to an immense market. Another major element of Ontario's economic growth was the development of urban-based manufacturing, stemming, in part, from the establishment of branch-plants of United States companies in Southern Ontario (MacInnis et al. 1990).

The 20th century also marked the emergence of new sectors of the economy. Growth in consumer spending fuelled an expansion of the retail sector. In addition, the development of a more mature and robust economy led to an increase in the size and influence of the Canadian financial services sector, which was concentrated in Toronto and Montreal. The post-Second World War population boom, coupled with a new conception of the role of government, contributed to a substantial growth in public sector employment, including jobs in health and welfare, education and the three levels of government.

The concentration of manufacturing in the urban centres of Southern Ontario was perhaps the main impetus behind the urbanization of the province. This clustering put a tremendous strain on the existing transportation infrastructure. The manufacturing industries consumed considerable materials and resources and needed a reliable system to ensure their delivery. The expanding and increasingly wealthy urban population boosted the demand for consumer goods. These stresses necessitated the expansion of the existing distribution system into a diverse and integrated transportation network.

The Ontario landscape, economy and society have been completely transformed over the last 150 years. In 1850, the population was largely rural, with most people working in agriculture or other forms of resource harvesting. By the 1960s, the population was largely urban, working primarily in the manufacturing and service sectors. These trends were not unique to Ontario. Across Canada the proportion of urban dwellers rose from 23 percent in 1871 to 50 percent in 1921 and 70 percent in 1961 (MacInnis et al. 1990).

2.2.2 Current Socio-economic Resources

Although Southern Ontario makes up only 10 percent of the province by area, it is home to 90 percent of the population (OMEE 1992e). Most of Ontario's 11.4 million people (Canadian Sourcebook, 1998) live and work in the province's cities and towns, where economic activity has steadily intensified since the Second World War. Over 60 percent of Ontario's residents live in municipalities with populations greater than 50,000.

Today Ontario has a strong and diverse economy. In 1994, the province's real gross domestic product (GDP–the value of production of goods and services in the economy) stood at $237 billion (1986$). This accounted for approximately 40 percent of Canada's total production. During the period from 1984 to 1994, the province's GDP increased by 37 percent. The magnitude of this increase is impressive, given that it includes the period from 1990 to 1993 during which the Canadian economy was mired in a deep recession.

The value of goods and services produced by the major sectors of the Ontario economy in 1994 is summarized in Table 1 (Ontario Ministry of Finance 1996). The manufacturing, service and financial sectors now account for more than 50 percent of the province's GDP. The contribution of the primary or resource industries, including agriculture, has declined to less than 3 percent. Despite their diminished economic position, these industries still play a significant role since their products are used as feed stock for many manufacturing and service enterprises.

In 1994, primary agriculture (value produced directly by farmers) contributed $2.8 billion to the total provincial GDP. This resulted in provincial farm cash receipts (gross farm income before expenses) of $6 billion, which constituted one-quarter of the Canadian total of $25.6 billion. Cash crops accounted for $2.5 billion in receipts, with $3.5 billion generated by livestock and other foodstuffs (OMAFRA 1994). The dairy industry, at 19 percent, produced the greatest share of farm cash receipts followed by cattle (16 percent), fruits and vegetables (10 percent) and hogs (9 percent).

The agriculture and agri-food system (i.e. suppliers, transporters, grocers and restaurants) contributed about $22 billion to the provincial GDP in 1994. This system is so extensive that about one in five Ontarians is employed in farming or related industries. The agriculture and food system is the second largest employer in Ontario, trailing only the automotive industry (OMEE 1992a).

The absorption of rich agricultural lands by ever-expanding urban centres in Southern Ontario is cause for growing concern. More than 450,000 hectares of farmland were lost to non-farm uses such as housing, roads, and shopping and industrial malls between 1981 and 1991. This constituted a net decline of 9.1 percent. The pressure to convert farmland to urban use is most intense in the Greater Toronto Area, from which about 5,000 hectares of farmland vanish each year (Thorp et al. 1996).

In 1989, the last year for which figures are available, Ontario had 80.7 million hectares (ha) in forest land. That included 38.3 million ha of

Table 1: Real Gross Domestic Product in Ontario, by Industry, in 1994

Economic Sectors	Real GDP (billions of 1986 $)	Percentage of Provincial Totals
Primary Industries Including Agriculture	5.3	2.2%
Manufacturing	51.1	21.5%
Construction	9.2	3.9%
Utilities	5.4	2.3%
Transportation, Storage and Communications	14.9	6.3%
Trade	26.5	11.2%
Financial, Insurance and Real Estate	32.6	13.7%
Community, Business and Personal Services	48.0	20.2%
Government Services	12.3	5.2%
Miscellaneous Industries	1.3	0.5%
Indirect Taxes Less Subsidies Plus Adjustments	31.1	13.1%
Gross Domestic Product (1986$) at Market Prices	**237.8**	**100.0%**

(Source: Ontario Ministry of Finance 1996)

productive forest land (available for cutting and growing) and 1.7 million ha in reserve forest land (set aside for conservation). The total volume of wood (growing stock) in Ontario was estimated to be 5.1 billion cubic metres (OMEE 1992c). That same year, the Ontario forest industry employed about 84,000 people directly and another 85,000 in related industries. The total value of its exports topped $3.9 billion, consisting primarily of newsprint (37 percent), wood pulp (24 percent), and other paper and paperboard products (21 percent). The United States accounted for 95 percent of these exports (Forestry Canada 1991).

The province of Ontario leads the country in terms of value-added production per cubic metre of wood consumed. The value of shipments per cubic metre of roundwood production in Ontario in 1988 was $409, compared to $193 in British Columbia, $337 in Quebec and $292 in New Brunswick (OMEE 1992c). However, since Ontario still exports a high percentage of commodity products (1.2 million tonnes of pulp annually), current development efforts are focusing on conversion to higher value items, thereby creating more opportunities for employment, suppliers and technology development.

The province's forests and wild spaces are the primary resource of the expanding wildlife industry, which includes activities such as wilderness camping, hunting, fishing, hiking and birding. Expenditures on wildlife activities by Ontario residents alone contribute more than $2.2 billion annually to the Ontario's GDP and sustain more than 62,000 jobs (Filion et al. 1987). In 1991, more than seven million Ontario residents aged 15 and older participated in some way in wildlife activities.

The fast-growing wildlife sector is proving to be a strong complement to Ontario's well-established tourism and recreation industry. Ontario's varied landscape, wide range of entertainment and attractions, and its proximity to United States population centres have combined to make it the destination for 50 percent of visitors to Canada. The tourism and recreation industry contributed $12.2 billion to Ontario's GDP in 1994 and employed 370,000 people (Ontario Ministry of Economic Development, Tourism and Trade 1995). One of the principal contributors to the success of this industry has been the recreational fishing on the Great Lakes, with an estimated total value of $3.4 billion per year (Fisheries and Oceans Canada 1994).

Ontario has also benefited from numerous rich mineral deposits spread across both northeastern and northwestern Ontario. In 1995, Ontario was responsible for $5.8 billion in mineral production (including metals, industrial minerals and mineral fuels), representing 13.5 percent of the national total. The sector employed 21,000 workers in mining, oil wells and quarrying (Ontario Ministry of Finance 1996).

Another by-product of the economic growth and urbanization of Ontario was the expansion of the construction industry. In 1994, the industry contributed $9.2 billion to the provincial GDP and employed 149,000 people. Construction activity peaked at $12.8 billion in 1989 but was significantly curtailed by the deep recession in the early 1990s. Annual production remained below $10 billion from 1993 through 1995.

The transportation industry (transportation by air, rail, water and truck, and storage) contributed $7 billion to Ontario's GDP in 1994, creating 142,500 jobs. Trucks and railways haul about two-thirds of the total tonnage of goods shipped between Ontario's cities and towns. There are 145 Canadian and U.S. ports on the Great Lakes and St. Lawrence system, which, since the early 1990s, have handled some 175 million tonnes of cargo. Shipping on both sides of the border has helped to generate approximately 60,000 jobs and add more than $3 billion to the two economies (Allardice and Thorp 1995).

3.0 ONTARIO'S CLIMATIC CONDITIONS

Much of the material in this chapter is drawn from Phillips (1990).

3.1 Climate and Weather

Although Ontario's weather is variable, its climate is more typically predictable. Weather describes the day-to-day and hour-by-hour changes in atmospheric conditions at any location, whereas climate synthesizes these day-to-day variations into a set of average or expected conditions. However, the climate at a site is more than a set of average values of weather elements such as temperature, precipitation or cloud cover. Climate is also defined by the variability of these individual weather elements and by the frequency with which various weather conditions occur. Traditionally, climate has been thought of as the history of weather. By assuming that climatic conditions prevailing in the recent past would continue to do so in the future, traditional practice has been to use statistics based on the past weather as a basis for planning future socio-economic activities and structures (WMO 1995). Today, the understanding of climate as the history of weather has expanded to incorporate the future expectation of weather, in the order of months, years or decades ahead. Understanding climate implies having information or estimates on the past, present and future conditions and their variability.

3.2 Ontario's Climatic Regimes

Even though Ontario's weather conditions can change from stormy to settled in a matter of days, its climate generally remains consistent from year-to-year. Although wet, dry, hot and cold spells occur, they usually do not persist as long as in other parts of Canada. Precipitation tends to be relatively predictable and consistent from season-to-season and year-to-year, distinguishing the climate of central and Southern Ontario from that of other parts of Canada (Phillips 1990). The exception to this changeable weather pattern occurs in the northern parts of the province where shallow, cold and dry Arctic air can predominate during the winter.

The climate of Ontario is marked by four distinct seasons. Summers are warm with occasional showers and thunderstorms, often becoming hot, hazy, humid and uncomfortable in the south. Autumn brings cloud and showers mixed with warm, sunny days and cool, crisp nights. Winters are harsh in the north and can result in a variety of precipitation forms over Central and Southern Ontario. Spring is normally the shortest season of the year, with day-to-day temperatures fluctuating considerably.

Ontario can be divided into three major terrestrial ecozones, as shown in Figure 1 and discussed in Chapter 2. These three ecozones are the Hudson Plains, the Boreal Shield and the Mixedwood Plains. Each zone experiences different subclimates. The Hudson Plains near Hudson and James bays and much of the Boreal Shield region north of the Great Lakes experience a continental climate similar to that of the neighbouring Prairies. Except for areas near lakes Superior and Huron, precipitation is low in winter and relatively high in summer. There is an enormous temperature range between the cold winters and warm summers, although readings are slightly more moderate in areas around the Great Lakes. Spring is a well-defined season, usually arriving by early May. The summers are warm and changeable with occasional showers and thunderstorms brought about by the regular passage of weather disturbances. These summer showers and thunderstorms produce much of the annual precipitation. Autumn arrives by early September and is characterized by more intense weather disturbances followed by outbreaks of Arctic air that lingers over the area for progressively longer periods.

The southeastern Boreal Shield, including areas to the north and east of Georgian Bay, experiences similar temperatures to the rest of the

Shield but with precipitation amounts more evenly distributed throughout the seasons. Near the upper Ottawa Valley, temperatures become more moderate in all seasons. Locations closer to the shores of the Great Lakes experience warmer winters with more abundant snow than comparable inland locations.

Southern Ontario, which includes the Mixedwood Plains, experiences less severe winters and the least spread between summer and winter temperatures. Much of the milder climate can be attributed to the moderating presence of the Great Lakes and the more southerly latitude of the area.

3.3 Shaping the Climate

The climate of any area is determined by the energy from the sun and the way that land masses, water bodies, and the atmosphere redistribute this energy. The unequal heating of the globe combined with the earth's rotation directs large-scale movements of weather systems. On a regional scale, the movements of weather systems and the climate they generate are influenced by the distribution of land and water, the presence of mountain ranges in the area and large water bodies like the Great Lakes and Hudson Bay. On the local scale, the character of the weather and climate is determined by influences such as local topography (hills and valleys, small water bodies) and ground cover (e.g. rural, urban, mixed, as well as type of vegetative cover). The earth's climate system is extremely complex and an important change in any one of these influences can bring about a change in climate.

Since much of Ontario lies in the path of several major storm tracks, high and low pressure systems frequently cross the area, causing regular alternation between settled and stormy weather on an almost daily basis. The settled weather is normally associated with high pressure systems that bring extensive masses of air (air masses) from such diverse sources as the Gulf of Mexico, the Arctic, and the Pacific and Atlantic Oceans. Shallow, cold and dry Arctic air tends to predominate over the north during the winter, although Southern Ontario can also receive its share of cold winter days while under the influence of Arctic air. Tropical air masses, usually from the Gulf of Mexico, enter the south in summer bringing high temperature and humidity conditions, afternoon or overnight thunderstorms and higher pollution concentrations. Tropical air is present over the Great Lakes about 30 percent of the time in summer but less than 10 percent of the time north of Lake Superior (Phillips 1990). The tropical air only rarely makes it to Southern Ontario in winter. Atlantic air brings moderate temperatures and typically cloudy skies whereas Pacific air tends to bring a mix of conditions ranging from moist and cool to sunny and mild.

A physical land feature that has a profound influence on Ontario's climate is the Appalachian Mountain range located outside the province, on the eastern rim of the Great Lakes Basin. The Appalachians tend to direct the brunt of storms moving along the Atlantic Coast away from Ontario. In rare cases, tropical storms have been able to push westwards over the Appalachians and redevelop in Ontario, bringing heavy precipitation. In 1954, Ontario's most memorable rainstorm, Hurricane Hazel, crossed the Appalachians and merged with another weather system over Southern Ontario, causing 80 deaths and over $130 million (1990 dollars) in storm and flood-related damages.

Ontario's location near the centre of North America would normally give it a continental type of climate similar to that of the Prairies. Instead, the Great Lakes moderate the climates of Southern and Central Ontario, leaving these areas with a hybrid mix of continental and maritime regimes. The result is a less extreme temperature regime than in the Prairies but with greater precipitation amounts than would be expected in a continental climate (Phillips 1990).

The influence of the Great Lakes goes beyond just moderating temperatures. Under some circumstances, the lakes also intensify storms, increase humidities and fog incidence, enlarge cloud cover in autumn and winter, accelerate wind speeds and create lake and sea breezes. In winter, moisture is readily picked up by the prevailing winds as they pass over the relatively warmer lakes. Some of this moisture is returned as "lake-effect snow" downwind of the lakes; this results in significantly greater snow amounts being deposited in "snowbelt" areas on the downwind shores. Since the lakes heat up and cool down far slower than the land does, winter temperatures near their shores are relatively warmer and spring temperatures are cooler than farther inland. In spring, passing moisture tends to condense above the cooler lakes, giving rise to shallow fog. The lakes also extend the growing season by delaying the arrival of autumn frosts. In Southern Ontario, the lakes have played a major role in the establishment of flourishing fruit-growing and wine industries by suppressing springtime maximum temperatures, delaying the leafing and blossoming of plants, and protecting tender plants such as fruit trees and vines from autumn frosts. This extended state of spring dormancy allows plants from somewhat warmer climates to survive in the shadow of the lakes.

Topography has a significant influence on local and regional climates. In Southern Ontario, two upland regions with elevations above 400 metres–the Dundalk Highlands and the slopes of the Boreal Shield in Algonquin Park–are considerably cooler and receive more snowfall than the surrounding lower lowlands. The Niagara Escarpment in Southern Ontario also exerts its influence on local climatic conditions. In winter, the effect of the Escarpment causes increased snowfall in the immediate vicinity from lake-effect snowstorms. The Escarpment's effect also has the power year-round to dissipate clouds and precipitation; both lessen and increase winds depending on wind direction; and warm the air masses that sink on the downwind side of the escarpment to the east (Phillips 1990).

Local influences that shape the climates of Ontario include urbanization, elevation, proximity to water bodies and local topographical features such as valleys. Under some weather conditions, particularly in winter, local urban areas can exert a significant warming influence on temperatures.The magnitude of the temperature difference between urban and surrounding rural areas generally depends upon the population of the urban area. At times, the urban effect can keep the core of Canadian cities some 2°C to 3°C warmer in midwinter than the surrounding rural areas. These differences can occasionally exceed 8°C.

3.4 Climatic Elements

The climate of a location consists of a large number of weather components or elements. Temperature and precipitation are the most commonly observed of these elements. Wind speed and direction, humidity, bright sunshine, cloud amount and type, visibility, evaporation, lightning, air pressure and soil moisture are also climate elements that significantly influence the built and natural environments at a location. This section describes some of the more common climatic elements of temperature, growing season and precipitation, including extreme precipitation events.

3.4.1 Temperature

Winter temperatures vary more year-to-year and day-to-day than summer temperatures. In winter, daily temperatures that are several degrees higher or lower than normal or average values are fairly common, as are large temperature differences or ranges between the daily minimum and maximum temperatures.

Winter Temperatures

Generally, winter temperatures are most severe in the northern parts of Ontario, away from the moderating influence of the Great Lakes. In those areas, winters can be bitter, with mean minimum January temperatures ranging from -21°C to -24°C becoming colder in the far northwest near Hudson Bay. Winter temperatures are slightly milder in the Lake of the Woods area, with average January minimum temperatures around -19°C. Locations on the north shore of Lake Superior have average temperatures in December to February some 1°C to 4°C above those of areas farther inland. Hudson and James bays, on the other hand, freeze over early in the winter season, nullifying any moderating influence that these water bodies could have on the cold arctic air. As a result, temperatures in that area are similar to those in the northern Prairies, with the lowest recorded temperatures measuring -50°C and colder.

Along the north shore of Lake Erie and in the Niagara Peninsula, mean daily minimum temperatures in January average -8°C to -11°C. Along the shores of Lake Erie, temperatures only occasionally dip below -25°C, and rarely reach these low values in the Niagara Peninsula (an important factor for fruit-growing). Farther east, along the shores of Lake Ontario, January minimum temperatures are colder, averaging from -9°C along western shores to -13°C in the east. Extreme minimum temperatures just north of the eastern section of Lake Ontario can drop to -35°C or colder. January minimum temperatures are colder north and away from the lower Great Lakes, with average values ranging from around -14°C in the Dundalk Highlands to -16°C in the Ottawa area. Average minimum January temperatures over parts of Algonquin Park drop as low as -21°C. Winter cold periods in Southern Ontario seldom last more than 10 days. The regular west to east progression of weather systems ensures that prolonged periods of hot or cold are infrequent.

Summer Temperatures

The influence of the Great Lakes is less marked in summer than in winter, since average daily summer temperatures on land are closer to the surface water temperatures. Surface lake temperatures are coolest near the shores of Lake Superior, averaging 8°C to 14°C in July and August, and highest near the shores of the more shallow Lake Erie, reaching 20°C to 23°C. Summertime afternoon temperatures decrease towards the north. In the far north, summer is brief, with July afternoon temperatures averaging from 18°C along Hudson Bay to 22°C along the shores of James Bay. The extreme southwestern portions of the province, which include the Windsor–Leamington area, are the warmest, with midsummer afternoon temperatures averaging 27°C or higher. Monthly summer temperatures here are among the highest in Canada, often matching those in the Okanagan Valley in the interior of British Columbia. In between the shores of Hudson Bay and Southwestern Ontario, average summertime maximum temperatures range from 23°C to 26°C. Along the northeastern shore of Lake Superior, considerably cooler summertime temperatures prevail, with daytime maximum temperatures barely reaching 16°C to 20°C on half the days of July and August. During the same period, a short distance inland, temperatures are 23°C or higher, similar to those farther south.

It is not unusual for parts of the province to have hot weather in summer, with maximum temperatures exceeding 32°C. Severe heat waves occasionally afflict Ontario, and summertime temperatures have exceeded 36°C at nearly all Ontario locations. The highest temperature ever recorded in Ontario, 42.2°C, occurred in Fort Frances in July 1936. A few days earlier, the maximum temperature in Toronto reached an extreme high of 40.6°C, which was matched for two days. The 1936 heat wave, which affected a large area of Canada from Alberta to the Ontario-Quebec border, was one of the most intense in Canadian history. More than 450 deaths in Ontario, almost half of them in Toronto, were attributed directly or indirectly to the high temperatures. Most hot spells across the province are short-lived, lasting days not weeks. A notable exception occurred in the summer of 1953, when the longest recorded heat wave struck Southern Ontario from late August to early September, leading to several heat fatalities. At that time, the waters of Lake Erie warmed to such a degree that millions of fish died from lack of oxygen.

On average, Southwestern Ontario experiences the highest frequency of hot, humid weather in Canada. A temperature-equivalent index, the humidex, is used to quantify the role of humidity in human discomfort on very warm summer days. The higher the humidex, the greater the discomfort. A humidex reading of 30 will cause discomfort for some people, and a reading of 40 will cause discomfort for most people. The greatest frequency of hot, humid days occurs in the Windsor area, where the mean humidex during the last week of July is 32. Extreme values of above 45, when many types of activity must be restricted, have occurred at several locations in Southwestern Ontario. Humidex values generally decrease with increasing latitude. A study by Lewis (1993), which incorporated a discomfort-based definition of heat waves, found that seven such heat waves had occurred in North Bay from 1953 to 1989 compared to 42 in Toronto. While heat waves, as defined by the study, may be expected on average only once in five years in central parts of the province, they tend to occur at least once each summer in southern parts of the province.

The transition seasons, spring and autumn, can be the most pleasant seasons of the year, with their daytime warmth and nighttime coolness. These seasons are, however, short-lived. Freezing temperatures can usually be expected in the south in late September or early October. Usually, the first freezing temperatures of autumn are followed briefly by "Indian Summer" weather–that welcome spell of sunny, warm and often hazy days and frosty nights that occur each autumn in eastern North America (Phillips 1990).

3.4.2 Growing Season

The length of the growing season is calculated as the mean annual number of days between the last frost (0°C) of spring and the first frost of autumn, as measured at a height of 1.5 metres above the ground. Normally, the last frost in Southwestern Ontario and along the shores of Lake Ontario occurs around the first week of May; the first autumn frost occurs during the first half of October, leaving a frost-free period of 140 to 180 days per year. Locations near the western shore of Lake Erie experience a growing season of 180 days or more, which is longer than any other place in Canada except along the Pacific Coast. The downtown Toronto core also experiences an equally long growing season due to its proximity to Lake Ontario and its urban heating influence. Locations along the St. Lawrence River and in the Dundalk Highlands to the south of Georgian Bay have a shorter growing season, averaging 130 to 170 days. Sites in Algonquin Park and those north of Lake Superior and Lake Huron have a frost-free season lasting, on average, 100 to 120 days. In Northern Ontario, the frost-free period lasts from 60 to 100 days. The last spring frost in the north typically occurs in late June in the far north and in late May around Sault Ste. Marie; the first frost of autumn usually appears by late August in the northernmost areas and during the last half of September near Sault Ste. Marie. Frost seasons can vary considerably over short distances because of topography, lake effects, vegetation or other land surface cover and soil type.

3.4.3 Precipitation

Precipitation provides few surprises across Southern and East-Central Ontario. Generally speaking, precipitation extremes are minimal, and wet and dry spells are rare. In short, rain and snow in Ontario are as predictable as can be in a temperate continental climate. Except in Northern Ontario, precipitation is fairly uniformly distributed throughout the year. The more vigorous and frequent storms of winter produce the same precipitation as the less well-organized low pressure systems and thunderstorms in the warmer and moister months of summer. Over Northern Ontario, with its more continental climate, about one-half of annual precipitation falls in summer. The amounts of precipitation that fall at a site are affected by prevailing winds, elevation, slope of land and location relative to the Great Lakes. The greatest amounts fall on highlands downwind of the lakes.

The south is wetter than the north. Annual precipitation totals range from less than 600 mm in far Northwestern Ontario to 800 to 1,100 mm in areas south of and near the upper Great Lakes. Total amounts exceed 1,000 mm on the eastern flanks of Lake Superior, Lake Huron and Georgian Bay. The driest areas in Southern Ontario are found in the rain-shadows of the highlands, including the eastern half of Algonquin Park and the Lake Simcoe–Toronto corridor east of the Dundalk Highlands, where precipitation totals are less than 850 mm. Relatively drier conditions are also found in the fruit-rich area of Essex County in the extreme southwest. Compared with the rest of Canada, annual precipitation amounts for all but the far northwestern part of the province are greater than the amounts observed over the Prairies but less than those prevailing over Southern Quebec and the two coasts.

The average number of days with measurable precipitation, including rain, snow, hail and sleet, ranges from 130 days in the rain-shadow areas of Southern Ontario to 180 days or more in the northeast part of the province around Kapuskasing and in areas to the lee of the Great Lakes.

In the most ideal scenario, annual precipitation amounts should be reliable, should be well-distributed over the year and should supply an adequate amount of water without detracting from comfort and recreation. On occasion in Ontario, flooding hazards can result from too much rainfall falling in a short period of time, snowmelt, ice jams and wind-driven water. Slow-moving low pressure systems and hurricanes, such as the remains of Hurricane Hazel from 1954, can produce long periods of continuous heavy rain sufficient for flooding. On July 19 and 20, 1989, a nearly stationary low pressure area triggered slow-moving thunderstorms over parts of Southwestern Ontario (Essex County) that dropped 260 to 400 mm of rainfall over a 20-hour period and resulted in widespread flooding, a train derailment, and significant disruptions to transportation, water supplies, electricity and telephone service. This event represented the largest one-day rainfall ever recorded at any weather station in Canada east of the British Columbia Coast Mountains. Flash floods can occur when an intense thunderstorm drops a deluge on a fairly small area in a short period of time. Urban areas with their more impervious surfaces are especially vulnerable to flash floods. On July 10 and 11, 1883, for example, an intense downpour brought a flash flood "wall of water" along the Thames River to London, carrying away buildings and drowning some 18 people. Flooding of the same river in 1937 left 4000 people homeless. On August 31 and September 1, 1961, thunderstorms over Timmins dropped some 90 mm of rainfall over a 12-hour period, leading to extensive flood damage, drowning five people and destroying roads and houses.

Across most of Southern and Central Ontario, thunderstorms normally occur on 25 days per year but the frequency inreases to as many as 35 days per year in Southwestern Ontario. Indeed, the London–Windsor area experiences more thunderstorms per year than most other areas in Canada. The frequency of thunderstorms drops off rapidly in the north to five days per year or fewer along the shores of Hudson Bay. Occasionally, hail can accompany severe thunder-storms and can cause heavy damage to fruit and garden crops, greenhouses and vehicles. On May 30, 1985, for example, hailstones as big as golf balls inflicted some $30 to $40 million of damages in the Leamington–Windsor area, smashing greenhouses and flattening early crops. As a result of this storm, many farmers subsequently had difficulty obtaining insurance coverage for crops and greenhouse structures. The worst of the thunderstorms may, on occasion, be accompanied by tornadoes.

Tornadoes are one of the smallest of all storms in terms of land area affected; but they are among the most severe and disastrous. The highest tornado frequency and greatest risk for tornado damage in Canada is in extreme Southwestern Ontario away from the shores of the Great Lakes. In the past, about one-third of all tornadoes reported in Canada have occurred in Ontario. Current statistics indicate that up to two tornadoes per 10,000 km^2 can be expected per year in Southwestern Ontario, decreasing to less than one per 10,000 km^2 north of Georgian Bay and Lake Huron (Newark 1983). In general, tornadoes occur less frequently near the shores of the Great Lakes, in the north and along the lower St. Lawrence River.

Ontario's snowbelts are legendary. On the upland slopes facing Lakes Huron and Superior and Georgian Bay, huge snowfalls in the 300 to 400 cm range fall each winter from November to late March. The uplands on the northeastern shores of Lake Superior receive the greatest total snowfall amounts of any area in Ontario (exceeding 400 cm annually). Much of the snowfall in snowbelt areas can be attributed to cold northwesterly to westerly winds blowing off the lakes and ascending the highlands. As the cold arctic air travels across the relatively warmer Great Lakes, it is warmed and moistened. Bands of snow form over the lakes and, once onshore, intensify as the air is then forced to ascend the highlands to the lee of the lakes, triggering heavy snowfalls. Areas on the downslope side of the higher ground to the lee of the lakes receive less than half the annual snow totals of the upslope snowbelt areas. For example, Toronto, Hamilton and other places to the lee of the Niagara Escarpment are snow-shadow regions with winter amounts of 100 to 140 cm. In the snowbelt regions, snowfall accounts for about 32 percent of the year's total precipitation; but in the snow-sparse area of Southwestern Ontario around Windsor and Chatham, the snow contribution is only about 13 percent.

The snowbelts of Southern Ontario have more than 75 snow days per year. Snow days are defined as days with measurable snowfall. In the north, from Lake Superior northeastwards to the shore of Hudson Bay, there are between 75 and 100 snow days per year. On the north shore of Lake Ontario, more than 40 snow days can be expected per year; in the Ottawa Valley, 50 per year; and at Point Pelee in the southwest, fewer than 20 per year.

Areas with the deepest snow cover are normally those with relatively higher snowfalls and temperatures that remain fairly consistently at or below zero. The deepest snow cover in Ontario, exceeding 100 cm, can be found along the northeast shores of Lake Superior. Heavy snow cover, with depths averaging 70 to 90 cm, can also be found in the area from Lake Nipigon extending eastwards through Kapuskasing. The deepest snow in both areas is usually reached in February or early March, with average maximum depths varying considerably from year-to-year. Snow cover in the south tends to be even more variable from year-to-year. Although snow can cover the ground from late December to early March, it often tends to melt completely at least once during this period. Measurements indicate that yearly maximum depths in the southwest away from the snowbelt areas average 15 to 50 cm, with the least snow cover along the shores of western Lake Erie. Snow cover is deeper and more consistent in South-eastern Ontario from Peterborough eastwards, with annual maximum depths averaging 25 to 50 cm. In snowbelt areas south and east of Lake Huron (including the western slopes of Algonquin Park), snow cover depths average 40 to 70 cm or more.

The winter storms that affect Ontario are usually more vigorous and affect larger areas than those of summer. Typically, intense winter storms that affect the central and southern parts of the province are accompanied by cold temperatures, ice or glaze, and heavy snow. One or two significant blizzards strike the province each winter, impeding traffic and forcing numerous delays and cancellations. These storms can cause severe icing, which also creates extremely hazardous travelling conditions and can cause considerable damage to trees, power lines and telecommunications structures, particularly when accompanied by strong winds. Freezing precipitation occurs on 10 to 15 days per winter in most parts of the province (but fewer in the far north). The exception is the Ottawa Valley area, especially northern sections, where freezing precipitation occurs, on average, on about 20 days per winter. Blowing snow causes another hazard to the travelling public and can be expected on 10 to 20 days per winter. The worst and most frequently occurring blowing snow conditions are found in areas to the lee of the Great Lakes (Phillips 1990).

3.5 Climate Trends and Variability

Just as the weather can change from day-to-day, the climate can change gradually over periods ranging from years to decades. Climate is naturally variable, but over longer time and distance scales than weather. Historically, Ontario has experienced both warmer and colder climates than it has now. In recent centuries, evidence indicates that Ontario's climate cooled for a significant period from between 1250 and 1400 through to the late 1800s (Little Ice Age). The 20th century has seen a warming across much of Canada from the 1890s to the 1940s, a cooling from the 1940s to the 1970s and a warming from the late 1970s to the early 1990s.

Across much of Ontario, mean annual temperatures have warmed by 0.5°C to 0.6°C since the 1900s, although the changes may not be statistically significant in the north. Figure 2 illustrates temperature trends for the Great Lakes Basin-St. Lawrence Lowlands climatic region, which includes Southern Ontario and Southwestern Quebec. The figure displays by year, for the period

1985 to 1997, the average annual annual temperature departures or differences from the 1951–80 average temperature values. The warming has occurred mainly during the winter and spring seasons, which is broadly consistent with land-based temperature trends for the northern hemisphere. Nighttime temperatures have warmed more than daytime temperatures. Daytime maximum temperatures have warmed by only 0.1°C to 0.2°C for the period, whereas nighttime minimum temperatures have shown a statistically significant warming (at the 95 percent confidence level) of around 1°C. These warming trends were determined at stations that were not locally influenced by urban warming effects.

The warming that has been observed so far in Ontario is consistent with global trends and broadly consistent with the projections of climate models. This regional warming could be due to an enhanced greenhouse effect. Alternatively, the increase in temperature, which is within the range of natural climate variability for the postglacial period, could be due to natural causes, including variations in the atmospheric and ocean circulation. It has also been suggested that at least part of the warming might be attributed to a natural climate adjustment or rebound from the colder climate of the 1400s through 1800s, with a return to the slightly warmer conditions that have more commonly prevailed since the last Ice Age.

Significant long-term changes in precipitation are more difficult to assess than temperature, particularly since precipitation is more difficult to measure accurately. Most precipitation-measuring instruments tend to underestimate precipitation totals. These amounts can also vary substantially from one location to the next and from year-to-year. The high variability of precipitation makes it more difficult to distinguish long-term trends from ordinary year-to-year and decade-to-decade variations. Nonetheless, after accounting for changes over time in precipitation measurements,

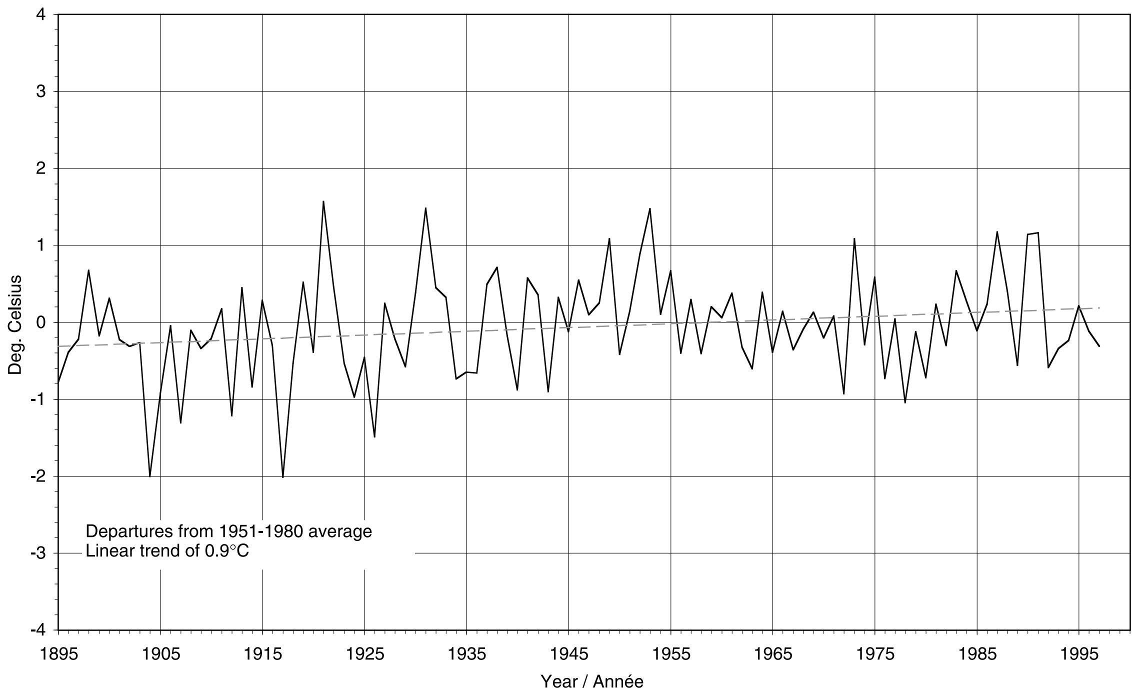

Figure 2. Great Lakes Basin-St. Lawrence Lowlands Climatic Region Annual Temperature Trend, 1895-1996 Compared To 1951-80. (Source: Climate Monitoring and Data Interpretation Division, Atmospheric Environment Service, Environment Canada, 1998.)

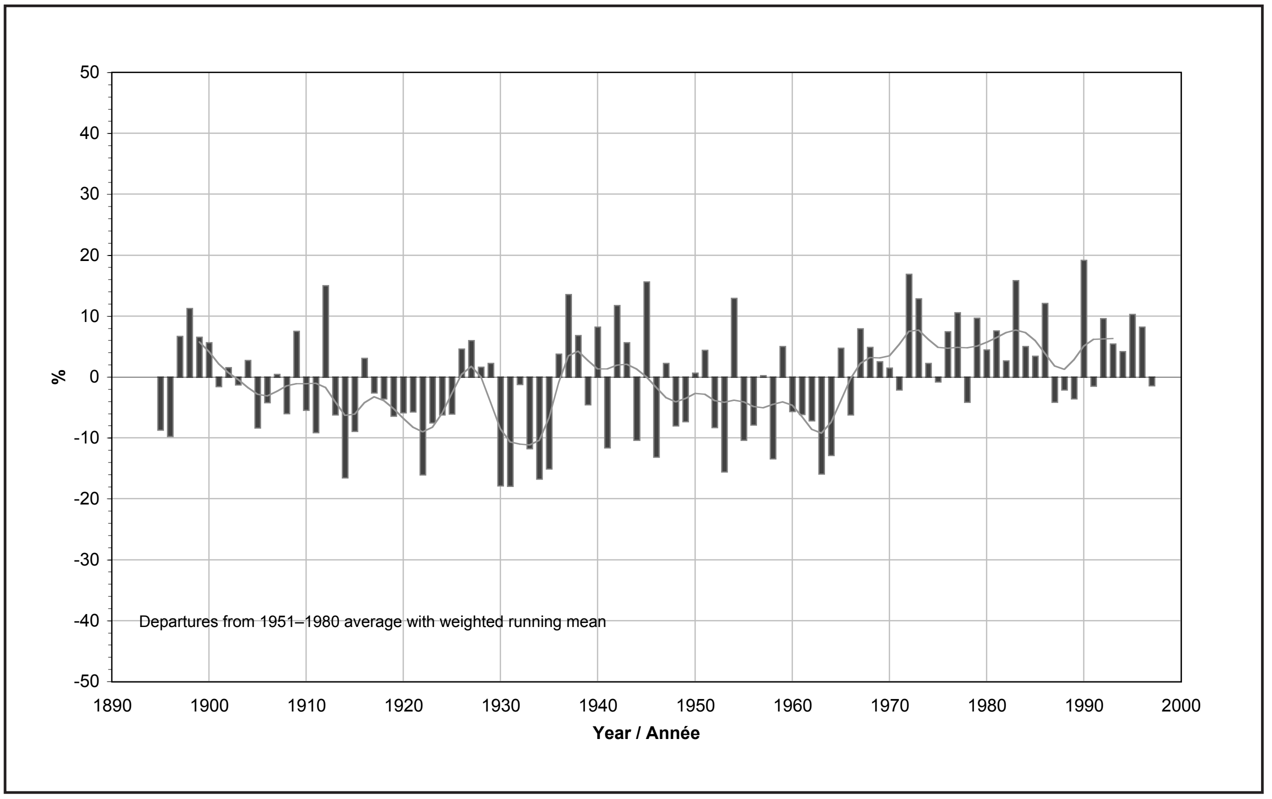

Figure 3. Great Lakes Basin-St. Lawrence Lowlands Climatic Region Annual Precipitation Trend 1895-1997, Compared With 1951-80. (Source: Climate Monitoring and Data Interpretation Division, Atmospheric Environment Service, Environment Canada, 1998.)

indications are that annual precipitation amounts are increasing in Ontario by about 1 percent per decade in the Great Lakes Basin–St. Lawrence Lowlands climatic region and by more than 2 percent per decade in the climatic region that includes Northern Ontario and Northern Quebec (Mekis and Hogg 1998). Annual total rainfall amounts have increased over the period 1895 to 1997 with the greatest increases in the south. Meanwhile, annual total snowfall amounts appear to be increasing in the north while decreasing in the south. Figure 3 indicates trends in annual precipitation for the Great Lakes Basin–St. Lawrence Lowlands climatic region for the period 1895 to 1997. The figure displays percentage departures of annual precipitation from average precipitation for the period 1951-80. The data used are unadjusted for changes over time in precipitation measurements.

Based on cloud amount data from 1953 to 1992, Ontario as a whole has experienced a small increase in average cloudiness since the 1950s. Cloud cover amounts from the 1950s until the 1970s were generally less than the 1953-92 average amounts, which means that most of the increase in cloudiness has occurred since the 1970s. Weather observations indicate a statistically significant 5 percent increase in cloudiness over Southern Ontario during the period 1953 to 1991 for the spring through autumn seasons. Northern Ontario has experienced a slight increase in cloudiness for the autumn season (Environment Canada 1995a).

Climate stability and variability are critically important to both ecosystems and the human societies within them. Since most living things are adapted to a relatively narrow range of climate conditions, their survival at a location depends on climate stability. Some climate variability is well-understood, such as changes that occur from season-to-season. But, many of the factors that force climate variability are poorly understood and fairly unpredictable. Short-term climate variability or fluctuations in climate are often associated with changes in ocean currents or sea surface temperatures, such as the El Niño and La Niña phenomena.

It benefits society to be aware of climate variability and the uncertainty that it brings and to consider the risks and opportunities associated with these year-to-year changes. The impact of this variability can be demonstrated by considering climatic conditions during two contrasting years. During the years 1988 and 1992, climatic conditions deviated from the "average" and had notable impacts on industry in the Great Lakes area. In 1988, the Great Lakes area was hit by a drought that also left its mark on much of North America. By mid-July, Southern Ontario had experienced its hottest July since 1955 with precipitation less than 40 percent of the average. The result was a rapid drop in Great Lakes water levels, water supply shortages and economic losses worth millions of dollars in the agriculture, forestry, and shipping industries. By contrast, the spring through autumn seasons of 1992 were one of the coolest and wettest in Southern Ontario since instrumented weather records were kept. July temperatures were the coldest this century in Ontario. The impacts of the cold and wet summer included stunted crops, a decline in tourism associated with outdoor activities and lower energy demands for air conditioning. Severe storms stemming from the remnants of Hurricane Andrew entered the Great Lakes Basin at the end of August causing localized flooding with several areas reporting 75 to 125 mm of rainfall accumulation in a single day (Koshida et al. 1993). Above-average precipitation and limited sunshine through the summer as well as killing frosts in September kept crops from fully maturing.

For any location, it is difficult to estimate whether the next year will be warmer or cooler or wetter or drier than the previous one or whether the next decade will have more or less storms or droughts. As a result, Ontario's economic and social activities must operate within a changeable climatic regime. Activities that are adapted to a variable and uncertain climate regime run fewer risks than those that are poorly adapted.

4.0 SECTORAL OPPORTUNITIES AND SENSITIVITIES TO CURRENT CLIMATE

4.1 Introduction

The atmosphere is an important resource. If our society is to function more effectively and efficiently into the future, it must learn to live within the bounds of this resource (Maunder 1970). While it is true that atmospheric processes are largely out of human control, society and industry can make decisions that render it less vulnerable to climatic variability and extremes. This chapter describes the impact of current climate on selected sectors of the Ontario economy.

Like other parts of Canada and of the world, Ontario's communities, economy and natural resources depend on a relatively stable climate. With its diverse economy and variety of landscapes, it is expected that climate change will affect every sector and region of Ontario in a different way. This chapter describes the sensitivity of the natural and the built environments in the province and their associated sectors to climate variability and change. The following five broad policy areas are identified for evaluation:

- Water resources (Great Lakes water levels, water supply and water demand)
- Human and ecosystem health (human health and ecosystem health including aquatic ecosystems, wetlands, forests and wildlife)
- The built environment (infrastructure)
- Industries (energy, transportation, tourism and recreation, forestry, agriculture, construction and finance)
- Regional air issues

Extreme events often provide the most tangible evidence of climate impacts; a few examples of extreme events and their impacts are included for most sectors. The extreme events have been extracted from Phillips (1986-91 and 96-98) and Allsopp et al. (1981) unless otherwise noted.

4.2 Water Resources

Renewable water resources can be defined as the proportion of precipitation that does not return to the atmosphere through processes such as evaporation. About 5 percent of the renewable water resources in Ontario occurs as direct runoff, whereas 95 percent makes its way back to the streams underground. Ontario's average annual runoff has been estimated at 9,600 m^3/sec (Sanderson et al. 1996).

Climate and water resources are intimately linked. This section examines the current physiographic and socio-economic environment surrounding water resources in Ontario, with emphasis on the Great Lakes, as well as more general water supply and demand issues.

4.2.1 Great Lakes Water Levels

The Great Lakes Basin is an oscillating system that varies with current climate variability and with the variability of the recent past (Cohen 1988). Geologic and archaeological evidence indicates that lake levels over the past 7,000 years have been considerably higher and lower than any recorded in this century (Larson 1985). Furthermore, long-term fluctuations in water levels tend to occur in decade-long intervals and appear to be caused by cyclic changes in climate. These fluctuations in lake water levels can move about a metre either side of the mean and have proved difficult to predict with accuracy on a year-to-year time scale (Lawrence et al. 1994).

Physical mechanisms for controlling Great Lakes levels include the regulation of outflows through locks at the St. Marys and St. Lawrence Rivers. These structures regulate flows to maintain shipping in the St. Lawrence Seaway, minimize spring flooding in the St. Lawrence Valley, maximize dependable flows for hydropower production and reduce damage to the

Lake Ontario shoreline in years of extreme levels (IJC 1973). Diversions into the basin exist at Long Lac and Ogoki on the north shore of Lake Superior, and a diversion out of the basin exists at Chicago. These diversions affect lake levels by approximately 8 to 10 cm (Center for the Great Lakes 1988). The combined long-term effects of these diversions add about 1.9 cm to Lake Superior, reduce Lakes Michigan and Huron by 0.6 cm, reduce Lake Erie by 10 cm and increase Lake Ontario by 3.2 cm (IJC 1985). A 1993 study by the International Joint Committee (IJC) evaluated the feasibility of regulating the levels of all five lakes and concluded that while it may be technically possible, it would not be economically or environmentally feasible to do so. Major dams and control gates would be required, as well as the deepening and widening of some channels–at the cost of billions of dollars to install and millions of dollars annually to maintain (IJC 1993).

Cumulative climatic processes are the main determinants of lake-level fluctuation and with current technology, these elements are virtually impossible to predict years or decades in advance (IJC 1989). Furthermore, the scarcity of hydrometeorological data in northern portions of the Great Lakes Basin makes it difficult to accurately measure the details of interannual variability, upon which shorter-term prediction of lake levels depends (International Great Lakes Technical Information Network Board, 1984).

The relationship between precipitation and water levels in the Great Lakes is somewhat complicated. Recent studies have concluded that extreme lake levels usually occur only during periods with several years of well-above or well-below average precipitation (Quinn 1991). Winter precipitation produces higher runoff and therefore has more direct implications for flows than summer precipitation; in summer, runoff is reduced by greater evapotranspiration (Rodionov 1994). Analysis of historical records, which date back for about 150 years, indicates that precipitation over the past 100 years generally has been relatively low (Quinn 1991), although annual precipitation amounts over the Great Lakes Basin and St. Lawrence Lowlands have been gradually increasing.

Future net basin supply (NBS) can be defined as the sum of over-lake precipitation (P), over-lake evaporation (E) and runoff (R) into the lake, or:

$$NBS = P + R - E$$

Since basin runoff (R) depends on precipitation, air temperature, humidity and wind speed, reliable predictions of all of the elements are required in order to forecast net basin runoff (Quinn 1991).

Air temperature is a key second variable in the water supply equation for the Great Lakes. The temperature records for the last 100 years in Ontario indicate warming from the 1890s to 1940s, a cooling from the 1940s to 1970s, and resumption of warming from the late 1970s to the early 1990s. In general, a warmer climate will increase evapotranspiration and lake evaporation, thereby decreasing Great Lakes water supplies (assuming that higher than normal precipitation does not occur).

Box 1: Impact of past climate extremes on lake water levels

- **October 19, 1844**: High winds cause storm surges on Lake Erie and Lake Ontario. Reports indicate 200 persons drowned in Buffalo and Toronto.
- **Spring-Autumn 1964**: A prolonged period of drought causes Great Lakes water levels to fall to extreme lows; losses to the shipping industry and other stakeholders were estimated to exceed $100 million.
- **November 14, 1972**: Strong winds and high water levels caused extensive flooding near the western end of Lake Erie. Damage amounted to about $25 million.
- **1985-1986**: Elevated water levels led to extensive erosion and inundation damage along the Lakes Erie and Huron and Georgian Bay shorelines (EARG et al.).

Fluctuating water levels make flood and erosion management difficult. Recent high water levels have led to management plans stressing more effective means to reduce shoreline erosion and flooding. Encroachment into low lying and flood-prone areas occurred during periods of low lake levels, leading to an increase of flood and erosion damage with the return of high lake levels. Property damage along the north shore of Lake Erie increased from $3 million in 1952 to $26 million in 1985 as a result of spring and autumn storms (Kreutzwiser 1988).

4.2.2 Water Supply

According to 1994 statistics, 96 percent of the water used in Ontario comes from its lakes, rivers and streams. The rest comes from a combination of ground and surface water (Environment Canada 1996).

Box 2: Long term water strategy for the Regional Municipality of Waterloo

Authors of a long-term strategy position paper prepared for the Regional Municipality of Waterloo suggested that the most effective means of reducing water demand in the residential sector was through the implementation of low-flow toilets, with an estimated increase in efficiency of 22.5 percent expected by 2001. In the industrial sector, the largest anticipated increase in water efficiency, 6.5 percent by 2031, was through equipment replacement and process modification. In the commercial sector, the largest benefit was seen to come through toilet replacement, increasing efficiency by 6.8 percent by 2006. In the institutional sector, toilet replacement was also the largest factor for increasing efficiency, by 18.8 percent by 2016 (Associated Engineering 1993).

At present, the Great Lakes water supply greatly exceeds demand. In 1991, water consumption was estimated to be growing by about 2.8 percent per year. Despite the Great Lakes abundant supply of water, there are areas of Ontario where freshwater resources are inadequate to meet expanding local demand (Brooks et al. 1988). Municipalities such as Waterloo face annual shortages during the summer months, requiring lawn-watering bans and other adaptation measures (see Box 2). Furthermore, in many areas, facilities to treat, distribute, collect and discharge water are inadequate to meet expanding demand. This problem stems partly from the low prices charged for water and partly from the inefficiency of many municipal systems as a result of leakage, and outdated and outsized systems.

While research is increasing into the sensitivity of surface water runoff to climate, less is known about the relationship between runoff and water supply (Riebsame 1988). In general, greater climatic variability means lower reliability of water supply.

4.2.3 Water Demand

Canada's per capita water use is the second highest in the world. In 1994, total per capita use in Ontario averaged 520 litres per day, less than the national average of 630 litres per day, but one of the highest in the developed world. This per capita consumption decreased by 15 percent from 1983 values (Environment Canada 1996).

Municipal water supply concerns are becoming one of the most critical issues in Canada (Environment Canada 1994). In 1991, one in five Canadian municipalities with water systems reported problems with water availability. If this existing situation is compounded with the warmer, drier climate projected under a CO_2-induced climate change, the problem could become critical (see Section 5.3).

Box 3: Lawn watering

A survey by a New York water utility indicated that homeowners give little consideration to climatic information when deciding when and how much to water their lawns. Realizing this, DeGaetano, Eggleston and Knapp developed a lawn-watering index based on an evapotranspiration model and daily weather data. This information can be disseminated through the local media. The study estimated that the use of such an index could lead to substantial reductions in water use (DeGaetano et al. 1995).

In 1991, 71 percent of withdrawals from the Great Lakes Basin were for thermal electric plants. Industrial withdrawals accounted for about

14 percent, and municipalities for about 12 percent. Of municipal withdrawals, 35 percent were for residential use; 26 percent for industrial use; 23 percent for commercial use; and 16 percent were wasted through leakage. Agricultural withdrawals accounted for only 0.9 percent of all withdrawals (Wardle 1991).

Climate can significantly affect water demand. Temperature extremes can cause increased demand for hydropower generation. In hot, dry weather, there is increased requirement for irrigation and lawn watering. Hot weather can also increase the industrial requirements for water for process cooling.

4.3 Human and Ecosystem Health

Human health, ecosystem health and climate are intricately linked. Information exists on the basic relationship between current climate and certain ecosystem components. However, less attention has been paid to ecosystem health as a whole and to the links between current climate and human health.

4.3.1 Human Health

The relationship between weather, climate and human health or human biometeorology has been a subject of study for decades (e.g. Tromp 1969). This relationship is both direct and indirect, since air quality is also strongly influenced by weather and climate: air pollution levels are affected by the transport and dispersion/dilution of pollutants, and also by chemical reactions between emitted contaminants that create secondary air pollutants.

In the past decade, a number of specific human health aspects have been explored: the relationship between air pollution, weather and respiratory disease; the relationship between high temperature and high humidity indices and their impacts on mortality and morbidity rates; the relationship between bright sunlight, or lack of it, and mental state; and the relationship between exposure to ultraviolet radiation and the occurrence of skin cancer and cataracts.

Research into heat and humidity and their association with health has produced the following conclusions:

- Mortality increases during heat-wave conditions, especially in areas of high air pollution and intense humidity (Ellis 1972).
- Heat stress depends on the temperature, the duration of the heat wave, humidity and wind speed (Jones et al. 1982).
- Higher rates of mortality from heat stress occur in areas where hot weather is uncommon and during the early part of the summer, indicating that some acclimatization is possible (Kalkstein et al. 1989, 1993).

Kalkstein (1995) suggested that the main cause of increased death rates during heat waves is heat stress, rather than air pollution. Burnett et al. (1995) found a near-linear relation between summer hospital admissions for respiratory complaints and previous-day ambient ozone and sulphate concentrations; they established that temperature variations had little effect on the relationships. More research needs to be done on the interaction between different atmospheric stresses and human health.

Weather can also affect the occurrence and severity of allergies and asthma. Maarouf (1989) found that high hospital admissions for chronic pulmonary disease (including asthma) reach a peak in autumn when stagnant weather conditions increase the likelihood of elevated pollutant levels. Weather has also been related to migraine attacks: migraines are more frequent with high humidity and associated weather patterns. While clear, sunny and dry weather (typically associated with a ridge of high pressure) ameliorates a migraine attack, unfavourable weather conditions may worsen the severity of an attack in progress (Nursall et al. 1980).

Cloudiness is another aspect of climate that appears to affect human health, both directly and indirectly. Cloud cover modulates the amount of bright sunlight and ultraviolet radiation received at the ground. Increased incidence of depression has been noted during protracted periods without much sunshine.

Finally, possibly the most obvious impact of weather and climate on human health, at least in terms of public consciousness, is that caused by severe weather and climate events. Box 4 provides some examples of severe events and their effects.

Box 4: Impact of selected severe weather and climate events on human health in Ontario

- **September 5, 1881**: Forest fires near Lake Huron destroyed at least 20 villages, killing 500.
- **July 1936**: A major heat wave shattered records across Ontario; 458 deaths were attributed to its effects.
- **October 15, 1954**: Rainfall from Hurricane Hazel triggered widespread flooding in Southern Ontario, causing 80 deaths.
- **August 20, 1970**: A tornado in Sudbury killed 4 and left 750 homeless.
- **April 3, 1974**: A tornado killed 9 and injured 30 at the Windsor Curling Club.
- **January 28, 1978:** A major winter storm paralyzed Southern Ontario, resulting in 9 deaths.
- **May 31, 1985**: A tornado outbreak in Central Ontario killed 12 and injured over 100.
- **Summer of 1995**: Ontario endured one of the most uncomfortable summers on record. On July 14, Windsor recorded the highest humidex ever in Canada. Ontario Hydro produced electricity at an all-time summer record level in response to the dramatic increase in the use of air conditioning. Remarkably, no human deaths were directly attributed to the heat.

4.3.2 Ecosystem Health

Species are adapted to particular environmental conditions, and their distribution is heavily determined by climatic variables such as temperature and moisture (Peters 1992). When these variables change, species tend to track their climatic optima, thus changing the location, abundance and associations of species. Significant and sustained changes in climatic variables, which have occurred intermittently throughout geologic time, force species to either adapt to the changes or face extinction.

Past changes in climate have caused large rearrangements in the composition and structure of the major vegetation regions across North America (Webb 1992). During several Pleistocene interglacials, when the temperature in North America was about 2°C to 3°C higher than it is now, species distribution was considerably different from today’s. Sweetgum trees grew in Southern Ontario while oranges grew around the western end of Lake Ontario (several hundred kilometres north of their present distribution) (Peters 1992).

Recent historical observations and evidence from the fossil record (particularly the pollen record) indicate the rates at which different species have migrated in response to past climate change. These past rates of migration provide some indication of the adaptability of species and ecosystems, and their potential future rates of migration due to climate change. This evidence indicates that even small temperature changes of less than one degree can cause substantial changes in the home ranges of species, suggesting that some species are very sensitive to climate (Peters 1992).

Aquatic Ecosystems

Climate affects evaporation, water vapour transport and precipitation, all of which determine the amount and distribution of freshwater. Over the past 25,000 years, freshwater ecosystems have undergone massive changes in distribution, correlated with trends in regional climate; future climate change is likely to produce comparable changes in the supply and distribution of freshwater (Carpenter et al. 1992).

Since temperature tolerances often govern both the local and biogeographic limits of freshwater fishes, distributions of aquatic species will change: some species will invade higher-latitude habitats or disappear from the low-latitude limits of their distribution as thermal limits are altered by climate change (Carpenter et al. 1992).

Lakes also experience vertical stratification, owing to density differences, as surface water temperatures vary from season-to-season. Biological activity near the lake's surface uses up nutrients in the surface waters, while the decomposition that occurs on the lake bottom depletes oxygen in deeper waters. An important mixing process in temperate lakes, termed "overturning", occurs in the spring and autumn when temperatures (at 4°C) and densities become uniform throughout the water column. Overturning is essential for mixing nutrients and oxygen throughout the water column (Purves et al. 1992). Lakes that do not experience overturning (those relatively warm lakes that do not drop to less than 4°C) and whose waters are not mixed by strong winds have their bottom waters depleted of oxygen. Such conditions favour species that can tolerate anaerobic conditions, such as anaerobic bacteria, sludge worms and carp.

Lake and large river waters are stratified into different thermal regimes. Because different species of fish have different temperature preferences, or tolerances, they tend to seek temperatures close to their preferences and to segregate. In the Great Lakes in mid-summer, the deeper, colder waters are dominated by the salmon family; cool intermediate depth waters are dominated by the perch family; and shallow, warm inshore waters are dominated by the sunfish family and minnows (Regier et al. 1989).

Wetlands

Wetlands, such as marshes, bogs and fens, are zones of contact between land and water. The most important determinant of the establishment and maintenance of specific types of wetlands is water availability, which affects the wetland's species composition and richness, primary productivity, organic accumulation and nutrient cycling. Major hydrologic inflows include precipitation, flooding rivers, surface flows, groundwater and tides in coastal wetlands (Mitsch et al. 1993).

Climate changes that modify water availability will affect wetlands (Wall et al. 1986b; Woo 1992). How wetlands adapt to climate change and associated changes in the water balancedepends on the particular wetland formation and the degree of change in both temperature and hydrology. For example, in the case of peatlands, a specific type of wetland formation, the seasonal distribution of rain is an important determinant of peatland survival because peatlands require a humid environment year-round. Climate changes that affect seasonal precipitation will, consequently, influence the existence and distribution of peatlands. Lacustrine wetlands (bordering lakes) are influenced by year-to-year variability in lake levels and by physical features of the terrain that determine whether the wetland adjoins the lake (an open wetland) or whether it is blocked from the lake, for example, by a sand bar (a closed wetland) (Mitsch et al. 1993).

Forests

The extent and composition of forest ecozones are generally determined by temperature, water availability and soils. Studies that have examined the responses of tree species to climatic variability indicate that species have shifted their geographical ranges in response to past climatic variability (Overpeck et al. 1990a, 1990b; Solomon et al. 1992; Schwartz 1992; Webb 1992). For example, pollen analyses of the mixed forests of Southern Ontario demonstrate that during the Little Ice Age cooling, which started sometime between 1200 to 1450 and ended around 1850, beech was replaced first by oak and then by pine (Campbell et al. 1993). Evidence indicates that between 5,000 and 6,000 years ago, beech and hemlock trees migrated northwards at average rates of 20 km to 25 km per century in response to climate change; however, rates of soil development may have been one factor limiting rates of migration (WWF 1992).

Wildlife

Any changes to habitats will, concomitantly, have an impact on wildlife. Animal species also respond to changes in climate according to their tolerance limits. Seasonal extremes of temperature and precipitation, the length of the growing season and the composition of the vegetation mosaic are all important determinants of the distribution, abundance and survival of animals. Mobile species are able to migrate fairly readily in response to climate change, provided that their migration is unimpeded by barriers and that they are able to find appropriate habitats under the new climate regimes.

Animals responded to the climatic warming that occurred between 14,000 and 10,000 years ago by migrating, but the direction and magnitude of range shifts varied among species, leading to the creation of new species assemblages (Graham et al. 1990).

Box 5: Impact of selected severe weather and climate events on ecosystems in Ontario

- **June 5, 1816:** A late freeze, probably related to the eruption of Mount Tambora in 1815, denuded trees, decimated crops and caused ponds to ice over, killing many amphibians and wetland dwellers.
- **March 30, 1848:** Ice jams in the Niagara River prevented water from flowing over Niagara Falls for two days.
- **April 13, 1858:** Strong winds generated wave action that breached the narrow isthmus across the western end of Toronto Harbour, forming the Toronto Islands.
- **August 25–September 3, 1953:** The longest heat wave on record in Southern Ontario warmed the waters of Lake Erie to such a degree that millions of fish died.
- **Winter 1958–59:** An estimated 40 percent to 50 percent of the deer population in Ontario died as a result of severe winter weather.
- **July 18, 1991:** A thunderstorm complex near Red Lake, in Northwestern Ontario, generated sustained severe winds that flattened a 1,500 km^2 section of the Pakwash Forest, in a swath 20 km wide and 75 km long.
- **Winter 1995-96:** A deep snow cover killed off huge numbers of deer in Northern Ontario. Snowpacks of about 100 cm also posed a threat to the moose population.

4.4 The Built Environment

A distinction can be made between the effects of climate and weather on the construction process and the implications of climate variability for structural design. The impacts of climate on the design and engineering of infrastructure are examined in this section. The impacts of climate on the construction industry (i.e. weather-related construction delays etc.) will be looked at in Sub-section 4.5.6 on Construction.

The built environment embodies most of the ways in which Canadians adapt to the rigors and extremes of their climate. The built environment underpins almost all of Canada's and Ontario's economic and social activities, providing the necessary infrastructure and modified indoor environments required to maintain a modern economy in a northern climate. The construction industry peaked in Canada in 1990, producing a total of $102.4 billion in repairs and new construction (15 percent of Canada's GNP). Ontario was responsible for the greatest share of these total expenditures (over 30 percent) (Dalgliesh 1998).

The most obvious way that humans adapt to a variable climate is by surrounding themselves and their social and economic activities with environmental separators or building envelopes. The built environment comprises houses, office buildings, factories and plant complexes; structures for supply, generation and distribution of water and electrical power and other energy sources (e.g. pipelines for gas and oil, coal handling facilities); facilities for collection and treatment of waste; networks of roads and waterways including bridges, canals, locks, wharves, airport runways, hangars; air and sea traffic control towers; communications towers; and miscellaneous other facilities needed in human society such as hospitals, amusement parks and penitentiaries (Dalgliesh 1998).

Accurate information on climate variability and change is essential if society is to design, build, operate and maintain structures in the built environment. For that reason, the building industry has long recognized the need to design for weather extremes. While natural atmospheric phenomena such as floods, extreme snowpacks, and strong winds and tornadoes may be inevitable, the losses and damages that these hazards engender need not be. Building codes and other infrastructure standards that set minimum specifications for design and construction offer one of the most effective approaches to limiting the effects of atmospheric natural hazards (adapting to climate). When a structure is designed, constructed and maintained to resist a hazard, then the hazard has minimal impact. Economically designing a structure to withstand these hazards, however, is not a simple matter.

Decisions by builders are primarily driven by the need to build both safely and economically. Climate data, particularly those defining extreme events, govern many aspects and costs of construction through the National Building Code of Canada (NBCC). This takes place through compliance with provincial building regulations and municipal bylaws, usually based on documents such as the NBCC and other national standards. The NBCC sets minimum building and design standards for, among other things, wind, snow, rain and earthquake loads. The appropriate balance must be stuck between strength (safety) and serviceability over the useful life of a piece of the built environment, on the one hand, and overall economy (initial costs plus maintenance), on the other. This depends on having realistic predictions of future wind and snow loads, temperature, rainfall, foundation conditions (e.g. permafrost, slope stability) as well as the risk of flooding or earthquake activity. Since service lives of structures can vary from less than 10 years to more than 100 years, predictions of future climatic extremes may require explicit adjustment for trends, some of which can be attributed to global warming impacts.

It is estimated that the Canadian construction industry incurs incremental costs of about 4% of total construction spending–about $4 billion per year–to cope with elements such as snow and wind loads (Burton 1994). Table 2 describes the various environmental load factors and the building components they affect.

To incorporate climatic data into the design process, weather design values are selected according to acceptable risk levels (Parry et al. 1988). The extent to which these objectives are achieved is most obviously measured in financial terms, such as savings in construction costs, heating and lighting bills, and repairs. In Canada, design of bridge piers depends on the levels of extreme floods and the size of ice jams; offshore structures are designed with consideration for the frequency and magnitude of iceberg impacts and waves; towns, roads and pipelines in the north are influenced by permafrost; and heating, ventilation and air conditioning systems in buildings are sized according to near-extreme heat and cold events (Davenport 1994). According to the Insurance Bureau of Canada, the highest proportion of insurance losses to infrastructure in Canada is due to wind action causing mainly structural damage.

A 1996 study conducted at the University of Toronto (Yazici et al. 1996) set out to investigate the influences of environmental loading on building design and the estimated construction cost. The building selected was a typical one-storey light manufacturing or warehouse complex. All design parameters conformed with the NBCC.

The environmental factors considered included snow, rain, wind, depth of frost penetration, temperature and solar radiation. The study found a

Table 2: Environmental Loads and Affected Building Components

Environmental Load	Affected Building Component
Snow and rain	Beams, girders, joists, columns and foundation
Vertical wind pressures	Beams, girders, joists, columns and foundation
Lateral wind pressures	Bracing foundation
Frost penetration	Foundation wall
Temperature and solar radiation	Building envelope, mechanical system, operating cost

(Source: Yazici et al. 1996)

Box 6: Impact of selected severe weather and climate events on the built environment in Ontario

- **Summer 1916**: Forest fires in the Matheson area destroyed the towns of Kelso, Val Gagne, Porquis Junction and Iroquois Falls.
- **January 27, 1938**: An ice jam in the Niagara River toppled the Honeymoon Bridge in Niagara Falls.
- **October 15, 1954:** Flooding triggered by Hurricane Hazel caused $25 million in damages. Over 200 mm of rain fell north of Toronto; this storm is used to help define flood plains for rivers in much of Southern Ontario.
- **August 31, 1961:** A series of thunderstorms produced over 90 mm of rain over a 12-hour period in Timmins, causing widespread flooding and drowning a mother and her four small children. This storm is used to define flood plains in Northern Ontario.
- **January 27, 1978:** A sudden pressure drop during a winter storm caused windows to pop out of skyscrapers in downtown Toronto.
- **May 31, 1985:** A tornado outbreak in Central Ontario damaged or destroyed more than 1,000 buildings.
- **July 20, 1989:** A series of heavy thunderstorms dropped in excess of 400 mm of rain near Harrow in Southwestern Ontario. Property and crop damage was estimated at $35 million.
- **July 14–15, 1995:** A thunderstorm complex ravaged portions of Southern Ontario, with high winds and one or two tornadoes. Damage was estimated in the millions of dollars.
- **January 4–10, 1998:** A devastating ice storm brutalized Southeastern Ontario and Southwestern Quebec, leaving millions of households without power for days to weeks and leading to at least 25 deaths, many from hypothermia. The storm directly affected more people than any previous weather event in Canadian history.

relatively linear relationship between all environmental factors examined and cost. The most significant component costs of the building were the building envelope costs (46 percent), the operating costs (24 percent) and the structural steel costs (22 percent).

Other climate-related considerations include the following:

- the effect of weathering on construction material–for example, wetting of materials, wind-driven rain, and freeze-thaw cycles affect porous materials;
- the impact of increased or decreased precipitation on soils, which can have a major bearing on the design and construction of foundations;
- the impact of frost heave and frost penetration;
- the importance of ground and air temperatures, solar energy, and winds on energy efficient design; and
- the impact of local climate on heating, cooling and lighting (United Kingdom Climate Change Impacts Review Group 1991).

Buildings account for one-third of energy use in Ontario for space and water heating, lighting, cooling, ventilation and equipment (Bakarat 1995). In reality, the built environment accounts for more energy consumption than that, considering the energy inherent in the manufacture of building materials. By constructing buildings that are more energy efficient as well as more durable over their service lives, the construction industry can significantly reduce outputs of greenhouse gases and assist in the mitigation of global warming.

4.5 Industry

This section provides information on what we know about the relationship between current climate and the following industrial sectors: energy demand and production, transportation, tourism and recreation, forestry, agriculture, construction and finance.

4.5.1 Energy

Energy infrastructure, including offshore oil and gas production and thermal power generation, have been identified as being among the most climate-sensitive industries (EARG et al. 1995).

Ontario's total end-use energy consumption increased by 10 percent between 1985 and 1995, rising at an annual rate of 1.5 percent. This rate is considerably slower than the overall growth in the economy, indicating an increase in energy efficiency (Karl Schaefer 1997, personal communication). Ontario imports roughly two-thirds of its energy (e.g. through imports of petroleum products), and uses more nuclear power than the national average. Recently, temporary technical problems have caused Ontario Hydro to close some of its nuclear reactors for repairs. This will result in higher use of fossil fuels to generate electricity than previously anticipated and will lead to higher emissions of greenhouse gases. Table 3 outlines the types and percentages of energy consumption in Ontario.

Hydroelectric generation often is the cheapest form of electricity production. Electricity accounts for 18 percent of the total energy used. As of 1987, 40 percent of all electricity in the province was generated by hydro, and the source for 41 percent of that amount was the Great Lakes (Sanderson 1987). Ontario imports coal for electricity generation and steel-making from Alberta and the United States. Crude oil is also transported by pipeline from Alberta and Saskatchewan.

Energy Demand

Ontario is the largest energy user in the country and projections show that it will maintain this position for the next 25 years. Total primary energy demand in this province is met mainly by refined petroleum products, electricity and natural gas. By 2020, it is projected that natural gas and refined petroleum products will still remain the main sources of energy, satisfying 61 percent of the primary demand (Mercier 1998).

Seasonal variations in energy demand are influenced by weather and arise from energy needed for heating, cooling and lighting buildings. Numerous studies have shown that the demand for energy is strongly correlated with changes in mean temperature. In fact, one study suggested that variations in mean monthly temperature accounted for 92 percent of the variation in mean monthly electricity demand (Sanderson 1987). Automobile fuel demands also fluctuate with weather conditions, increasing on weekends with nice weather as people travel to vacation or recreation destinations.

Energy Supply

Climate affects a number of parameters on the energy supply side, including efficiency of thermal generating units and their cooling apparatus, water supply for hydroelectric plants, distribution infrastructure (towers, poles, wires, transformers, etc.) and transportation. Climate also has a direct impact on alternative energy sources–wind patterns

Table 3: 1995 Ontario Energy Consumption

Energy Type	Percentage of Ontario Energy Consumption	Sector Use
Oil	38%	transportation, residential
Natural Gas	35%	residential, commercial, industrial
Electricity	18%	commercial, industrial
Coal	5%	industrial, power
Other	4%	various

(Source: Yazici et al. 1996)

and cloud cover are important determinants of the feasibility of wind and solar energy, respectively.

Box 7: Impact of selected severe weather and climate events on the energy industry in Ontario

- **1964:** Hydroelectric power output from Ontario Hydro installations at Niagara Falls and Cornwall diminished by 26 percent and 18 percent, respectively, owing to low water levels on the lower Great Lakes.
- **January 13–15, 1968:** A three-day period of freezing rain, followed by snow, crossed Southern Ontario. Up to 2.5 cm of ice accreted on exposed surfaces, damaging power lines. Repair efforts were hampered by the closure of several highways, including Highway 401, in the London area.
- **Winter 1976–77:** The record-breaking cold spell caused an estimated increase of $135 million in demand for heating fuel in Ontario; electricity demand increased by an average of 109,000 kW/h.
- **January 4–10, 1998**: A record ice storm left more than 500,000 eastern Ontario residents without power, destroyed over 100 transmission towers and damaged 30 percent of the destribution system in region.

Warm weather reduces the efficiency of electrical transmission lines, whereas freezing rain and high winds can damage lines and towers. Lightning strikes can disrupt the distribution of electricity. Freeze-thaw weather cycles can cause problems for electrical supply through falling ice, ice accumulation on overhead conductors and salt deposition. Hot weather can reduce the efficiency of turbine engines used to pump gas in pipelines. On the other hand, frozen ground hinders accessibility to underground portions of the distribution infrastructure and maintenance of underground gas pipelines.

4.5.2 Transportation

As of 1990, the transportation and utility sector employed 230,377 people in the province of Ontario (Hickling Corporation 1994). The four major modes of transportation are considered below, namely marine, automotive, rail and air transport.

Marine Transport

Water transport is the most efficient means of moving bulk cargo. The Great Lakes, which form the busiest waterway in the world, serve the waterborne cargo requirements of 17 states and 4 provinces in North America (Sanderson 1987). This waterway is highly dependent on water levels in all sections of the route. An extremely low water level can limit the maximum carrying capacity of vessels. It is estimated that once a lake level falls below its minimum threshold for marine transport, every further 2.5 cm

Box 8: Impact of selected severe weather and climate events on marine transport in Ontario

- **September 14, 1882:** The steamer Asia sunk in an early-season gale on Georgian Bay, with the loss of 126 lives.
- **November 9, 1913:** Twelve vessels and 270 crew were lost on Lake Ontario in a storm that brought winds estimated at 140 km/h.
- **November 11, 1940:** A storm claimed three ships and 69 lives on Lake Ontario.
- **Spring-autumn 1964:** Freighters were forced to operate 725 to 1,360 tonnes below capacity, to clear the bottom of Lake St. Clair, owing to low water levels. Losses in total cargo capacity for the season were estimated at 8.6 million tonnes, and economic losses for U.S. ore carriers alone were estimated at $13 million.
- **November 29, 1966:** The laker D.J. Morrell broke up in a gale on Lake Huron; 28 people died.
- **November 10, 1975:** The Edmund Fitzgerald, with a crew of 29, was lost in hurricane-force winds on eastern Lake Superior.
- **December 9, 1976:** A freighter ran aground in the St. Marys River, while trying to avoid ice jams, trapping nearly 70 ships. The St. Lawrence Seaway was kept open for several days, despite unusually heavy ice conditions, to permit foreign vessels to exit the seaway.

water level reduction would force ships to reduce their loading by as much as 180 tonnes (Allsopp et al. 1981).

Great Lakes shipping is also sensitive to shorter-term climate phenomena. For example, late autumn temperature and wind patterns affect the formation of ice and determine when the St. Lawrence Seaway must close. Similarly, spring conditions determine when the ice will break up, allowing the seaway to reopen. Fall and winter storms are often accompanied by high winds, which can quickly generate large waves and create hazardous conditions for shipping. In winter, the combination of very cold temperatures and high winds can produce freezing spray, whichalso can make operating conditions dangerous. Strong winds associated with thunderstorms, squalls and waterspouts can also pose a threat to safety for smaller vessels. Finally, when strong winds blow along the axis of Lake Erie, storm surge or seiche conditions can be created, which can lower the water level significantly for a period of several hours in the shallow western basin of the Lake and affect shipping if water levels are already low.

Automotive Transport

Automotive transportation accounts for 70 to 90 percent of passenger traffic in most parts of Canada (IBI Group 1990). There are five million passenger automobiles in Ontario, accounting for 37 percent of the national total and placing Ontario just under the national average of automobiles per capita. In terms of freight transportation, highways carry more than half the total tonnage of goods shipped between Ontario's cities and towns. Recent data indicate that about 25 percent of the fossil fuel energy consumed is used for transportation purposes. Combined with rail transport, truck transport accounts for two-thirds of Ontario's intercity tonnage.

Temperature extremes affect design and operation of automotive transport, including use and operation of block heaters, cooling systems, passenger and cargo compartment climate control, diesel fuel type, gasoline deicing and lubricant selection. Other climate impacts include visibility restrictions (caused by precipitation, fog, blowing snow, solar glare); traction impairments (caused by freezing precipitation, refreezing of melted snow, snow, rain); and pollutant dispersion, which have led to emission controls. In addition, salting of roads, an adaptive response to climate conditions, has prompted adoption of measures to inhibit corrosion of vehicle components (use of galvanized steel and plastics) and contamination of local water sources.

Box 9: Impact of selected severe weather and climate events on automotive transport in Ontario

- **January 28–31, 1977:** Most roads in Niagara Region were blocked by snow. Winds gusting from 80 to 110 km/h caused drifts as high as 8 metres. Highway crews could not open the Queen Elizabeth Way because of abandoned cars. Snowploughs sheared the roofs off several buried cars.
- **Winter 1976–77:** By the end of January 1977, productivity losses in commerce in Ontario, primarily due to traffic disruptions, were estimated at $50 million. On February 10, the Ministry of Transport and Communications estimated that road maintenance costs for the winter were about $5 million over budget, as a result of increased labour costs.
- **January 12, 1984:** Snowsqualls off Lake Ontario caused a 200-car pile up on the Queen Elizabeth Way. Eighty-nine people were injured, and damage amounted to $1 million.

Climate affects the initial design and maintenance costs of roads. It has been estimated that environmental factors may account for between 50 percent and 80 percent of pavement deterioration, depending on the volume of traffic (Nix et al.1992). Furthermore, the salt often used to treat road surfaces damages the ecosystems adjacent to roadways, local water sources, and structures in the built environment, thereby incurring further indirect costs to the environment and society.

During adverse weather conditions the number of accidents increases; roads and bridges can be rendered impassable by snow, flooding, fallen trees or high winds; road network operating costs are increased (owing to snow removal, anti-icing treatment and repair of damaged traffic signs and signals); and public transit use is increased in urban areas.

Rail Transport

Coupled with Great Lakes transport, rail transport plays a central role in carrying major export commodities such as grain, and forest and mineral products as well as a number of manufactured goods (IBI Group 1990).

Many of the impacts of climate on railways are indirect. For example, unfavourable conditions for Great Lakes shipping (ice cover or low water levels) could mean an increased demand for rail transport. Climate can also affect demand for, or supply of, bulk commodities that are often carried by rail, such as coal and grain.

Box 10: Impact of selected severe weather and climate events on rail transport in Ontario

- **January 15, 1976:** In Windsor, trains were delayed and four-metre snowdrifts caused CNR passenger trains to be turned back twice in one night at St. Marys.

Weather can affect railways in a number of ways. Severe storms may damage tracks, bridges, signals or communication lines. Heavy snowfall, floods and earth slides triggered by heavy rainfall can cause accidents and delays. Climate-induced conditions such as permafrost limit the range of rail viability. Passenger and freight schedules can be upset by low visibility due to fog or precipitation (Maunder 1970). Passenger comfort and some temperature-sensitive freight require either insulated and heated or air-conditioned compartments and extremely low temperatures can affect hauling capacity of locomotives.

Air Transport

Air transport must operate under a broad variety of weather (and climate) conditions. Knowledge of weather conditions at the ground and aloft is therefore important for avoiding hazards to aviation and in planning flight paths and fuel consumption. Weather observing and forecasting in support of the aviation industry are, in fact, mainstays of the weather service.

Cloud amounts, cloud heights, surface weather visibility, winds, temperatures and weather including thunderstorms, snow, freezing rain all critically influence air transport. Strong cross winds restrict landings and take-offs, and smaller aircraft may be unable to operate in those conditions. Significantly impaired visibilities and very low cloud ceilings restrict the operation of all but the most sophisticated aircraft. When these conditions are expected at destination, commercial airliners must carry sufficient fuel to allow them to reach an alternative airport; this reduces cargo capacity and operating efficiency. Snowfall and freezing rain can constitute hazards to aviation and necessitate aircraft deicing and runway treatment to improve traction. Either of these required activities can delay operations and/or reduce airport traffic capacity, which in turn can disrupt airline schedules, resulting in inconvenience and increased costs.

Box 11: Impact of selected weather events on air transport in Ontario

- **March 10, 1989**: An Air Ontario turboprop crashed into dense bush shortly after takeoff from Dryden Airport, killing 24 of the 69 people aboard. One of the principal causes of the crash was the accumulation of ice and snow on the airframe prior to take-off.

A number of other weather elements affect in-flight operations; generally speaking, the preferred option is to alter course to avoid these conditions. Strong head or tail winds can affect aircraft operating range and the flight time required to reach destination. Clouds with a high content of supercooled liquid water can cause rapid aircraft icing in flight. Thunderstorms and strong warm and cold fronts can cause wind shear and heavy turbulence. These weather conditions are especially hazardous during take-offs and landings.

4.5.3 Tourism and Recreation

Climate is one of the factors that shape the outdoor environment and influence participation in outdoor recreation. As noted in Section 2.2, this industry represents a significant part of Ontario's GDP, contributing $12.2 billion to GDP in 1994 and employing 370,000 people.

Not every climate is suitable for all outdoor activities; skiing requires adequate snow cover, and beach use requires warm temperatures and sunny skies. The following climatic elements influence summer and winter outdoor recreation activities:

Summer: Air temperature
Humidity (directly and in combination with temperature)
Precipitation
Cloud cover
Visibility
Wind speed
Water temperature
Water levels and flows

Winter: Duration of daylight
Air temperature (directly and in combination with wind speed)
Precipitation
Cloud cover
Visibility
The presence and quality of snow and/or ice cover
(Crowe et al. 1973a)

To some extent, the range of acceptable conditions can be extended by making artificial snow or putting on an extra layer of clothing; nevertheless, climate remains a determinant in achieving satisfaction (Crowe et al. 1973a).

Crowe et al. (1973a, 1973b, 1973c) classified Ontario's climate according to its suitability for various outdoor activities. For the summer season, activities were divided into five broad groups. Table 4 shows the desired weather conditions and indicates the level of sensitivity of each activity to deviations from these weather conditions.

Observations show that there is a higher correlation between weather and participation for swimming than for sightseeing from a car (Crapo 1970). These results indicate that there is a difference in climate sensitivity among activities and suggest that activities requiring a greater degree of direct contact with the outdoor environment are more sensitive to weather conditions.

In some cases, however, the influence of climate on participation can be masked or overshadowed by other elements. Visiting the beach, an activity classified as highly sensitive to climate, is not highly dependent on weather conditions in Sauble Beach, Ontario, for example. Rather, participation levels are more highly influenced by the availability of leisure time, which in turn is determined by the day (weekday, regular weekend, or holiday weekend) and season

Table 4: Weather Requirements and Sensitivities for Summer Outdoor Activities[1]

Activity Type	Desired Weather	Sensitivity
Swimming	Sunny, warm (including water)	High
Beach Use	Sunny, warm	High
Vigorous Activities	Not excessively hot or cold, some sun, dry, no precipitation	Moderate
Passive Activities	Not excessively cold, some sun, no precipitation	Moderate
Landscape Touring	No significant precipitation	Low

[1]**A similar classification was established for the winter season.**

(Source: Crowe et al. 1973b)

Box 12: Impact of selected severe weather and climate events on tourism in Ontario

- **Winter of 1982–83:** The Southern Ontario ski industry suffered major losses as a result of the lack of snow.
- **1980’s** high and low water levels: Provincial parks sustained property damage due to fluctuating water levels with at least 13 of 25 parks suffering increased expenditures related to shoreline cleanup, capital repairs and shore protection.
- **1988–90:** Many wetland areas became inaccessible during low water levels owing to exposed mudflats; water pollution levels increased in some areas as a result of low streamflows.
- **Winter of 1994–95:** Ski resorts suffered serious losses as a result of unseasonably mild early winter temperatures, 10 days of rain in January and a March break with temperatures approaching 20°C.

type (peak or off-peak) (Alexander 1997a). Some monthly averages do exist for climate-recreation relationships, with recreation levels increasing for months with higher average daily maximum temperatures (Alexander 1997a). It is difficult to separate the effect of school and work holidays from that of climate, since the bulk of school holidays are in the summer.

4.5.4 Forestry

As noted in Section 2.2, forestry is a major sector of the Canadian economy. Forests are sensitive to climate. There is ample evidence of major changes in the location, extent and composition of forests that are related to climatic conditions (Smit 1993). The potential exists for the boreal forest to be reduced and for hardwoods and grassland to be extended into areas formerly occupied by softwoods (Environment Canada 1994).

The estimated costs associated with adaptation of Canada’s forests to current climate are outlined in Table 5. These costs are approximate and incomplete (e.g. no figures are available for land-use adjustment and operational management) but provide an indication of the numbers involved.

Unlike annual plants, which adapt to and grow in the weather conditions of one season, trees must adapt and survive in year-long weather conditions over a period of 30, 100 or even 500 years. In some respects, this makes trees somewhat more flexible because they have evolved to withstand minor variances in climate from year to year. On the other hand, because of the tree’s long growth period, the forestry industry is inherently vulnerable to changes beyond the natural adaptive capability of the tree.

Climate affects many of the physiological processes within trees that ultimately lead to the production of wood. With mean daily temperatures of around 20°C or more, boreal tree species

Table 5: Estimated Costs of Adaptation of Forestry to Canada’s Climate

Sector/Activity	Estimated Total Cost of Adaptation ($M)	% Attributable to Climate Adaptation	Costs of Climate Adaptation ($M)
Research	125.5	40.0%	50.2
Pest Protection	39.3	40.0%	15.6
Fire Protection	391.5	86.0%	336.7
Total	**556.3**		**402.6**

(Source: Herbert, 1994.)

Box 13: Impact of selected severe weather and climate events on forestry in Ontario

- **1961:** Almost 480,000 ha of forest were burned in Ontario, over 400,000 of this in the Sioux Lookout District in Northwestern Ontario; losses totalled almost $32 million.
- **1974:** About 524,000 ha were destroyed by fires in the Red Lake and Dryden Districts. Damages were estimated at over $12 million, and fire suppression costs were $5 million.
- **1976:** Over 540,000 ha were destroyed across Northwestern Ontario, between Lake Nipigon and the Manitoba border. Losses amounted to almost $29 million, and fire suppression costs exceeded the amount budgeted by the province by $21.5 million.
- **1980:** Over 560,000 ha were destroyed by fire. Fire suppression efforts alone exceeded budget estimates by $35 million. In the Red Lake District, fires forced the evacuation of 5,400 residents, the largest air evacuation in Ontario history.
- **1988:** The 1988 forest fire season in Ontario was the second worst since record keeping began in 1917. A total of 3,260 fires were reported and more than 390,000 ha of forest were destroyed (EARG et al. 1995).

achieve the optimum net rate of gain of wood (Van Kooten et al. 1989). Important constraints on the production of wood include the length of the growing season, mineral availability and moisture supplies. Climate also plays a major role in determining fire frequency and severity, and the extent of pest infestations. Finally, climate can also affect harvesting operations, particularly in winter when frozen ground facilitates the transport of logs.

4.5.5 Agriculture

It is widely accepted that agriculture is very sensitive to climate (Smit 1993). Agricultural productivity depends on many interrelated factors, whose relationships are not yet completely understood. Climate and atmospheric factors such as temperature, precipitation and solar radiation are important inputs for the growth of vegetation. The non-climatic factors that must also be considered include soil characteristics and farm inputs such as energy, fertilizer and pesticides. It should be emphasized that it is not always easy to make valid generalizations about the effects of climate on agriculture; not only are there likely to be varying degrees of absolute change in different locations, but the relative effect of these changes depends very much on the existing conditions (Parry et al. 1988). Certain non-climatic forces, such as economic or government policy, can magnify, moderate or nullify a climatic effect and can greatly influence the nature of responses. There is a need for integrated assessments to identify, instead of assume, significant interactions among influencing forces and farm responses.

Box 14: Impact of selected severe weather and climate events on agriculture in Ontario

- Significant drought-related losses in various crops in Ontario were reported in 1916, 1921, 1933, 1934, 1936, 1949, 1963, 1973 and 1978; and due to excessive moisture in 1927, 1943, 1945, 1947, 1967, 1969, 1972, 1975, 1976 and 1977.
- **May 30, 1985:** A hailstorm in the Leamington area caused $40 million in damage.
- **Summer 1986:** Record rainfalls–in excess of 600 mm for the July to September period (Broadhurst 1988)–in a broad swath across Southern Ontario caused an estimated $100 million in crop damage.
- **Summer 1992**: The 1991 eruption of Mount Pinatubo in the Philippines disrupted weather patterns around the Northern Hemisphere for several months. In Ontario, summer weather included hailstorms and freak snowstorms; estimated losses to Canadian agricultural production were $250 to 350 million, and $207 million was paid out in insurance (Herbert 1993).

Table 6: Estimated Costs of Adaptation of Agriculture to Canada's Climate

Sector/Activity	Total Cost ($M)	% Attributable to Climate Adaptation	Costs of Climate Adaptation
Research	325.0	80.0%	260.0
Pesticides	707.1	40.0%	282.8
Heating Fuel	186.8	100.0%	186.8
Crop Insurance	652.4	90.0%	587.2
Irrigation	16.0	80.0%	12.8
Total	**1,887.3**		**1,329.6**

(Source: Herbert, 1994.)

Climate variability also has a highly significant impact on the efficiency of agricultural operations. The estimated costs of adapting agriculture to current climate are outlined in Table 6. As with the forestry costs, these costs are approximate and incomplete (e.g. they do not include land use and operational costs), and assume that no adaptation has taken place or new opportunities taken advantage of. However, these figures provide an indication of the numbers involved.

In addition to the direct effects of climate, there are indirect effects such as the vulnerability of soil to erosion, which depends, among other things, on the moisture content of the soil and on the timing and intensity of rainfall and wind (Rosenberg 1992). Also, flooding from excessive summer precipitation can cause losses in areas of poor drainage.

4.5.6 Construction

The field of construction is highly sensitive to weather, particularly in Canada. Weather limits many construction tasks, such as excavation, earthmoving, pile driving, foundation works, concrete placement, steel erection, masonry, crane operations, exterior finishing, paving and road building (Davenport 1994). Snow, for example, affects operations on site and a variety of weather conditions, including snow, can affect transportation to and from the site (United Kingdom Climate Change Impacts Review Group 1991). Wind can affect the operation of cranes. High humidity interferes with plastering and painting and, in conjunction with high temperatures, may affect cement. Low humidity and high evaporation rates can crack concrete. Finally, variations in temperature, solar radiation and cloud cover play a very important role in the thermal expansion and contraction of materials (Maunder 1970).

Climate also has an indirect effect on the construction industry. In preparing tenders for work, for example, contractors need to assume down time for inclement weather. In addition, severe weather events at more distant locations can increase the cost of building materials and labour.

4.5.7 Finance

Summaries of the costs of climate have been provided in the forestry and agriculture sections above. This Section deals mainly with the insurance and compensation industry's costs that are associated with climate.

The crop and property insurance industry is very vulnerable to climate variability and to extreme events. The worldwide annual insured cost of weather-related disasters has risen rapidly since the 1960s.

No consolidated data were found for the financial impact of tornadoes, forest fires or hail; however, data on flood damage exist. Between

1837 and 1989, 507 flood events have been recorded in Ontario. Damage from 127 of these floods was estimated at between $378 million and $1.3 billion (in 1989 dollars), affecting 1,550 municipalities. Shoreline damage, mostly to property, was estimated at $188 million (in 1989 dollars) for floods occurring between 1859 and 1987. An ice storm from January 4 to 10, 1998 brought severe destruction to Eastern Ontario, Southwestern Quebec and areas near the Bay of Fundy in New Brunswick and Nova Scotia. The storm brutalized one of the largest populated areas of North America, leaving millions of households without power for days to weeks and leading to at least 25 deaths, many from hypothermia. The storm directly affected more people than any previous weather event in Canadian history. Record losses are estimated for roof collapses, burst water pipes, temporarily shelter and accomodation, and cleanup costs, with the bill for the insurance industry alone likely to exceed $1 billion.

4.6 Regional Air Issues

Munn and Maarouf (1997) identified six issues of the atmospheric environment currently being assessed in Canada: climate change, stratospheric ozone, acidic deposition, smog (e.g. ground-level ozone episodes), suspended particulate matter and hazardous air pollutants. The last four can be

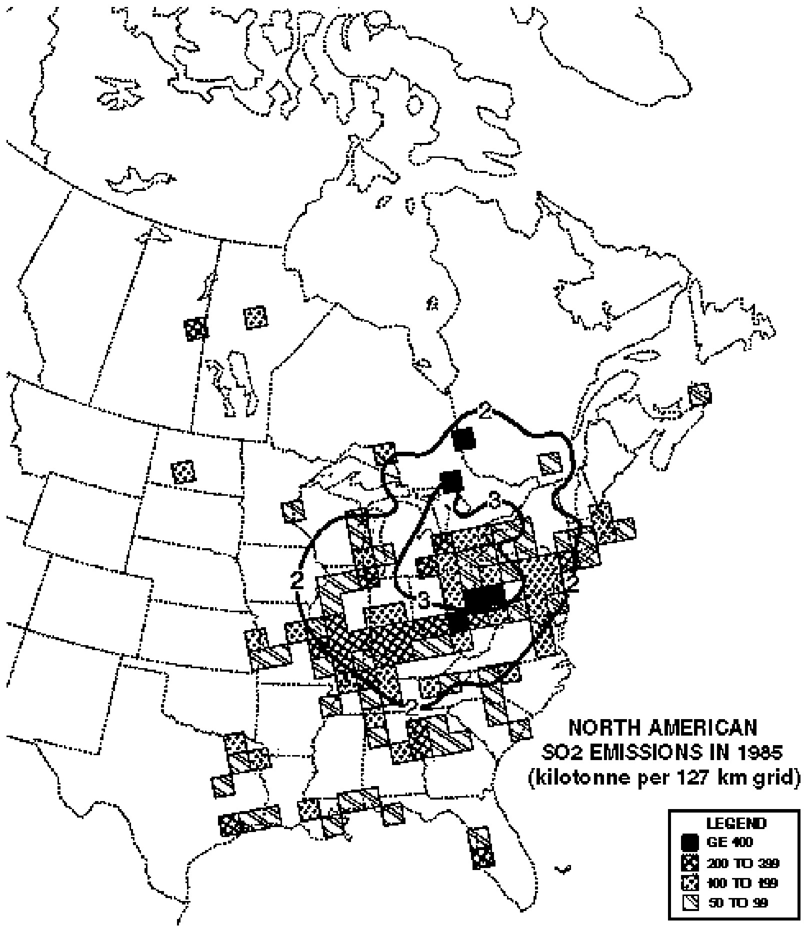

Figure 4. Sulphur dioxide emission patterns: superposition of the 1982-87 six-year average excess sulphate concentration isopleths (2 and 3 mg/l) on the 1985 SO_2 emission pattern. A comparable map of NO_x emissions and excess nitrate concentration isopleths shows a similar pattern. (Source: Environment Canada 1990.)

termed “regional” air issues, dealing with air quality on scales ranging from fifty to thousands of kilometres. By contrast, the first two air issues (climate change and ozone depletion) are global in scale. “Local” air quality problems can usually be connected to individual sources that affect areas on the scale of a few kilometres or less.

These regional air problems are due to the widespread emissions of modern industrial society. A recent report by the Ontario Ministry of Environment and Energy (OMOEE 1995) shows that associated ambient pollution levels and emission rates have been decreasing, but there are still periods during which provincial air quality criteria are exceeded. Moreover, current projections are that some of these reductions may be reversed in future (NEIPTG 1996), as a result of population and economic growth. The health costs are already significant: Land et al. (1995) estimated that for the Windsor–Quebec corridor between 1997 and 2020 the total savings from reduced concentrations of particulates, ozone and airborne toxic chemicals could be $7 to $21 billion (in 1994 dollars).

Weather and climate are important factors in air pollution, affecting the dispersion and transport of contaminants, and also affecting the reactions between these contaminants, which produce secondary pollutants such as ground-level ozone. The linkage between climate change and these four regional air issues is complex and only partially understood (Maarouf et al. 1997).

4.6.1 Acidic Deposition

The acidic deposition problem in Canada as a whole is the subject of recent scientific assessments (Environment Canada 1990, 1997). Areas of Southern Canada (including Southern Ontario) and the Northern United States that border the Great Lakes receive the highest levels of acidic deposition in the eastern half of North America (IJC 1996), reflecting the location of the greatest emissions of sulphur and nitrogen oxides (Figure 4, Environment Canada 1990).

The processes that control the distribution and concentration of acidic precipitation are dependent on weather conditions (mainly wind, temperature, humidity and precipitation) that affect the transformation, transport and deposition of acid rain (Martin 1989). The displacement between the maximum emission and the maximum deposition areas is attributed to the averaged effects of long-range transport.

4.6.2 Smog

Two types of smog are of concern in Ontario. The first is photochemical smog (Los Angeles-type or summer smog), which is dominated by photochemical processes whose components of concern are secondary pollutants, primarily ground-level ozone (O_3), and other oxidation products such as peroxyacetyl nitrate (PAN). The second is sulphurous or London-type (UK) smog, which is mainly made up of particulates and gaseous oxides of sulphur (Oke 1997).

The occurrence of smog events in summer depends on the presence of precursor gases. Ozone is created when precursor gases react together through a sunlight-driven process. The precursor gases are nitrogen oxide compounds (NO_x) and volatile organic compounds (VOCs), whose concentrations show relationships with temperatures. Therefore, ground-level ozone concentration is typically high on hot, sunny summer days. Emissions of the precursor gases related to summer smog have been decreasing over the past 24 years in the province, but ground-level ozone concentrations still regularly exceed provincial air-quality criteria. This is partly caused by transport of the precursor gases from the U.S. Midwest and the Ohio Valley. Figure 5 shows the average number of days per year on which the National Air Quality Objective for ozone (maximum acceptable hourly value) is exceeded. The general decrease in frequency moving from Windsor towards the northeast indicates the diminishing effects of transport from the United States. The local maximum along the northwest shore from Lake Ontario reflects the emissions from the Greater Toronto Area, which can also have an impact on downwind portions of the United States. The highest concentrations of ozonetend to occur along the shores of the Great Lakes, where localized lake breeze circulations can prevent dispersion (OMOEE 1995).

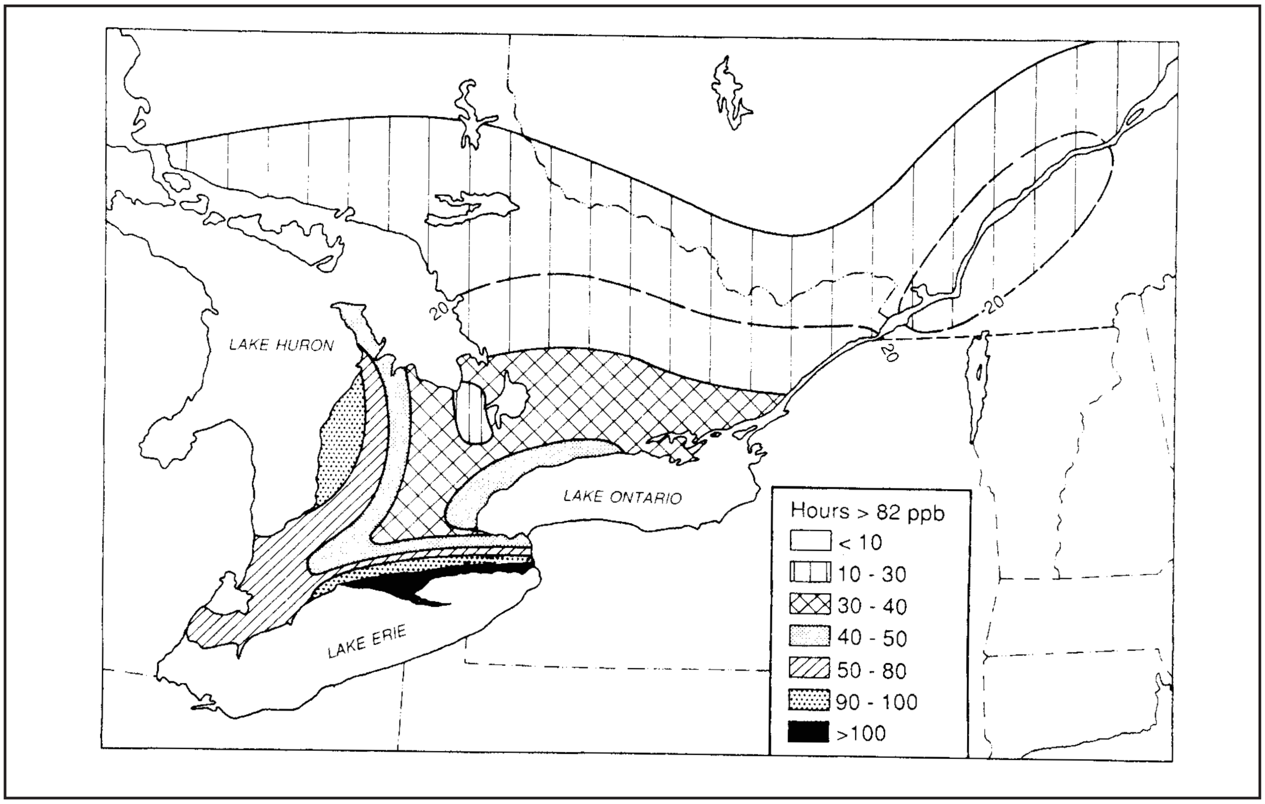

Figure 5. Average number of days per year in Ontario on which the hourly maximum ozone exceeds 82 ppb, the National Air Quality Objective maximum acceptable level. (Source: Fuentes and Dann 1993, based on 1980-1991 data.)

In Ontario, London-type smog is more localized than summer smog. It is most often problematic in Hamilton and parts of Metropolitan Toronto.

The Ontario Ministry of Environment and Energy has developed preliminary estimates of the economic cost (health effects) associated with smog. Depending on the scenario, reduced ground-level ozone concentrations could save between \$74 and \$716 million annually. This estimated value of savings takes into account reductions in mortality and morbidity (including chronic bronchitis), hospital admissions, asthma, restricted activity days and other respiratory problems in the year 2015 (OMEE 1996).

4.6.3 Suspended Particulates

Suspended particulates, or aerosols, include both solid particles and droplets (excluding phases of water) suspended in air and ranging in diameter from 0.005 to 100 µm (10^{-6}m), though typically less than 40 µm. These particulates vary widely in chemical constitution, and arise from many different natural and human sources. Substances known to be toxic (such as asbestos or radionuclides) are commonly not considered in this category; the effects of biological materials, such as spores and pollen (typically larger than 10 µm (10^{-6}m)) are also not considered for air quality purposes

The issue of suspended particulates is receiving increasing attention because of the health hazards associated with inhalable and respirable particulates, those smaller than 10 and 2.5 µm in size respectively (CEPA/FPAC WGAQOG 1997). Anthropogenic emissions of particles less than 2 µm in size typically are produced by the condensation of hot vapours from a combustion process. Larger particles are produced by mechanical processes such as abrasion or grinding. Fugitive dust is often a large source, which is not considered in all inventories.

In areas of dense urbanization and extensive road networks, transportation is a significant source of particulates. In the City of Toronto, an estimated 70 percent of suspended particulates come from transportation, compared with 13 percent over the entire province (Municipality of Metropolitan Toronto 1996). Monitoring reports of total suspended particulates (OMOEE 1995) show significant improvements during the 1970s, but mixed progress in more recent decades. Data for fine particulate fractions are insufficient for trend detection.

The formation, ground-level concentrations, transport, variability, size and chemical structure of particulates are affected by weather conditions and climate. There are linkages with both the acidic deposition and smog issues, since some particulates are a secondary pollutant, formed by photochemical processes, and ground deposition of some aerosols contributes to total acidic deposition.

4.6.4 Hazardous Air Pollutants

Toxic or hazardous air pollutants (HAPs) include a range of chemicals such as heavy metals, polychlorides, radionuclides, agricultural pesticides and persistent organics. Their transport, transformation and deposition depend on wind patterns, moisture, temperature and humidity.

For some HAPs, particularly persistent organic pollutants (POPs) such as certain pesticides, the transport process does not happen all at once but consists of a series of steps comprising a process termed “the grasshopper effect.” For this class of HAPs, temperature controls the rates of evaporation, condensation, and re-evaporation or re-volatilization, determining the amount of toxin that is available for transport by wind and eventual wet or dry deposition in other locations. As a result of the grasshopper effect, POPs gradually move away from the area in which theyoriginated, in a cycle of successive evaporation and deposition phases. Long-range transport of airborne pollutants is believed to be responsible for elevated levels of POPs in such relatively pristine areas as the lakes of Northern Ontario, most notably Lake Superior.

Monitoring programs cover only a small number of compounds out of the total number of HAPs in the atmosphere, precluding a comprehensive view of their presence, impacts and trends in Ontario. About 200 chemicals have been identified as HAPs on the basis of their potentially harmful effects on human and ecosystem health (Bradstreet 1995).

5.0 SECTORAL OPPORTUNITIES AND SENSITIVITIES TO FUTURE CLIMATE

5.1 Introduction

Knowledge about the potential impacts of climate change is essential in order to formulate and implement appropriate response strategies. This information is the foundation upon which sound policies, based on a mixture of measures, can be built. These measures could include (EARG et al. 1995):

- *limitation*: reducing greenhouse gas emissions to limit anticipated climate changes and impacts;
- *adaptation*: taking steps to adapt to these climate changes and impacts; and
- *information gathering*: investing in research to reduce the uncertainty about climate processes and impacts.

Less investment in limitation measures will lead to more rapid climate change and greater adaptive expenditures. In the end, some adaptive measures will still need to be considered, even if the most stringent limitation measures are adopted in future.

However, trying to predict or assess future climate and the impacts of that climate is extremely complicated. Not only is the current understanding of the climate system lacking in some significant areas, but so is the understanding of how climate interacts and affects many aspects of our social and biophysical environment. There are a multitude of intricate interconnections between various economic and natural sectors that make a comprehensive integrated assessment of impacts extremely difficult. These uncertainties are compounded further by the fact that the assessments, of necessity, are made on the assumption that societal values, goals and economics will remain as they are today. Looking back over the changes that have occurred in the 20th century alone, it is evident that this will not be the case. While there are many arguments to suggest a cautious approach in using General Circulation Models (GCMs), the models remain one of the most useful tools in identifying trends and providing indications of what the future climate will be like in the event of a doubling of greenhouse gases or equivalent carbon dioxide concentrations.

5.2 Future Climate Scenarios

Scientists use computer simulations or models to understand the behaviour of the global climate system and to predict its future evolution. These climate models vary from simple descriptions of a few physical processes to very large and sophisticated GCMs that attempt to simulate an interactive climate system over time covering three dimensions. GCMs have become the primary tool for assessing the net effect of increasing atmospheric concentrations of carbon dioxide and other greenhouse gases on global climate (EARG et al. 1995).

The behaviour of components of the climate system can be described by equations based on the fundamental laws of physics, including the laws of thermodynamics and conservation of mass, energy and momentum. A model of the whole climate system can be created by combining many equations of many processes into a large integrated model that can consider how changes in one equation will influence the other equations and vice versa (model feedbacks). These GCMs also contain information on present and future concentrations of greenhouse gases, with the more recent versions incorporating atmospheric aerosols. About a dozen GCMs exist world-wide, including a Canadian version.

The Canadian Centre for Climate Modelling and Analysis (CCCma), under the Atmospheric Environment Service of Environment Canada, has developed a series of atmospheric GCMs of increasing complexity. The earlier models are described in this report as the Canadian Climate Centre (CCC) GCMs. Recently, the CCCma developed a global coupled atmosphere-ocean model.

5.2.1 Types of Future Climate Scenarios

The various outputs from general circulation models or other climate models are called climate change scenarios. These scenarios refer to plausible future climates. At present, we have no way of determining the best type of climate scenario to use; nor can we determine the accuracy or probability of occurrence because of the many uncertainties that remain. Nevertheless, a range of climate scenarios can highlight this uncertainty and indicate the nature and extent of sensitivities to climate variability and change. It should be pointed out, however, that even a range of scenarios may not necessarily circumscribe the future climatic conditions that will eventually emerge. Furthermore, modellers are just beginning to examine the role of climate variability and extreme events, in addition to climate means, in the development of the scenarios.

General Circulation Models (GCMs)

As noted above, GCMs are the most advanced, physically based tool for developing climate change scenarios. They represent some of the complex interactions of physical processes that link (1) the radiation budget of the atmosphere and surface with global circulation, and (2) the hydrologic cycle and heat exchange with the ocean. These models have generally been used to provide simulations of the global climatic response to a doubling of the atmospheric concentration of carbon dioxide; they provide an internally consistent representation of the sensitivity of the climate system to increased greenhouse gas concentrations (Kattenburg et al. 1996). Although these models are very complex, they are still a crude representation of the real climate system and are limited by our knowledge of climatic processes and feedback mechanisms, such as aerosols, water vapour, cloud cover and changes in vegetation. Furthermore, while these models can capture the important large-scale features of the global climate system, their coarsespatial resolution and the fact that temperature and precipitation patterns can vary significantly on a regional scale imply that the model results should not be used blindly. As a result, advances in the development of regional climate modelling capabilities are being followed closely. GCM outputs should be regarded as broad-scale sets of possible future climatic conditions, not as predictions (Carter et al. 1994).

GCM simulations can be classified broadly into two types: equilibrium and transient. The simulations from earlier years are generally "equilibrium 2xCO_2," that is, the atmospheric concentration of CO_2 is doubled, and the GCM is run until it achieves an equilibrium with respect to the perturbed radiation forcing. More recent simulations are mainly "transient 2xCO_2." In these experiments, GCMs are typically allowed to reach equilibrium with a base level of CO_2 concentrations, and then these concentrations are gradually increased. Clearly, the latter process more faithfully replicates the actual situation. Such experiments indicate that the climate system response will lag increases in atmospheric CO_2 concentrations by many years. Therefore, conditions described by equilibrium 2xCO_2 experiments may not be realized until well after CO_2 concentrations have doubled.

It is important to make this distinction between equilibrium and transient experiments, because many of the earlier impacts studies that were performed for Ontario used equilibrium 2xCO_2 simulations to drive models of other processes affected by climate (e.g. Cohen et al. 1988). Consequently, it is difficult, if not impossible, to estimate a date by which the impacts described in these studies might be realized. Certainly, it would be inappropriate to use forecasts of the date when CO_2 doubling is likely to occur, owing to the aforementioned lag in climate system response. Given current projections for greenhouse gas emissions, climatic conditions similar to those described in equilibrium 2xCO_2 simulations will probably not be realized until the latter part of the 21st century.

Grid-point output from GCMs actually represent area averages of quantities over a four-sided grid space, centred on that point; so these are not point values. The model represents grid squares as homogeneous areas over which sub-grid scale features such as the Great Lakes are smoothed (Grotch et al. 1991). Due to the coarse spatial resolution of present generation GCMs, all continental grid points are classified as land. In GCM grid-point arrays for North America, there are no water points over most of the Great Lakes region and over other large inland water bodies (except for Lake Superior and Hudson Bay). Consequently, the GCM outputs do not reflect the presence of features that have a considerable effect on local climate. Estimating lake temperatures, precipitation over the lake surface, lake-effect precipitation, lake ice cover or lake evaporation requires additional procedures that use GCM-simulated air temperature, wind, etc. as the starting point (e.g. Croley 1990a, b). While this sequential modelling approach gives some indication of the impact of the Great Lakes on the local climate, it does not give the total picture since the Great Lakes also exert considerable impact on the general circulation.

The GCMs that have been used for the studies quoted in this report are the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), the Oregon State University (OSU), the Canadian Climate Centre (CCC) and the second generation Canadian Climate Centre (CCC GCM II) models.

Limited Area Models (LAMs)

One way to develop climate model output at finer spatial scales than those from GCMs is by employing Limited Area Models (LAMs), which are higher resolution meteorological models tuned to represent important physical processes over a smaller domain. The nested LAM uses the large-scale meteorological fields produced by the GCM as a first guess and for boundary conditions, and uses relevant physical processes to generate plausible estimates of climate variables at higher resolution. LAMs usually run at grid resolutions of 10 to 100 km (Giorgi et al. 1991).

Owing to their coarse resolution, neither GCMs nor LAMs are proficient at simulating convection, which typically occurs on the scale of a few kilometres. Convection is the principal mechanism responsible for warm season precipitation and severe summer weather (e.g. thunderstorms and tornadoes). Convection also playsan important role in some cold-season events.

Historical Analogues

Employing historical analogues to develop scenarios involves the use of known historical climatic situations to represent a changed and often extreme climatic condition that might occur in the future. Historical climate analogues can be derived from paleoclimatic data (such as tree rings, pollen, lake sediments and ice cores) or from the historical observational record (IJC 1993; Carter et al. 1994). While the physical mechanisms and boundary conditions giving rise to these climates are most certainly different from those involving greenhouse gas-induced climate change, analogues can focus on climate anomalies that can have significant short-term impacts (i.e. droughts, cold spells). Shifts in magnitude, frequency and duration of extreme events often affect society more markedly than changes in average climate conditions, and thus their impacts need to be better understood. While these scenarios should not be used as forecasts of the future state of the atmosphere or of society on which to base specific policy responses to hypothetical regional climate changes, they are an effective learning tool (Changnon 1991). In addition, historical analogues and other scenario-generating techniques are useful for sensitivity studies, and there is no reason to exclude them from impact analysis. Given the weaknesses of historical analogue scenarios, the IPCC (Intergovernmental Panel on Climate Change) suggests they be used in conjunction with physically based scenarios, such as those from GCMs (Carter et al. 1994).

Climate Transposition

Climate transposition, also known as a spatial analogue, involves relocating an existing, analogous climate condition to the study area

(Changnon 1991; Carter et al. 1994). Transposition climate scenarios, like historical analogue scenarios, were developed specifically to introduce changes in the mean and the variability of climatic elements to examine the sensitivity of systems to both these changes. The published results of coupled GCMs under doubled CO_2 conditions suggest that continuing increases in atmospheric trace gas concentrations will result in warmer conditions, comparable to climates south of the Great Lakes. Therefore, the future climate of the Great Lakes may be similar (at least in terms of annual means and other very general features) to the present climate of regions to the south and west of the Great Lakes.

The most significant problem of this approach is arguably the effects of stationary features of the climate system, which affect climate independently of anthropogenic forcing of the atmosphere, including topography, latitude (available solar radiation/seasonal distribution) and large bodies of water such as the Great Lakes.

5.2.2 Future Climate Scenarios for Ontario

From a global perspective, the various GCM experiments appear to agree upon a number of important aspects.

- A doubling of CO_2 or its equivalent will eventually cause an average global temperature rise of 1.5°C to 4.5°C. Results clearly exclude a zero change in temperature (IPCC 1996a).
- Over the next century, the rate of global average temperature rise will be 0.2°C to 0.5°C per decade. The cooling effect of increases in industrial aerosols may reduce this rise by 0.1°C per decade (IPCC 1996a).
- Land areas will warm more than oceans. High northern latitudes will warm more than equatorial regions. The greatest warming will occur in high northern latitudes in winter. Precipitation and soil moisture could increase in high latitudes in winter. Drier summer soil conditions could be found in interior continental regions of northern mid latitudes.
- Studies for northern mid latitudes suggest that a larger percentage of rain could fall as heavy downpours (Whetton et al. 1993).
- Over the next century, sea levels will rise by 3 to 8 cm per decade and will continue to rise for centuries after the global climate has stabilized (IPCC 1996a).

In Ontario, results from some of the latest GCM simulations, with an atmosphere containing twice the current amount of greenhouse gases, suggest an average warming of 2°C to 5°C by the latter part of the 21st century. Even if greenhouse gas concentrations stabilize at that point, temperatures would continue to increase thereafter, with an overall warming of 3°C to 8°C expected. The increases are indicated to be greater in winter than in the summer. These changes would significantly decrease the duration of the annual snow season, would lengthen the growing season, and could increase the frequency and severity of extreme heat events in summer.

While changes in the mean annual temperature could be dramatic, the greatest impacts are expected to result from the indirect changes in other climate conditions. These include changes in rainfall patterns and soil moisture, and possible changes in the frequency and severity of weather disasters such as severe thunderstorms, hailstorms, tornadoes and even hurricanes (EARG et al. 1995).

5.3 Water Resources

The most profound direct impacts of changes in the climate system are expected in the hydrologic cycle: increases in evapotranspiration, regional changes in precipitation (snowfall and rainfall), and changes in surface runoff and soil moisture (Idso 1989).

5.3.1 Great Lakes Water Levels

The impact of a greenhouse gas-induced climate change on the water levels of the Great Lakes has been the subject of numerous studies. The results of these studies are summarized in Table 7. All the scenario results suggest that the water levels will decrease to, or perhaps below, historical low levels. (Cohen 1986, 1987, 1988; Hartmann 1990; IJC 1993). As noted in Section 5.2, it is quite likely that the climatic conditions giving rise to the impacts described will not be experienced until the latter part of the 21st century.

Cohen's 1987 study set out to determine "the sensitivity of annual net basin supply and soil moisture levels in the Great Lakes Basin to changes in certain climate parameters, over a wide range of climate parameters." The study focused in particular on temperature, precipitation, atmospheric vapour pressure and wind speed, with the major goal being to determine how much additional precipitation would be needed to overcome a warming of 2°C. This study acknowledged that consumptive use will have a significant impact on future net basin supply, but did not consider it. The main conclusion of this study was that most of the scenarios project a decrease in net basin supply and a decrease in the summer soil moisture content despite an increase in annual precipitation. The scenarios that included changes in surface wind speed and humidity revealed significant changes, reflecting the importance of lake evaporation to net basin supply. These parameters are not well handled by the GCMs so use of their outputs to derive specific predictions of net basin supply involves a substantial element of uncertainty.

Another 1987 study, based on equilibrium 2xCO_2 scenarios, concluded that mean Great Lakes levels may be reduced 30 to 80 cm and mean flows in the connecting channels may be reduced by 20 percent. Furthermore, if International Joint Commission (IJC) estimates of consumptive use of Great Lakes water for the year 2035 are superimposed on this scenario, the frequency of low levels (such as those of the 1930s and 1960s) would occur in 8 out of 10 years (Sanderson 1987).

In studies by both Croley (1990b) and Hartmann (1990), average lake levels were estimated to fall in all lakes, dropping to below historical low means in Lakes Michigan and Erie. The declines shown by Croley and Hartmann are the result of higher air temperatures reducing snow-pack and increasing evaporation. Neither of these studies considered the potential increase in consumptive uses.

A study by Mortsch et al. (1996) applied four GCM scenarios to historical climate time series data as per Croley (1990b, 1993). The study also used climate transposition scenarios (described earlier). The combination of these scenarios gives a fairly comprehensive sensitivity study but should not be considered a prediction. The results indicate, in general, a warmer climate with uncertain changes (that is, either positive or negative) in precipitation. The modelling results suggest that the potential exists for major changes in the hydrologic cycle in the Great Lakes Basin. In the four GCM scenarios, the supply of water to the Great Lakes decreases although precipitation increases throughout large portions of the basin. The warmer air temperatures and higher rate of evaporation and evapotranspiration increase moisture loss, decrease runoff and lead to a decline in lake levels. The warmer climate leads to increased water surface temperatures and changes in the thermal structure in all lakes, resulting in potential changes in ice cover and habitat temperatures. In some GCM scenarios the lake-level decreases are quite significant (e.g., Lakes Michigan-Huron and Lake Erie levels drop more than 1 metre in three of the GCM scenarios). Water-level declines of this magnitude would have important impacts on wetlands, fisheries and human use of the shoreline. Decreased flows in the St. Lawrence River would allow salt water to penetrate further upstream. Again, since none of these scenarios take proper account of the influence of the lakes themselves or other important physical processes in and around them, the results must be interpreted with care.

5.3.2 Water Supply

The impacts of climate change on both quantity and quality of water supply will manifest themselves in many ways. Several terrestrial components of the hydrologic cycle will be affected by the changes in temperature, precipitation, evaporation and evapotranspiration. These components are runoff, groundwater recharge, stream flow and soil moisture.

Table 7: Impacts of Climate Change Scenarios on Various Climate Variables Significant to the Great Lakes

Model Variable	GISS [a]	GISS [b]	GISS [c] (transient)	GFDL [a]	GFDL [d]	CCC-GCM	CCC GCM II [e]	GISS [e]	GFDL [e]	OSU [f]
Temperature	• increase	• increase	• increase	• increase	• increase	• increase	• increase	• increase	• increase	• increase
Precipitation	• no change	• annual increase • decreases in August-December	• decrease in autumn	• decrease	• slight spring decrease • significant decrease in summer	• increase in northwest • decrease in southeast	• increase in north • decrease in southwest	• increase in north • sharp autumn drop	• wet winters • drier springs	• increase moving southeast to northwest
Evapotrans-piration	• increase			• marginal increase						
Snowmelt	• decrease			• decrease						
Runoff	• decrease			• decrease			• decrease	• decrease	• decrease	• decrease
Lake evaporation	• increase			• increase						
Water Deficit	• increase			• increase						
Wind speed		• decrease in autumn • increase in winter								
Net Basin-supply (NBS)	• decrease by 4–20% (depending on winds)				• decrease by 4–18% (depending on winds)					
Water Level			decrease by: • 0.4–0.5 m Superior, • 1.3 m Michigan-Huron • 1.0–1.2 m Erie				• decrease	• decrease	• decrease	decrease by: • 0.47 m Superior, • 0.99 m Michigan-Huron • 0.87 m St. Clair, • 0.79 m Erie

[a] Cohen 1986; [b] Cohen 1987; [c] Smith 1991; [d] EARG et al. 1995; [e] Mortsch and Quinn 1996; [f] Hartmann 1990

Smith et al. (1993) and Smith (1991) analyzed the potential impacts of a doubling of atmospheric CO_2 on direct surface runoff in the Grand River Basin, using three GCM model outputs. The results indicated a decrease of 12 percent to 35 percent in the contribution of surface water to the Grand River flow.

Studies of changes in surface water resources and groundwater recharge rates suggest large decreases in water supply. For groundwater supply, the effect is dependent on both the rate of uptake and the depth of well being used. The results of a study by McLaren et al. (1993) project a 15 percent to 35 percent reduction in the rate of groundwater recharge for the Grand River Basin under a $2xCO_2$ climate change scenario. This reduction in recharge rate led to a 17 percent to 39 percent reduction in groundwater discharge to the Grand River.

In general, it is anticipated that a warmer climate will mean earlier peak stream flows. If the anticipated increase in winter precipitation comes in the form of snow, the peak flows will also be greater since there will be a larger accumulation of snowpack. If the winter precipitation comes in the form of rain and runs off immediately, it is anticipated that peak flows will be smaller and winter floods more frequent (Nuttle 1993). It has been estimated that under $2xCO_2$ scenarios, stream flow will decrease by 8 percent to 25 percent in the Great Lakes Basin (Cohen 1986, 1987; Hartmann 1990) and by 16 percent in the Grand River (Sanderson et al. 1990). In the James Bay area, it is estimated that stream flow will increase by 10 percent to 16 percent (Singh B. 1988). Areas that have decreased peak flows are likely to also have decreased stream flow late in the summer.

Soil moisture has been estimated to decrease by 14 percent to 67 percent in the Great Lakes Basin (IJC 1991). Sanderson et al. (1990) estimated that the summer moisture deficit may double in the Grand River Basin by the latter half of the next century.

The changing climate may also lead to greater variability of water levels and flows. Much of existing industry, built environments, and transportation and distribution systems are not resilient to changes in flows and levels, especially if destabilized by a greater number and severity of extreme events. The impacts of this variability are likely to affect aquatic ecosystems, wildlife, tourism, recreation, transportation, power generation, fisheries, effluent and drinking water treatment, and the local availability of water for agriculture, industry and urban areas.

5.3.3 Water Demand

Cohen (1987) studied the possible impacts of climate change on municipal water use. Using two GCM scenarios, summer water use was projected to increase by 5.6 percent under one scenario and by 5.2 percent under the other scenario. If winter water use remained unchanged, the scenarios suggested that the annual average increase would be 2.6 percent and 2.4 percent respectively. While noting the conservative nature of the study–it did not include extreme events–the study concluded that this would have only a marginal effect on Great Lakes water supplies and levels.

In the agricultural sector, Brklacich (1990) estimated that more irrigation would be needed in Southwestern Ontario for the three crops that were assessed. Declines in water levels in lakes and rivers due to climate change may be exacerbated by irrigation withdrawals. However, implementing water-saving techniques could reduce the total water used in agriculture, including aquaculture and golf courses, by an estimated 16 percent to 23 percent (Ecologistics Limited 1993).

Implementing water management strategies may successfully mitigate some of these increases in demand; however, the net effect province-wide is unknown, especially given the uncertainty of growth in demand for water outside the Great Lakes region (EARG et al 1995).

Boundary Waters

Future disputes over water supply are likely to make existing challenges in water management more difficult, especially in the Great Lakes Basin as agencies justify conflicting demands of various stakeholders. Conflicting demands are likely to intensify, both among sectors (e.g. agricultural, municipal/residential and recreational) and among geographic areas.

Potential changes in the Great Lakes have regional, national and international implications for interprovincial and binational management of water resources. At the continental level, demands for diversion of Great Lakes water are likely to intensify. There could be demands for water levels to be raised in the Mississippi River system and for water to be supplied to areas of the Southern United States that have already made intensive use of their surface water resources (such as the Colorado Basin, or areas such as the Plains states, where the Ogallala Aquifer is being drawn at a rate faster than its natural recharge rate). In addition, there could be demands for diversion of water through New York (via the Hudson River system) to supply the expanding Boston-New York-Washington megalopolis.

Actions such as water control measures, construction of new water infrastructure for diversions and improved management of water resources aimed at increasing sustainability may be required in order to adapt to new conditions brought about by climate changes. At the very least, these actions are likely to require refinement and strengthening of institutions for the governance of water resources and their uses in Ontario. Climate changes may also lead to pressures for diversion of water within Ontario, complementing the continental pressures, to divert water from the Hudson Bay–James Bay watersheds into the Great Lakes basin and then ultimately out of the basin.

As such demands intensify, water could well become a continental issue in the 21st century in the same way that oil and gas were a continental issue in the 1970s and 1980s.

5.4 Human and Ecosystem Health

5.4.1 Human Health

Climate change is expected to have some adverse impacts on human health. Some of these impacts will be direct and others indirect. Direct effects could include an increase in deaths related to heat stress, especially since consecutive days of high humidity and hot conditions early in the summer season contribute most to sizeable increases in mortality in Toronto. Likely indirect effects include changes in the range of vector-borne diseases and water and food-borne diseases; and an increase in the incidence of respiratory disorders from climate and air pollution (see Sections 4.6, 5.7) (McMichael 1996). Winter mortality will be affected minimally by climate change; these deaths are largely dependent on the spread of infectious diseases, and a few degrees increase in winter temperature is unlikely to lessen indoor confinement to a degree where transmission of such diseases would be noticeably diminished (Kalkstein 1995).

Direct Impacts in Ontario

Few studies have been conducted specifically on the effect of climate change on human health in Ontario. Kalkstein et al. (1993) estimated the potential impacts of climate change on human heat-related mortality for 10 cities in Canada, including Toronto and Ottawa. There appears to be a significant relationship between weather and mortality in Toronto and Ottawa. For cities that only occasionally experience hot, humid air masses during most summers, the effects could be very negative. According to the World Health Organization (WHO 1990), some level of acclimatization to heat will occur. It is expected that short-term heat waves or periods of intense heat, rather than long-term warming, will have the most profound and direct effects on health. Heat stress and thermal discomfort are also intensified by increased humidity.

Potential changes in severe weather events could also pose an increased threat to human health. In addition to the direct effects of cold weather, heavy rain, large hailstones, heavy snowfalls and snowpacks, and high winds, extreme events can cause contamination of water systems and create breeding sites for insects or favourable conditions for rodents that carry disease (Patz et al. 1996). For example, heavy rains in the Southwestern United States in 1993 led to an explosion in the population of deer mice, which contributed to an outbreak of hantavirus. A new strain of the virus has been found in western Canadian provinces in the past two years, and another strain has been found in most eastern provinces (Evanson 1997). During the summer of 1997, an Owen Sound area resident who succumbed to hantavirus was the first confirmed fatality in Ontario attributed to this outbreak.

A build-up of greenhouse gases in the lower atmosphere has the potential to trap more heat near the surface of the earth resulting in a relative cooling of the stratosphere. This would produce conditions more favourable for the depletion of protective ozone in the northernmost latitudes. Polar stratospheric clouds which accelerate ozone removal processes require temperatures of -80°C or lower. Depletion of the stratospheric ozone during the last 15 years has increased surface UV-B levels in southern Canada. Increased UV radiation levels have been linked to increased incidence of skin cancer, cataracts, and deficiencies in human immune systems. However, the interactions and impacts are uncertain since controls from the Montreal Protocol and subsequent amendments on stratospheric ozone-depleting substances are expected to allow the ozone layer to recover to normal levels (pre-1980 conditions) by the year 2050.

Impacts on Ontario from Other Areas

Concern exists regarding diseases that have not previously existed in Ontario but may move into this region. For example, scientists fear that illnesses once common only in hot climates are moving northwards into Southern Ontario. One such example is St. Louis encephalitis, carried by the Asian tiger mosquito (Evanson 1997). Malaria and Lyme disease are other diseases feared to move north, although the IPCC considers the emergence of malaria unlikely (McMichael et al. 1996), given our existing public health resources (disease surveillance, surface-water management and treatment of cases). Pearce (1995), however, suggests that the most virulent form of malaria could spread into Ontario. Malaria has been predicted for parts of Southern Ontario under some 2xCO_2 scenarios, and at least one model has suggested that the disease may invade other parts of the province. Furthermore, Pearce suggests that unprepared or non-immune populations are most at risk and that seasonal malaria reduces the amount of immunity that a population can build up, leading to a higher death rate.

Climate change is expected to cause changes in many of the variables affecting the atmospheric concentration of pollutants, but it is not possible to determine the degree of change at any specific location (WHO 1990). Asthma and hay fever are two examples of allergies that are triggered by aero-allergens that cause high seasonal morbidity (Maarouf 1995). Since ground-level ozone, particulates and toxics appear to be most prevalent in Ontario when hot and humid maritime Tropical (mT) air masses are present, changes in the frequency and northward extent of episodes involving these pollutants will likely be correlated with the increased incidence of mT air masses.

5.4.2 Ecosystem Health

As noted in Sections 5.2 and 5.3, climate change is expected to cause increased temperatures and may affect hydrologic regimes, thereby altering the environmental conditions under which particular ecosystems were formed and to which species and ecosystems are currently adapted. Many ecological systems could be dramatically changed. For example, large shifts could occur in ranges of species, community assemblages could be restructured and some corresponding species could become extinct (Peters 1992; Campbell et al. 1993).

Ecoclimatic zones, defined as broad areas characterized by distinctive ecological responses to climate and expressed through vegetation, can be used as indicators of potential changes in climate (Anderson et al. 1998).

Figure 6 illustrates the major changes in eco-climatic boundaries that have been projected for Canada under a 1981 GISS climate model $2xCO_2$ scenario of climate change (Rizzo et al. 1989). It should be noted that this model makes a number of generalized assumptions (e.g. reducing ecoclimatic regions of Canada to only 10, thereby obscuring the heterogeneity of regions; and not considering the suitability of the substrate in the new location). As a result, the projected changes in distribution should be viewed as suggesting the general direction of change, and not as a specific predictor of the future distribution of ecoclimatic zones and ecosystems. The results suggest that arctic, subarctic and boreal ecoclimatic zones will contract as cool temperate, grasslands and moderate temperate regions expand northwards (Rizzo 1990; Rizzo et al. 1992).

The changes in ecoclimatic boundaries under climate change only suggest areas where temperature and precipitation may be suitable for the broad vegetation groups. A number of factors may hamper the ability of vegetation groups, and other associated species, to migrate to areas with favourable climatic conditions. The shifting of ecoclimatic zones will affect aquatic ecosystems, wetlands, forests and wildlife distribution. Species that are unable to migrate in response to climate and/or are unable to adapt to changed local conditions will become at least locally extinct. Because individual species experience different sensitivities to climate and have varying abilities to migrate, biological communities are not likely to migrate as whole systems. Consequently, climate change will produce new distributions and assemblages of species, create new predator-prey interactions and new interspecific interactions (such as parasitism) and cause widespread disruption to communities and ecosystems (Peters 1992).

Of particular concern is the rate of projected climate change. Some reports suggest that the rate of climate change, particularly when combined with other factors such as land-use change, could exceed the capacity of natural adaptation to support current biodiversity.

Aquatic Ecosystems

Climate change is expected to have considerable impact on the hydrologic regime. The Great Lakes Basin will likely experience changes in precipitation, decreased runoff, increased evapotranspiration and decreased water levels (see Section 5.3.1). Impacts of climate change on northern regions of Ontario remain unclear, but evidence from other northern regions of Canada suggests that runoff may increase (Cohen et al. 1994). The effect on water resources associated

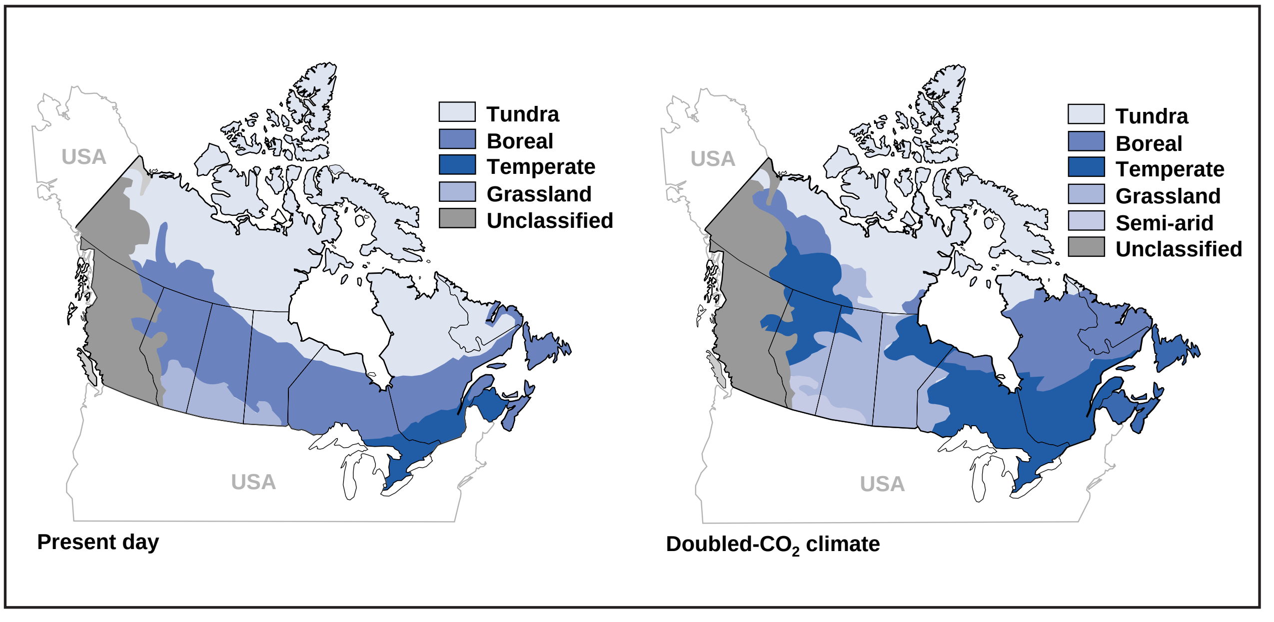

Figure 6: Changes In Ecoclimatic Boundaries Under A $2xCO_2$ Climate (Adapted from Rizzo 1990.)

with climate change is expected to alter the aquatic ecosystems, resulting in fish species redistribution (Minns et al. 1992).

The consequences of global change for freshwater ecosystems have not been investigated. Most of the studies that have attempted to predict impacts on Ontario fish species have concentrated on the Great Lakes. In the southern part of the basin, where climate warming is anticipated to cause a major increase in the areal extent of waters that are warm in summer, the centrarchid family (e.g. black basses and sun fish) and the percichthyid family (e.g. white bass and white perch) are expected to expand their ranges at the expense of the percids (e.g. walleye and yellow perch) (Meisner et al. 1987; Regier et al. 1988; Meisner 1990). But the percids may expand their ranges in the northerly half of the basin, where the midsummer warming of waters that formerly were too cold for the percids expands the area of cool waters that the percids prefer. In the summer, many of the nearshore parts of the Great Lakes and stream waters will become too warm for salmonids (e.g. lake trout, brook trout, Pacific salmon, lake whitefish and lake herring), but these fish will experience optimal temperatures earlier in spring and later in autumn (Regier et al. 1988).

Although fish species are expected to alter their lateral and vertical spatial distribution in response to climate change, the ultimate impact of such rearrangement on total fish production is uncertain and will depend on factors such as the influence of nutrient loadings from human activities and the impact of climate change on wetlands. Fish production in Lake Erie, for example, may suffer from adverse synergistic interactions between climate warming and cultural nutrient loadings. On the other hand, the colder and quite sterile waters of the northern part of the basin may benefit from synergism between climate warming and moderate inputs of nutrients from human sources. Throughout the basin, the impact of climate change on the distribution and productivity of wetlands (discussed below) and on their efficacy as spawning and nursery areas will affect fish production levels (Regier et al. 1988).

One of the few studies on a boreal lake in Northern Ontario suggests that climate change and acidic deposition, by decreasing the dissolved organic carbon concentrations in lake water, will increase the penetration of UV-B irradiation, which would have potential negative repercussions for aquatic organisms and would compound the existing stress from the increased acidity in northern lakes (Yan et al. 1996).

Many streams are expected to undergo fluctuations in water-renewal rates and to have reduced water levels in response to climate change. As these streams dry, mobile organisms become concentrated, resulting in intensified competition among organisms. Reduced water flow can also concentrate pollutants, which could increase the severity of the impact of the pollutants on aquatic organisms. The fluctuations in the water-renewal rate could also cause fluctuations in primary production and cycling of nutrients, which could affect the productivity of the stream and its ability to support its full complement of aquatic organisms. Ultimately, these changes in water supply and their associated impacts could negatively affect the survival of aquatic organisms; in addition, these changes will only compound the stresses aquatic organisms currently experience as a result of watershed modifications and the contamination of aquatic resources by humans.

Finally, aquatic ecosystems may be more vulnerable to species invasion under climate change scenarios. Evidence suggests that fish species such as the white perch, which experience decreased over-winter mortality at slightly elevated water temperatures, could migrate to and invade water bodies previously outside their ranges (Johnson et al. 1996). Mandrak (1989) assessed the probability of 58 common, widely distributed species invading the upper Great Lakes (Lakes Superior and Huron) from the lower Great Lakes (Lakes Michigan, Erie and Ontario) and the probability of the lower Great Lakes being invaded from the Mississippi and Atlantic coastal basins. Of these 58 species, 27 were judged to be potential invaders of the Great Lakes as a response to climate warming. The change in fish distribution and abundance would have implications for commercial and recreational fishing (see Section 5.6.3).

Wetlands

Wetlands, which provide habitat for many species, are among the most productive ecosystems. Important functions of wetlands include flood mitigation, aquifer recharge, pollution trapping, carbon cycling and providing resources such as peat. Wetlands are expected to be directly affected by changes in hydrologic and energy systems. The climate variables of temperature, precipitation and solar radiation and the resulting water supply changes are the most important factors affecting wetlands.

The total area and distrubution of wetlands will be altered by climate change, but impacts will vary from region to region and from one type of wetland formation to another. Shoreline wetlands along the Great Lakes will be affected by changes in lake levels, although the degree of impact will depend on the type of wetland formation: certain open shoreline wetlands may be able to migrate lakeward, whereas more enclosed wetlands will dry out, resulting in an associated loss of ecological diversity (Wall et al. 1986b; Meisner et al. 1987; Koshida 1989; Mortsch 1990;).

A study of the potential impacts of climate variability on a Northern Ontario wetland basin suggests that a temperature increase of 5°C, without any change in precipitation, would reduce the level of the water table and lead to drying out of wetlands, with repercussions for wetland formation and species composition. On the other hand, this same degree of warming when combined with a wetter climate would keep the basin water storage at a level close to the historical level and would maintain the wetland (Woo 1992). While subarctic wetlands may shrink, those in the boreal region of the Hudson Plains may persist, although their composition may change; shallow lakes and tundra ponds may be converted into wetlands as evaporation intensifies (Woo 1992).

Changes in structure of wetlands and littoral areas may reduce their efficacy as spawning and nursery areas, and changes in fishery yields of preferred species are expected (Meisner et al. 1987).

The anticipated changes in wetlands will affect human activities through a loss of income from animal and crop resources of a wetland, and through the reduced ability of wetlands to support recreation and tourism, education and science. It is possible, however, that some of these losses could be offset by converting some wetland areas to other productive uses such as agriculture.

Forests

Many studies have attempted to predict the impacts of climate change on forests and the forestry industry (Solomon 1986; Maini 1988; Lavender 1989; MacIver et al. 1989; Pollard 1989; Rizzo et al. 1989; Wheaton et al. 1989; Wheaton et al. 1989; IPCC 1990; Overpeck et al. 1990a, 1990b; Schwartz 1991; Cohen 1994). Although considerable uncertainty remains in accurately predicting the response of forests to climate change (Cook et al. 1991), the application of certain climate change scenarios to models of tree response suggest a northward displacement of forest zones with an eventual decrease of up to 80 percent in the extent of boreal forests in Canada (Wheaton et al. 1989; Overpeck et al. 1990a). In Eastern North America, studies suggest that the north and south boundaries of boreal forests, mixed conifer-deciduous forests, and deciduous forests may shift as much as 500 to 1,000 km during the next 200 to 500 years (Overpeck et al. 1990a).

Certain characteristics of boreal forests (including the fact that stands are mainly even-aged and their distribution is often limited primarily by temperature) make these forests particularly sensitive to future climate change. Moreover, temperature increases are expected to be greatest at the latitudes where the boreal forests are located (Duinker 1990). The boreal forests, like other forest ecosystems, are expected to migrate northwards though vegetation will only begin to approach a state of stability in relation to local climate when the rate of climate change slows substantially. The southern boundary of theforest is expected to shift more than its northern boundary, resulting in a net loss in forest size (Duinker 1990) The boreal forest is currently susceptible in the southern border regions where moisture shortages or high fire frequencies seem to limit conifer growth.

While the boreal forest in Ontario is expected to be degraded (by the combined effects of thermal stress, increase in diseases and pests, and greater fire frequency and intensity) and to have its distribution considerably reduced, the distribution of hardwood forests could expand into the southern transition zone of the boreal forest (DPA Group 1986; Hengeveld 1991).

Under doubled CO_2 concentration, the ranges of sugar maple, beech, eastern hemlock and chestnut tree species are predicted to shift more than 500 km northwards during the next century. Tree migration rates following the last glacial period, which are believed to approximate maximum migration rates for most trees, averaged 10 to 40 km per century, with a maximum rate of 200 km per century for white spruce (Schwartz 1992). For example, beech trees in Michigan would need to move 100 km northwards per degree Celsius of warming, or about 300 km per century, which is greater than range extensions in the past (WWF 1992).

The above discussion highlights the great distance that forests may be required to migrate inresponse to climate change. Of particular concern is the rate of climate change, which various studies suggest may be faster than any seen in the last 10,000 years and may be as much as 15 to 40 times faster than past natural climate change (Peters 1992; Kattenberg et al. 1996). This rate of change may well exceed the ability of forests and other types of vegetation to adapt to new climatic conditions. Plants with less efficient seed-dispersal mechanisms, such as woodland herbs, may be in danger of extinction (WWF 1992).

Computer models of northern hardwood and boreal transition forests indicate that response to climate change appears to be affected more by the rate of climate change than by the absolute magnitude (Solomon et al. 1992). Furthermore, some studies suggest that current levels of habitat fragmentation will reduce potential migration rates to below those observed in the geologic past (Schwartz 1992). Finally, it should be noted that any possible countervailing positive effects from the increased levels of CO_2 in the atmosphere (CO_2 fertilization), such as greater efficiency in water-use for most plants and increased photosynthetic rate of some plants, have not been included in these estimates of tree migration rates.

Climate-related factors such as fire, insects and disease play key roles in the health of existing stands and in restocking. Climate change may lead to additional damage to forest ecosystems from pests and diseases, increased competition from unwanted species and increased fire frequency and intensity (Singh T. 1988). Although wildfire is a natural part of the boreal forest ecosystem and one that plays an important role in the regeneration of many tree species, changes in temperature, soil moisture and humidity suggested by GCM simulations could substantially increase wildfire frequency and intensity, resulting in changes to forest biomass and composition (Overpeck et al. 1990b; Ryan 1991).

In addition, climate change may cause forests to lose vigour and thus be particularly susceptible to wildfire, with a potential 40 percent to 50 percent increase in forest fires throughout Canada (Sedjo 1991; Flannigan et al. 1991). Rapid climate change may cause massive tree dieback in the mixed forests of Southern Ontario, thereby producing a large fuel supply for wildfire (Campbell et al. 1993). Furthermore, the regeneration of burned areas may not take place under new climatic conditions because of the increase in fire intensity. Forests can take centuries to recover from severe burns, particularly in northern areas, where boreal forests may be replaced by grasslands or temperate deciduous forests.

Finally, wildfires may not only act as agents for change in ecosystems, but also create a feedback by increasing the flux of carbon to the atmosphere, further enhancing climate change. Following a time lag, which may last a century or more, the opening of the forest canopy may causean increased albedo, leading to a cooling effect. Either effect has serious implications for climate change (Campbell et al. 1993).

The increased frequency of disturbance, especially fire, and the increased incidence of contagion that are expected under climate warming may affect younger stands of boreal forests more than older ones, possibly impeding the establishment and migration northwards of new, younger stands (Li et al. 1996).

Ultimately, these climate-induced changes in distribution of forest ecosystems, combined with associated diebacks (Solomon 1986; Reed et al. 1992), are expected to change both supply and demand of forest resources.

Forest management can mitigate some of these effects, and the level of management will play an important part in determining the degree of effects experienced. Management options include more frequent and intensive thinning to capture mortality, more intensive tending of coniferous plantations and more aggressive pest management (Duinker 1990). Greater efforts to identify trees whose genetic characteristics make them more adaptable to new conditions and increased transplanting of propagules and seedlings in new regions could assist tree migration. Nevertheless, efforts to assist tree migration could be hindered by the slow growth of trees: even if conditions in an area meet the needs of a seedling, by the time it matures, the climate will have changed again and may no longer be suitable for the adult tree.

Wildlife

Changes in the distribution of vegetation directly affect wildlife distribution and survival. As boreal and temperate forests migrate polewards, creating transitional forests or habitats, many species (e.g. many birds, caribou and slow-dispersing moisture-loving forest plants) will be unable to have their specific ecological needs met in the transitional forests or the habitats that replace them (WWF 1992). In addition, projected increases in forest fires could parallel past events and destroy moose and caribou habitat, leading to increased competition for food and a temporary decrease in numbers (Fritz et al. 1993).

Climate change could lead to direct habitat loss through means such as changes in water levels, forest cover, snow cover and water temperatures in lakes and streams. Decreases in habitat size tend to increase the risks of extinction of populations. Climate change could also create fragmentation of existing wildlife habitat in many ways. For example, increases in storm intensity and frequency as a result of a changing climate could lead to more frequent and intense fires caused by lightning strikes. Where forest habitat is already partly fragmented with patches linked by corridors, fire can sever these links, causing even greater fragmentation and consequent disruption of migration pathways. Fragmentation of habitat can result in a reduced gene flow across the landscape, as well as population declines within the remaining patches (Anderson et al. 1997). Migration of climatic zones northwards could leave current reserves and parks as habitat islands. These reserves and parks could suffer species losses as a result of their size, their isolation and a shrinkage of suitable habitat. These protected areas will no longer experience the climatic conditions necessary for the preservation of the originally intended species.

In many cases, the current suitability of most ecosystems in Canada as wildlife habitat is determined as much by human management of these habitats (e.g. agriculture, forestry and fisheries) as through natural characteristics of these systems. As a result, changes in human-related land and water use may have as much influence on the quantity and quality of wildlife habitat as changes induced directly by climate change (Anderson et al. 1997). In the case of wetlands, for example, it has been estimated that since 1800, about one-seventh of Canada's wetland resource, which is an important habitat for wildlife, has been converted or lost through agriculture, urbanization, recreation and other human-related changes.

More research is needed to assess the potential impact of climate change on Ontario's wildlife species and their habitats. Research is also needed to assess specific impacts on individual species.

Implications for Biological Diversity

Worldwide, the extinction of plant and animal species is accelerating as a result of human activities, and climate change will add to the stresses. Due to Ontario's current climate, its biological diversity (or biodiversity) is not as great as in other areas of the world. Nevertheless, Ontario's biodiversity is under threat from competing land-use activities such as urban development, agriculture and forestry. Additional stresses associated with climate change, including the extent and rate of warming, the increase in fire frequency and intensity, and the increased incidence of diseases, will compound the pressures exerted on Ontario's biodiversity.

Our national and provincial parks and biological reserves, which have a duty to protect selected ecosystems and species, have been formed on the basis of the current distribution of species and ecosystems. Climate change will affect protection efforts since changing environmental conditions will alter species assemblages and ecosystems. The current distribution of parks and reserves in Canada may no longer support the ecosystem or species it once did. Changing climatic conditions may cause the extinction of, or decline in, species as they are forced to compete with new introductions of species in a changing habitat.

Species currently threatened with extinction will be subjected to the greatest risk of extinction. Species that are highly specialized (including many rare species) and thus less able to adapt to changes in temperature, precipitation and climatic zones may be replaced by generalist species, thereby changing the ecological and aesthetic characteristics of the natural world as climate change progresses (Henderson 1989).

Climate change could exacerbate the factors that contribute to species' extinctions. For instance, rare species can be driven to extinction by an increase in catastrophic events such as fires. Climate change could also enhance the opportunities for successful establishment of exotic species, Historically, the introduction of exotic species has been a major cause of species extinction.

Finally, even if species have the ability to migrate rapidly enough to adapt to climate change, their dispersal is sometimes impeded by human development, limited suitable habitat and habitat fragmentation, all of which effectively act as barriers to dispersal (Peters 1992).

An influx of species migrating from the south may add to Ontario's biodiversity, but will also be an agent of change, possibly causing increased extinctions through new predator-prey interactions and new interspecies competition. Some concern regarding the impact on biodiversity appears to be justified in the face of the expected break-up and reassortment of communities, the disturbance of food webs and food supply, and the effect of a human-dominated and fragmented landscape.

Climate change will put conservation of existing species under significant pressure. There are also likely to be more frequent conflicts between agricultural and forestry land uses and the conservation of biodiversity as economic activities are adapted to climate change. Land used for a certain purpose in the present may no longer support that use with a changed climate. Current land-use planning is inflexible with regard to these potential changes; a more integrated approach will be required to facilitate changes in land-use designations, while ensuring that the overall needs and balance of each land use are met.

Humans value biological resources both for use and non-use (such as existence or intrinsic) values. While damage costs for some of the lost uses of plant and animal species may be quantified, the cost of species loss to traditional cultures and lifestyles or to the portion of society that values species for their existence or intrinsic values is more difficult to quantify.

5.5 The Built Environment

As in Chapter 4, a distinction is made here between the effects of climate and weather on the construction process and the implications of climate variability for structural design. The potential impacts of climate changes on the design and engineering of infrastructure are examined in this Section. The possible impacts of climate change on the construction industry will be looked at in Sub-section 5.6.6.

Concern over global warming is focusing concern on climate variability and extremes. The experiences of the insurance industry world-wide display, in dramatic fashion, the impact of extreme events on the built environment. Disaster losses in Canada from 1992 to 1996 rose 65 percent compared to the previous five-year period, mostly caused by severe weather. The three most costly Canadian disasters occurred in this decade: Calgary's hailstorm of September 1991 ($343 million), the Saguenay region's flood in July 1996 (more than $350 million) (Harries 1997) and the January 1998 ice storm with its record losses. The IPCC (1996b) Second Assessment Report states: "Within the construction sector, it is essential to identify the standards required and adhere to these. Often, incorrect construction is to blame for damages and indeed, one the great future issues will be how to 'retrofit' substandard buildings" (with respect to current building codes and associated standards).

The building industry has long recognized the need to design for weather extremes through use of climatic design values. Whether the costs of coping with factors such as snow and wind loads (4 percent of construction costs, or about $4 billion a year) will increase or decrease remains unclear. As winters become warmer, snow-load requirements will likely decrease in some areas and increase in others, depending on the type of precipitation received (snow or rain).

Climate change will mean a reduced need for winter heating; increased need for summer cooling; and greater possibility of foundation instability from higher winter rainfall, increased frequency of freeze-thaw cycles and drier summers.The more frequent freeze-thaw cycles could also increase weathering of materials. Since heating,ventilation and air conditioning systems in buildings are sized according to extreme heat, cold and wind (Davenport 1994), their specifications may need to be re-evaluated to ensure that they continue to perform satisfactorily. In far Northern Ontario, degradation of permafrost may affect the stability of existing structures and the conditions for future construction.

The safety, serviceability and economy of the built environment depends strongly on accurate and realistic predictions of climatic variables, particularly extremes. Even without taking into account the potential trends caused by global warming, long-standing gaps and deficiencies in the determination of climatic design values today prevent optimum decisions from being made now and into the future (Dalgliesh, 1997). For example, good geographic coverage is lacking in some areas and this will worsen if one result of global warming is the relocation of industrial and agricultural activities to previously less populated areas.

With regard to adapting existing structures to climate change, it is unknown whether the margin of safety built into the National Building Code will be sufficient to maintain safe and economical structures, even with good workmanship and materials. However, in areas where the current code is deficient, those deficiencies could be exacerbated or ameliorated by changes in climate. As a result, climatic design values for national infrastructure codes and standards will need to be continuously assessed. For example, temperature loads for structures such as bridges and railway lines will require review (United Kingdom Climate Change Impacts Review Group 1991) as will snow and wind loads for buildings. Furthermore, return periods for major floods will have to be assessed as a result of increased peak flow in some areas. Safety standards will have to be revised to reflect such changes.

The design life of the structure will also be important in assessing the required changes as a result of climate change. Structures with a design life of 30 to 50 years will need to consider a different set of climate factors than will a structure with a design life of 100 years. Although bridges, roads and buildings can have a physical lifetime of several hundred years when properly maintained, urban infrastructure often has a relatively short life span because population, urban activity and other factors can change significantly within a shorter period (Scott 1995). Similarly, different components of structures will display varying sensitivities to climate change. For example, heating, ventilation and cooling systems have a shorter design life than the building they are housed in and can be changed more readily to adapt to a changing climate.

Changes in the frequency or intensity of extreme events will have consequences for the property insurance industry and possibly for disaster-relief agencies. Additional funding is needed for the development of a network supporting the investigation of natural disasters. Disaster investigations pay dividends in mitigation and adaptation measures for future events (Dalgliesh 1998). Performance of structures during extreme events should be monitored to confirm and further fine-tune climatic design values.

In Canada, buildings account for more than one-third of all energy use including space and water heating, lighting, cooling, ventilation and equipment. The built environment consumes more energy than that, considering the energy inherent in the manufacture and transport of building materials. Buildings can contribute to the mitigation of global warming by becoming more energy-efficient and reducing greenhouse gas outputs. The pursuit of energy efficiency requires increased attention to the construction of durable and healthy building enclosures. Considering the embodied energy needed to manufacture building materials, owners need to extend the useful life of structures by providing for change in use at some later stage. Research may be required into ways of incorporating flexibility in design, allowing economical rearrangement and reuse of components and assemblies (Dalgliesh, 1998).

In addition to those listed in Section 4.4, considerations concerning the effects of climate change on the engineering and design of buildings and structures include the following:

- the impact of climate change on the water table, water supply and water demand;
- the impact of changed precipitation patterns on the design of surface drainage; and
- the impact of climate change on flooding (United Kingdom Climate Change Impacts Review Group 1991).

5.6 Industry

This section reviews what is known about the relationship of climate change with the following industrial sectors: energy, transportation, tourism and recreation, forestry, agriculture, construction and finance.

5.6.1 Energy

Much of the information in the following energy sector relates to hydropower production and residential energy consumption. As was noted in Section 4.5.1, Ontario uses less hydroelectricity and more electricity from nuclear power plants than the national average.

Energy Demand

Ontario is Canada's most significant energy user. Today, primary energy demand in the province is met mainly by refined petroleum products, nuclear electricity and natural gas. By 2020, it is projected that natural gas and refined petroleum products will remain Ontario's main sources of energy (Mercier 1998).

Overall, greenhouse gas emissions from the energy sector in Canada are projected to increase by 22 percent by 2020. These projections reflect some of the benefits of incentives (regulations, research and development, financial incentives and information) aimed at reducing greenhouse gas emissions.

The energy demand sector can be highly dependent on climatic conditions through space heating and cooling requirements. Bhartendu et al. (1987) found that "space-heating requirements per household in Ontario would change significantly in two $2xCO_2$ scenarios, but actual total energy consumption would depend on population growth." Their study concluded that for moderate or low population growth, total residential energy consumption for heating and cooling would be less in 2065 than it was in 1985. Under high population growth scenarios, energy consumption would be higher than it was in 1985, despite climatic warming. It was also found that the lower demand for space heating in winter along with a higher demand for cooling in summer could result in net savings. These results are corroborated in the 1987 Sanderson study, which concluded that the total annual energy demand would decrease by

2 percent to 3 percent. The changes in energy demands and costs associated with increased cooling are more difficult to estimate than those associated with decreased heating since heating loads depend strongly on temperature while cooling loads depend on many climatic elements (temperature, humidity, solar radiation, cloud cover, wind). It is difficult to estimate the net changes in many of these elements under climate warming.

A recent study conducted at the University of Toronto analyzed the relationship between an increase in temperature and the occurrence of heat waves. This study concluded that an increase in the number and duration of heat waves is highly probable; furthermore, a strong correlation exists between maximum temperature and peak power consumption (Columbo 1997). This indicates that while overall demand may decrease, peak power demand may increase, requiring alteration to the structure of the electrical power supply system.

Studies on transportation indicate that higher temperatures would have some influence on vehicle-fuel consumption. For example, the warm-up period for engines would be reduced under a warmer climate, resulting in greater engine efficiency. However, warmer summer temperatures could also lead to increased use of air-conditioning in vehicles and a greater requirement for refrigeration in the trucking industry. Changes in weather and climate conditions could also affect transportation operations and fuel efficiency in directions and intensities that are not completely known now.

Energy Supply

Hydroelectric power production could be reduced if stream flows decrease and lake levels are lowered. While less severe than the levels shown in the climate change scenario, the extreme low levels and flows of the 1960s resulted in production losses of 19 percent to 26 percent on the Niagara and St. Lawrence Rivers (Allsopp et al. 1981).

The reliability of the flows through the Great Lakes makes the Great Lakes hydro generating stations very valuable for energy generation. In 1979, 41 percent of Ontario Hydro's hydraulic generation used Great Lakes water (Sanderson 1987). Using an equilibrium 2xCO_2 GISS model experiment, Sanderson's study concluded that the St. Marys plant, located on the St. Marys River, would increase production by 2.5 percent because of the greater difference in elevation between Lake Superior and Lakes Michigan–Huron, given that levels in the latter are reduced more than those in Lake Superior. However, production at the Niagara plants would decrease by 18 percent at the DeCew plants and by 13 percent at the Sir Adam Beck plant; production at the St. Lawrence plants would be reduced by 2 percent to 5 percent. If we superimpose the increase in consumptive uses of water projected by the IJC for the year 2035, the decreases would range from 39 percent at the DeCew plant to 22 percent at the Beck plants, with a slight increase at the St. Marys plant. The effect of increased consumption was not evaluated for the St. Lawrence plants. In general, changes in the hydrologic cycle may result in more variability in water supply for hydroelectric power production.

These losses may be compensated for by an increase in the use of fossil fuel, nuclear power and alternative forms of energy. It has been estimated that replacing this lost production with a mix of nuclear and fossil fuel generation would cost Ontario Hydro between $34 million and $65 million (in 1979 U.S. dollars) annually.

Other considerations include the vulnerability of pipelines to permafrost degradation in other parts of Canada, possible decreased efficiency of thermal generating units and the lower capacity of power transmission lines as temperatures rise and transmission losses increase (Moreno et al. 1995). Furthermore, changes in the frequency of freezing precipitation would have corresponding implications for icing of power transmission lines. Changes in storm frequency could affect the infrastructure that supports the transmission and routing of electricity, causing transmission lines to become less reliable and requiring strengthening of the infrastructure.

Solar and wind energy production are highly sensitive to weather and climate changes. While climate change might mean modified wind regimes, more frequent storms and changes in cloud cover, the regional distribution of these changes are not well understood. As a result, the design and location of solar and wind equipment might have to be adapted to new climatic conditions. Windmills, for example, may have to be built to more robust specifications to withstand more extreme winds. Some thermal energy plants in the province that burn coal transported by ship from the United States could be affected by lower Great Lakes water levels. These lower water levels would result in maximum loads carried on lake vessels being reduced, owing to draft limitations in some channels.

5.6.2 Transportation

An IBI report completed for Transport Canada states that there are likely to be substantial impacts on all modes of transportation, some beneficial and some resulting in increased costs (IBI Group 1990).

Reduced ice on the Great Lakes is expected to increase the length of the shipping season. Lower lake levels could also adversely affect inland (lake) shipping by reducing the maximum capacity for vessels and increasing the operating costs for ports and shipping channels. Changes in shipping conditions on the Great Lakes could also affect demand for bulk shipment by rail. In addition, changes in production of climate-sensitive commodities such as agricultural products could affect demand for rail and marine transport.

The need for snow removal and aircraft deicing could be reduced in Southern Ontario. Shorter seasons are anticipated for winter road maintenance in Northern Ontario. In summer, higher temperatures could have the effect of requiring greater maintenance of roads because pavement buckles under long periods of intense heat; however, construction practices can minimize this impact. Other less apparent and less certain effects include the costs associated with the increases in variability of climate, including rain, fog, snow and ice.

Further considerations include the higher consumption of fuel resulting from increased use of air conditioning in vehicles in urban areas. The possible northward spread of agriculture, forestry and mining activities would result in new demand for transportation infrastructure in these areas (Irwin et al. 1990). Table 8 summarizes the results of impact studies on transportation.

5.6.3 Tourism and Recreation

Impact studies suggest that the direct effects of climate change will generally be negative for winter activities and positive for summer ones. The length and reliability of Ontario’s outdoor winter recreation season are projected to decrease with climate change. For example, the reliability of suitable skiing conditions is based on the snow-cover suitability percentile, defined as the percentage probability of a day with snow-cover of at least 5 cm, no measurable liquid precipitation and a maximum temperature lower than 4.5°C (modelled after Crowe et al. 1973c). Table 9 shows the projected impacts of climate warming on the ski seasons in the Lakehead, southern Georgian Bay, and Kitchener areas.

In most Ontario locations, climate change is projected to shorten the ski season and decrease the reliability of suitable snow cover. In Kitchener and the Southern Georgian Bay area, the entire season will be reduced to either marginally reliable or unreliable conditions, with snow cover significantly reduced over the economically important Christmas break. Projections are more optimistic for the Lakehead area, although the season may be shortened to the extent that revenues currently collected over the school March break may be lost with warmer winters.

The opposite effect is projected for beach and park visitation. On the basis of an increase in future temperatures, the number of annual camper nights spent in provincial parks are projected to increase under both the GFDL and GISS climate scenarios (Wall et al. 1986a). Similarly, assuming that the climate-temperature relationships observed over the recent past are applicable at the time when an equivalent doubling of atmospheric carbon dioxide is reached, increases are projected for beach and park visitation in Sauble Beach, Ontario (Alexander 1997a).

Lower lake levels (Cohen 1986; Sanderson 1989) and changes in stream flow and water quality are projected to have a negative effect on

Table 8: Impacts of Climate Change on Transportation

Area	Biophysical Change	Impacts
Marine: Great Lakes	• Lower lake levels	• Reduction in available draft and efficiency of lake fleet leading to higher shipping costs. • Lower levels may be mitigated with control structures. • Frequency of low-level years could increase to 8 years out of 10. • Increased dredging costs with associated environmental costs.
	• Longer ice-free season	• Ice-free period will increase length of shipping season.
Roads: South	• Generally higher temperatures	• Lower efficiency of heat engines which may be offset by less requirement for "warming up". • Less winter maintenance because of reduced need for snow removal. • Better drainage required.
	• Higher winter temperatures and greater precipitation	• Better drainage required.
Roads: North	• Higher temperatures	• Increased costs of road construction and maintenance (e.g. degradation of permafrost and higher snowfall). • Less use of winter roads; more demand for cargo movements. • Shorter seasons for winter maintenance but greater snow removal effort (increased snowfall) during the snow season (but confidence in this impact is low due to the number of factors involved).
Rail	• Higher temperatures	• Lower efficiency of heat engines. • Possible decrease in winter maintenance. • Longer Great Lakes shipping season will even out seasonal demand for eastbound grain but could also mean loss of winter bulk traffic. • Possible increase in agricultural traffic.
Air	• Higher temperatures	• Lower "lift" of aircraft. • Lower efficiency of heat engines. • Less use of winter airstrips. • Longer season for float planes.
	• More precipitation/ stronger winds	• More down time and/or need for navigation aids. • Northward shift of winter storm tracks (but this is uncertain) could result in fewer snow delays.

(Source: IBI Group 1990.)

Table 9: Reliability of Snow Cover for Skiing: Comparisons of the Past with Climate Change Scenarios

		November			December			January			February			March		
		I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Lakehead	Normal			▨	■	■	■	■	■	■	■	■	■	■	■	▨
(McBoyle et al. 1986)	GFDL				▨	■	■	■	■	■	■	■	▨			
	GISS					▨	■	■	■	■	▨	■	▨			
Southern Georgian Bay	Normal						▨	■	■	■	■	■	▨			
(McBoyle et al. 1986)	GFDL							▨	▨	▨	▨	▨				
	GISS															
Chicopee, Kitchener	Normal					▨	▨	■	▨	■	■	▨	▨			
(Brotton 1990)	CCC GCM						▨	▨		▨	▨	▨				

I - 1st to 10th day of month
II - 11th to 20th of the month
III - 21st to end of month

■ reliable-75% or greater probability of suitable snow cover
▨ marginably reliable-50% to 75% probability of suitable snow cover
□ unreliable-less that 50% probability of suitable snow cover

Climate Change Models
GFDL - Geophysical Fluid Dynamics Laboratory
GISS - Goddard Institute for Space Studies
CCC GCM - Canadian Climate Centre General Circulation Model

closed marshes (e.g. Point Pelee) along the Great Lakes shoreline. Wetlands provide important habitats for migrating waterfowl and other birds,and are hatching grounds for fish. Therefore, in addition to the loss of the amenity value of wetlands, their reduction will cause a decline in hunting, birdwatching and other outdoor activities (Wall et al. 1986b). Lower lake levels could also cause navigational difficulties and increase the width of beaches (Rissling 1992; Alexander 1997a). Furthermore, as happened during previous episodes of extremely low water levels, the aesthetic quality of beaches may be compromised by rotting vegetation (Allsopp et al. 1981) and declining water quality.

The projected changes in recreation are subject to several types of uncertainty. The results presented here illustrate only potential changes in recreation due to the direct effect of climate change, but there are several reasons why the projected increases may not be realized. As a result of limitations in the General Circulation Models at the regional scale (Cohen 1991), the magnitude and timing of future climate change is uncertain. In addition to uncertainties involved in the projection of the future climate itself, it is unclear how changes in climate will translate into changes in participation in outdoor recreation. Further, climate change will not occur in isolation while everything else remains static; rather, climate is just one of several elements that will evolve. Changes in other recreation areas, population and the availability of leisure time are just a few of the socio-economic elements that may be just as influential on recreation in Ontario, or even more so. Finally, even if the climate becomes more suitable for summer outdoor recreation, participation levels will be limited to some extent by the capacity of the tourist area. Unless capacity is expanded, increases in participation will likely be limited to the off-peak season, when levels are currently below capacity.

In summary, climate change is projected to have both positive and negative impacts on recreation in Ontario. The effects on outdoor recreation will have an influence on the entire provincial tourist industry because changes in participation in outdoor activities will influence indoor alternatives. Although projections of the impacts of climate change may be useful in making decisions that will produce the most desirable future for the outdoor recreation sector in Ontario, such projections must be considered in the context of the following issues: the magnitude and timing of climate change, new climatic limits on outdoor recreation, the socio-economic context in which climate change will occur and capacity limitations.

5.6.4 Forestry

The forestry sector is particularly vulnerable to long-term changes because of the long life spans or turnaround cycles (50 to 200 years) of forests and the relatively low levels of management input. Long-term (50-year) effects of climate change on wood supply could be significant as the supply from existing species runs out and the supply from new species is insufficiently developed. IPCC Working Group 2 considered that the boreal forests (which makes up approximately 29 percent of Canada's existing forest land) would be the most affected of the world's forests, partly because of the large temperature changes expected in areas where these forests grow.

Future climate conditions are expected to provide both opportunities and increased vulnerabilities for different regions of Canada (Smit 1989, 1993). Some economic studies (Van Kooten et al. 1989; Van Kooten 1990) indicate that global warming has the potential to increase world forest biomass and harvest volumes and to reduce prices. These studies concluded that both Canadian and American consumers would benefit initially, whereas timber owners would suffer from lower prices.

Changes in air temperatures are expected to have significant impacts for the northern boreal forest, while changes in the water balance may be more critical in determining any changes to the southern boreal forest. Temperature increases could lead to increases in forest growth rates in marginal areas that are currently limited by temperature but the increases may also lead to more damage from pests and disease, encourage competition from unwanted species and cause increased fire frequency and severity. Opportunities exist in the southern limits of the boreal forest for establishment of temperate forests, which may have to compete with other land-use pressures. Some studies suggest that the boreal forest in Ontario will be degraded and may ultimately be replaced by hardwood species (DPA 1986; Environment Canada 1991). At the northern border of the boreal forest, depending on soil type and water balance, new opportunities may arise as forest cover expands and provides industry for northern communities. Forest industry operating costs may increase because of a shorter winter harvesting season (Canadian Climate Program Board 1991).

Significant non-climate-related factors are also expected to affect the future of the forestry industry. In general, the following broad trends are anticipated in the boreal forests:

- A major shift will continue from old growth supply to planted and second growth supply.
- Large resources in boreal forests will be available to support expanded production if required.

It is evident that Ontario's forestry industry is vulnerable to current climate conditions, especially fire hazards and other issues such as land-use change. However, much uncertainty is associated with these results. It is important to keep in mind that the above conclusions have been based on impact studies that use a range of climate scenarios and different assumptions about external variables. As a result, the various studies and their conclusions cannot be easily compared with each other.

5.6.5 Agriculture

Northward expansion of agricultural viability is expected under climate change. However, this expansion will be limited by soil capability, increases in pests and plant diseases, and the frequency and severity of agricultural drought (Smit 1991). Although uncertainty exists about the results of the impact studies, the Canadian agricultural industry is clearly vulnerable to current climatic conditions. Future climatic conditions will provide opportunities for some regions of Canada and will cause others to become more vulnerable (Smit 1989, 1993).

While the exact nature of the impacts of climate change on agriculture remain unclear, the indications are that short-term climatic variability will continue to cause short-term perturbations in agricultural output and that future long-term changes in climate may alter the long-term agricultural potential of different regions (Parry et al. 1988). The magnitude and direction of potential long-term impacts are often crop and region specific.

Carbon Dioxide

Carbon dioxide or CO_2 is essential for photosynthesis and crop growth. If all other climate factors were to remain constant, a doubling of carbon dioxide concentration would be considered advantageous for crop growth (particularly wheat, rice and soybean) since it would increase the rate of photosynthesis and make water use more efficient. In fact, the IPCC Working Group 1 Report (IPCC 1990) states that the increase in CO_2 may lead to an improvement in crop yields as well as an enhanced ability to adapt to stressed environments. These results are based on studies conducted in laboratory conditions. Few studies have been published on the effects of increased CO_2 in combination with changes in temperature and rainfall in the field (Parry et al. 1991). In fact, the benefits of increased CO_2 may be negated by increased air pollution or UV radiation (Wolfe et al. 1993).

Increased CO_2 may also have an effect on the water requirements of some plants. Some studies have shown that increased carbon dioxide concentrations may lead to reduced transpiration and more efficient water use, lowering plants requirement for water. While yield results vary depending on the scenarios used, studies in the Prairies have shown that the benefits of this change may be more pronounced in areas that are currently very dry (Brklacich et al. 1994). However, many uncertainties remain, such as questions on the extent to which increased leaf area will offset reduced transpiration (Parry et al. 1991). In indoor labora-tory studies, increases in water-use efficiency have been observed, but these benefits may be negated in actual situations if higher leaf-to-air vapour pres-sure gradients result from higher leaf temperatures.

Temperature

In general, greenhouse gas-induced warming is expected to result in a potential increase in many crop yields. Longer and earlier frost-free periods extending the growing season by three to five weeks may provide opportunities to offset agricultural losses due to moisture losses for some crops. The investigations to date suggest that warmer frost-free seasons will accelerate the rate of development for grain crops, thereby reducing the time between seeding and harvest. In northern agricultural regions, new opportunities can be expected for production of grains and other crops such as oilseeds, forages and potatoes. The evidence on oilseeds indicates that increases in crop-moisture stress will suppress yields in many areas (Brklacich et al. 1998).

An increase in temperature and precipitation could create more favourable conditions for pest infestation. Pests that do not currently pose a threat may, under climate change, become more threatening.

Water Balance

Water availability will also be affected by climate change. While actual precipitation may increase in some regions, this will likely be offset by an increase in temperature of serveral degrees which will cause increased evapotranspiration, decreasing the amount of water available, particularly in dry seasons.

Table 10: Summary of Impacts of Climate Change on Ontario Agriculture

Temperature	Water Balance	Growing Season	New Opportunities	Vulnerability
• Impact of higher temperatures will vary from soil to soil and crop to crop.[1] • Temperature gradient between north and south will be reduced.[2]	• Drier seasons will mean moisture deficiency may become a critical constraint.[1] • Total growing season precipitation will increase because frost-free season will increase (length of frost free period less predictable - length of season more variable).[2] • Increased irrigation requirements are expected in Southwestern Ontario for corn[5,6],soybean and wheat.[6]	• Longer growing season may mean greater fluctuation in farm profits (length of season more variable).[1] • Available growing period for Northern Ontario may equal current season in Southern Ontario (depending on influence of lakes).[2]	• New opportunities may be presented in Northern Ontario.[1] • Grain corn, barley may become profitable in Northern Ontario.[2] • Economic opportunities for grain corn in Eastern & Central Ontario may improve.[2] • Longer season may mean new opportunities for soybeans in Northern Ontario.[2] • Land-base suitable for growing grain corn may increase by up to 5% in Central Ontario and by as much as 167% in Eastern Ontario.[1]	• Soils with relatively low moisture capacity are most sensitive to climate change.[6] • Barley yields will be reduced on lands with a low drought tolerance in Eastern and Central Ontario.[6] • One study concluded that barley and corn yields may decrease by up to 20%,[2] while another indicated that corn yields would decrease by as much as 14%,[5] in Southern Ontario. • Soybean production may be reduced in Central, Western Southwestern and South Central Ontario from 7% to 12%.[6] • Wheat production may decrease by 58% in Eastern Ontario, and 27% in Southwestern Ontario.[6]

[1] Brklacich and Smit 1992; [2] Smit et al. 1989; [3] Smit 1987a; [4] Hall and Burkholder 1993; [5] Viau and Mitic 1992;
[6] Brklacich 1990.

Radiation
The relationship between radiation and photosynthesis has been studied for several plant species. Studies on wheat and other crops show a linear relationship between radiation and photosynthesis within a certain range (Sinha 1991). Therefore, it is likely that a decrease in radiation resulting from increased cloud cover will result in altered crop productivity. Further research is needed on the potential implications for Canadian agriculture.

Impacts on Ontario
Specific studies of the effect of climate change on Ontario's agriculture have been conducted since the mid 1980s (Land Evaluation Group 1985, 1986, 1987; Smit et al. 1989; Brklacich 1990; Brklacich et al. 1992). Regional studies have also been conducted at smaller scales (Viau et al. 1992; Hall et al. 1993). Estimates of agricultural land production potential can be derived from the integration of agro-climatic and crop yield data along with an agricultural land database. These studies forecast a considerable expansion of the land suitable for commercial crop production into northern agricultural regions. One study suggests that while agricultural production potential in Ontario may decline, overall prospects would continue to exceed 1981 levels of production (Brklacich et al. 1992). In southern areas, climate warming is expected to expand the production of speciality crops such as fruits and vegetables beyond lakeside locations. Table 10 provides a summary of the results of these studies.

Opportunities for agricultural expansion will likely present themselves in three main categories: (1) expansion of existing practices, (2) introduction of new crops in existing areas, and (3) introduction of practices in new locations where agriculture is currently not feasible. If all other variables such as soil moisture and pest infestation remained constant, which they will not, Central Ontario could benefit from increased production potential of 40 to 50 percent (Hengeveld 1991).

Brklacich et al. (1992) analyzed impacts on the agriculture industry in Ontario in terms of long-term averages for monthly precipitation and temperature, and precipitation variability. The results show that the long-term changes in climatic averages are projected to have only modest effects on Ontario's food production. However, should climate variability increase, increased variability in agricultural productivity will mean greater fluctuations in annual farm profits. The ability of the industry in Ontario to manage this potential increase in risk is not known. While the altered climate may present new opportunities for crop production in Northern Ontario, it is uncertain whether these opportunities will offset losses in the south.

Smit et al. (1989) conclude the following:
- The impacts of climate warming extend across relatively broad regions and the direction and magnitude of these impacts will vary from region to region, soil to soil and crop to crop.
- Grain corn and soybeans will be more affected than barley and hay forage.
- Longer, hotter and drier growing seasons will mean that moisture deficiencies will become a critical constraint to production.
- Soils with relatively low soil moisture capacity appear especially sensitive.
- Any policies relating to climate change should be cognizant of regional variations.

Smit (1989) reviewed the comparative advantage of Canadian agriculture under climate change and suggested that it will provide both constraints and opportunities for food producers, which will vary from region to region. This would result from "changes in production opportunities within Canada, but also from shifts in opportunities elsewhere in the world." Estimates indicate that the costs of agricultural production may increase, with the exception of heating fuel costs (Herbert 1994).

5.6.6 Construction
Since both extreme events and average climatic conditions play a direct role in the construction process, a changing climate will have an impact on the construction industry. In general, it is

expected that warmer winters will lengthen the construction season in most of the province. Furthermore, changes in weather conditions could affect the transport of materials to and from the construction site. For example, a decrease in snow in the southern areas of the province would decrease transportation disruptions, whereas increased snow in more northern areas may increase disruptions. The degree to which climate change will affect current winter and summer construction techniques is not clear. Winter construction techniques include the use of temporary enclosures and the heating and thawing of foundation materials. Since strong winds can halt construction and sometimes destroy work in progress, any changes in wind patterns will also affect the industry.

5.6.7 Finance

Within the financial services sector, the property insurance industry is most likely to be directly affected by climate change; it is already vulnerable to climate variability and extreme events. As stated in Sub-section 4.5.7, the worldwide annual insured cost of weather-related disasters has risen rapidly since the 1960s. This trend will lead to restrictions in insurance coverage or steep price increases. If insurance is unavailable or unaffordable, new enterprises may be unable to start up and banks may become liable for financial losses where transactions are backed up by property (Dlugolecki 1995). There may also be increased reliance on government agencies to provide disaster relief if insurance coverage is withdrawn.

Climate change will worsen the financial implications of weather-related disasters. Under future climate change, variability and extremes could increase. Recent empirical evidence suggests that climate variability is becoming increasingly relevant on a global scale. The International Decade for Natural Disaster Reduction Secretariat (IDNDR) has documented evidence that on a worldwide basis, climate-related disaster losses have increased more rapidly than those from earthquakes since 1963. This indicates the importance of re-examining the need to better adapt to current climate variability, as well as to climate-related extremes (IDNDR 1994).

Other elements of the financial service sector may also be affected by climate change, although the details are less clear. For example, changes in human health may affect the health and life insurance and pension industries.

5.7 Regional Air Issues

As described in Sub-section 5.2.2, it is expected that with increasing greenhouse gas concentrations future temperatures in Ontario will increase, while precipitation and wind patterns may also change. These changes can be expected to affect the four regional air issues described in Section 4.6 (acidic deposition, smog, suspended particulates and hazardous air pollutants or HAPs) through their dependence on the following three conditions (Torvela 1994):

1. emission and volatilization rates,
2. transport and deposition rates, and
3. generation and destruction rates via chemical reactions

Maarouf et al. (1997) and Alexander (1997b) have described the qualitative linkages among these air issues, and provide an overview of the potential effects of climate change. A more quantitative evaluation of the magnitude of these interactions has not yet been done. At present, the main impediments are the absence of emission rate and concentration data for all the relevant compounds and an incomplete understanding of air issue interactions.

5.7.1 Emission Rates

Climate models suggest that for an equivalent doubling of atmospheric carbon dioxide, average annual temperatures in Ontario eventually will increase by 3°C to 8°C, with higher increases occurring in the winter months than the summer (EARG et al. 1995). The increase in temperature will affect pollutant emissions in several ways.

An indirect effect of rising temperatures in Ontario (particularly Southern Ontario) is that the energy demand in summer will increase due to greater requirements for air conditioning and refrigeration. Thus, climate change may affect atmospheric concentrations of pollutants by increasing energy-related emissions during the summer months, unless offset by increases in hydroelectric power production.

Increasing temperatures should affect emission rates of some substances directly: VOCs released from gas tanks and solvent use would increase, as would VOCs released from vegetation (Maarouf et al. 1997). Increased drought, caused by increased evaporation, would be accompanied by an increase in the amount of dust and smaller particulates available as primary pollutants and as vehicles for atmospheric transport of HAPs.

An increase in temperature will also influence the partitioning of pollutants. The atmosphere can act as either a source or a sink for pollutants in the Great Lakes (Hoff et al. 1996). Since volatilization is highly related to temperature (Henry's Law), an increase in temperature could potentially result in the release of pollutants that have already been deposited into the lakes or onto land (Bernabo 1989; Mortsch et al. 1996). The air-water partitioning of HAPs may also be affected by a temperature-induced reduction in the frequency of lake turnover (EARG et al. 1995).

5.7.2 Transport and Deposition Rates

The transport of pollutants depends almost entirely upon meteorological conditions, such as wind speed and direction, humidity and atmospheric stability (Torvela 1994). Any changes in wind patterns and directions will have a significant effect on how far and to where pollutants are transported.

The deposition rates of pollutants partially determine their residence time in the atmosphere. Therefore, changes in the type (rain, snow), frequency and amount of precipitation–e.g. fewer precipitation events of greater intensity–will influence pollutant deposition (IPCC 1996b). Precipitation is an especially important factor in acid deposition.

Increases in the magnitude, duration and frequency of extreme heat events similar to those experienced in Toronto (and Chicago) in the summer of 1995 (EARG et al. 1995) will likely produce more severe "pollution events" than are currently experienced. Such heat events are also periods of low pollutant dispersion, so that local emissions will accumulate with time rather than dispersing over broad areas. These impacts will be most serious in urban areas, which are important as both pollution and local heat sources.

5.7.3 Chemical Reactions

Atmospheric residence times will also influence the extent to which emitted or primary pollutants can be chemically transformed into secondary pollutants. Higher temperatures will increase the number rates of chemical reactions so that formation of aerosols will increase (Huebner et al. 1994).

Increased summertime temperatures in the province could increase the formation of tropospheric ozone (a major constituent of smog), provided that the cloudiness, wind and precipitation conditions remain constant. Increases in photochemical pollutants such as ozone could be offset to a degree if increases in cloudiness reduce the solar radiation available to drive the reactions, if precursor compounds are removed by wet deposition as a result of more frequent precipitation events or if wind patterns change.

5.8 Societal and Environmental Considerations

The assessment of climate change scenarios suggests that the province can expect a range of impacts, both within and across sectors and regions. The majority of the discussion to this point has considered the physical and economic impacts. However, there are a number of other societal and environmental considerations that merit debate in the discussion of climate change and adaptation. The societal considerations include the following:

- The adverse impacts and the benefits of climate change will be distributed unevenly

across sectors and regions (inter-regional, inter-sectoral equity issues);
- The political and social consequences of climate change outside of the province and country will have substantial impacts regionally;
- The impacts will be distributed unevenly over time across generations (intergenerational equity issues).

The equity issues concern the fact that the impacts and benefits will be unevenly distributed across society. Some sectors may be at a disadvantage under a changed climate while others may benefit. The same holds for regions of the province, for different population groups, and for different generations. Even within sectors there will be winners and losers. For example, farmers from some regions producing grain corn may increase yields while those producing wheat and barley may not be so fortunate (Brklacich et al.1998; Smit et al. 1989). In the area of public health, for example, the old, the very young, and those suffering from ill health may be at greater risk from climate change than the broader population (EARG et al. 1995). Similarly, groups with more disposable income may be in a position to take protective measures that may not be options for poorer people.

Globally, the stresses of climate change could become “destabilizing”. In a world where the economies and politics of nations and regions are increasingly connected to each other, the political and social consequences of climate change elsewhere could become quite substantial locally. As climates change in other regions leaving droughts, floods, the movement and proliferation of disease and changes in agricutural practices, the indirect impacts in Ontario likely will be rises in environmental refugees and increased calls for disaster relief, economic assistance and peace-keeping (EARG et al. 1995).

The impacts and costs of climate change will also be unequally distributed among generations, raising questions about intergenerational equity. Future generations have no say in the politics and decisions of today that will ultimately affect their well-being. Actions taken now to reduce greenhouse gases and limit climate change will reduce the vulnerability of future generations to the impacts of climate change. On the other hand, failure to act in timely fashion will likely result in greatly increased losses to our descendants.

The role and impacts of a changing climate in disturbing natural ecosystems and in exacerbating biodiversity loss extend well-beyond the realm of economics. Because of the intrinsic value of the natural world, it is neither possible nor appropriate to express much of this value in money. Instead, society is becoming increasingly aware of its dependence on the rest of nature and of the interdependencies which exist between different forms of life, between living systems, and between the physical and chemical environments which surround life on the earth.

6.0 OPPORTUNITIES FOR ADAPTATION

Impact studies based on 2xCO_2 scenarios suggest that many sectors of the Ontario economy, society and environment will be affected by climate change. In order to help ensure the continued health of the economy, it will be important for Ontario to develop strategies to deal with climate change and variability. A sustainable and robust economy means one that is strong and efficient yet preserves the natural environment; it is both productive and resilient; it is one that will be competitive in world markets and will help to sustain the communities and societal structures that are currently enjoyed and valued. Climate change could entail alterations to average conditions and to both the frequency and the magnitude of climate-related hazards that threaten productivity. As with other issues that will present challenges to Ontario's economy, climate change and variability need to be considered in the light of future international markets and competitiveness. Climate directly affects the ability of many Ontario industries to produce goods and services efficiently. At least some future climate change is inevitable, given both past and future trends in atmospheric greenhouse gas levels. To reduce the threats of future climate change, Ontario should develop strategies that reduce the vulnerability of society and the economy to the current climate.

6.1 Characteristics of an Adaptive System

For the most part, suggested adaptive responses to future climate scenarios have focused on the system's ability to minimize adverse effects. Little attention has been given to the broader scope of adaptation, including identifying opportunities or alleviating problems caused by present conditions such as extreme events or actions that are maladaptive. A theoretical approach to developing adaptation strategies can be followed by applying the characteristics of a good adaptive system to the particular case of a changed climate. The major characteristics of a good adaptive system have been identified as robustness, resilience, flexibility and stability (based on Smit 1993).

Robustness (analogous to a low level of vulnerability in Smit's model) relates to the ability of the system to withstand disruption caused by an event. For example, it is anticipated that some areas will be faced with reduced soil moisture and more drought stress as the climate changes. Choosing a species of tree that is more drought resistant may improve the robustness of the stand to endure this stress.

Resilience is the "elasticity" of the system in the face of a hazard and its ability to re-establish a state of equilibrium. It is the system's ability to "bounce back, absorb negative impacts or changes and recover from them in ways that enhance the health and well-being of society, but not necessarily by returning to the original position" (Burton 1992). This is of particular importance for systems affected by climate change, since they will probably not be able to return to conditions that existed before the system was perturbed. In the case of individual timber harvesters, the resilience of their operations would depend on their ability to change the way they operate after a significant forest fire had depleted their stands. Securing access to stands in different regions or planning some alternative use for the land after forest fires are ways of preserving productivity. Resilience is enhanced both by reducing the vulnerability of the system to future conditions through increasing flexibility and by allowing for optimal responses to be identified and implemented.

Flexibility refers to the degree of manoeuvrability that exists within the system. For the forest industry, this might be the ability to alter on-site operations as seasons change. Flexibility can be increased, for example, by diversifying across species where possible; flexibility can be reduced by financial constraints that prevent investment in new varieties or new opportunities for the business.

Stability refers to the ability of the system to return to an equilibrium state after a temporary disturbance. Climate change is clearly not anticipated to be a temporary disturbance, but a dynamic and sustained stressor of the global system. As such, stability is not expected to be an important adaptive characteristic for systems undergoing climate change. Resilience and flexibility should be much more valuable attributes for such systems.

The hallmark of a good adaptive system is its ability not only to minimize the negative impacts of the unexpected, but also to benefit from change, whenever possible, by maximizing opportunities (Holling 1978). Adaptation strategies for systems affected by a changing climate need to promote and enhance the characteristics described above, in order to cope with and take full advantage of future atmospheric conditions.

6.2 Coping Mechanisms

Coping mechanisms as defined in hazards research can be used to describe categories of adaptive responses. Burton et al. (1993) have described six different coping mechanisms used in response to hazards: *bear the loss, share the cost, modify the events, prevent the effects, change resource use* and *change location.* These have been modified for the purposes of developing adaptive responses to a changing climate. The six categories of coping mechanisms (Figure 7) used in this chapter to define a system's ability to adapt to climate change are *bear-the-loss, modify-the-event, prevent-the-effects, conduct research, provide-education* and *avoid-the-impacts*. In a socio-economic system, the ability to implement these mechanisms is determined not only by technical factors, such as economics, but also by societal values: Are the results of change worth the price?

Bear-the-loss mechanisms take no action to prevent or mitigate the impacts of an event, and the resultant losses are borne by the individual or shared among an associated group. In the case of the crop insurance industry, the costs of compensation are distributed across the agricultural sector in the form of insurance premiums. One side-effect of these mechanisms is that they can encourage maladaptive decisions. In the agricultural sector, an example of a maladaptive decision might be the selection of a crop or cultivarthat maximizes profits under optimal growing conditions, but that could fail if growing conditions were below average. These types of actions may reduce a system's stability, resistance,

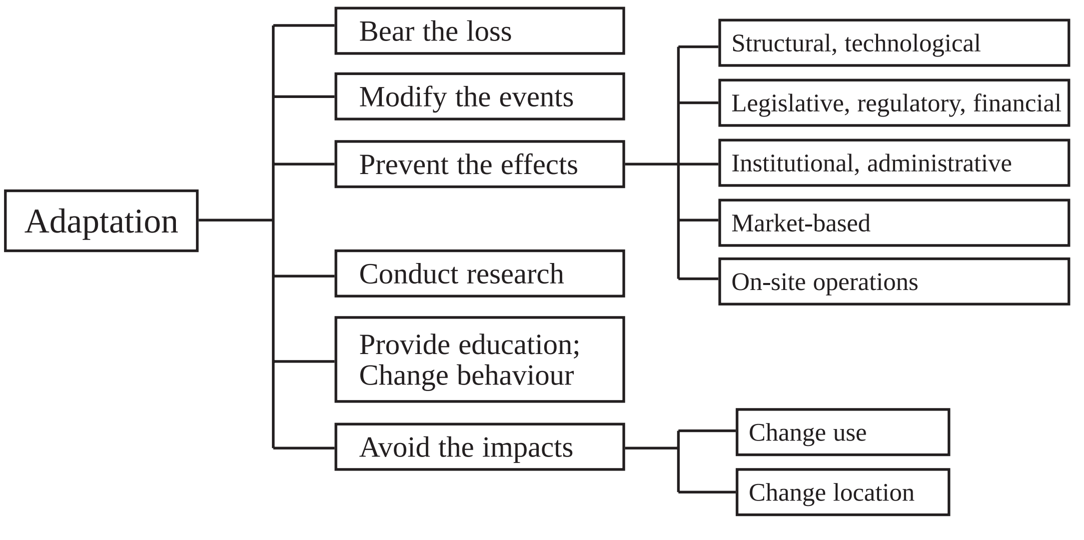

Figure 7. Classification of adaptation responses (Adapted from Burton et al. 1993.)

flexibility and robustness. In the long term, the level of effort or cost of adjustment required for these mechanisms is likely to exact a higher price than other responses.

Modify-the-event mechanisms take direct action to minimize losses by modifying the event at the outset. For example, in coping with climate change, society has the option of mitigation: limiting greenhouse gas emissions to reduce the growth of atmospheric concentrations.

Prevent-the-effects mechanisms make moderate changes in activities or behaviour that minimize or avoid the impacts of an event. These mechanisms promote actions that will likely reduce vulnerabilities to a changing climate. This category is broken down into five sub-categories that address a range of issues from maladaptation to resilience.

1. *Structural/technological* measures are either physical structures or measures that rely on technological innovation to minimize impacts.
2. *Legislative/regulatory/financial* measures are those that require governmental intervention to develop laws, subsidies and incentives, zoning and building codes, and taxes.
3. *Institutional/administrative* measures are those that require changes in the structure or function of an institution or administration. These measures may include a range of changes, from policy changes in an existing administration to developing a new institution to regulate activities. They can increase the system's resilience and decrease its vulnerability.
4. *Market-based* measures are activities that attempt to influence the operation of the free market to help adaptation to take place. For example, a government or a group of governments may establish a market for pricing harvesting rights in the forestry sector to account for the real cost of forestry lands. This could encourage adaptive decisions regarding the use and development of the land that are better attuned to a changing climate.
5. *On-site* operations are actions that deal with the management of resources at the site of operation. For example, harvesting techniques may need to change to adapt to future climate conditions, such as less snow cover during the winter months.

Research mechanisms are activities that enhance the understanding of (1) potential impacts and vulnerabilities created by climate change and variability, (2) adaptive processes, and (3) potential measures to cope with future changes. Research measures often call for more study of impacts and vulnerabilities to future climate or for a strengthening of current activities to help identify vulnerabilities as they occur (i.e. monitoring systems). An effective linkage between research activities and policy development is essential to ensure that research planning is productive. If policy institutions fail to identify the information required for improving adaptive responses, researchers cannot undertake the necessary activities to provide the required solutions.

Education mechanisms identify both activities that promote understanding of the importance of adaptation and potential adaptation actions that can be undertaken. These mechanisms help distribute information that will enable people to make good adaptive decisions and thereby help them to adopt behaviour patterns more attuned to their environment. Education can be used to emphasize individual responsibility in adapting to a changing climate. Encouraging individual action could be a way to obtain maximum benefit from dwindling government funding.

Avoid-the-impacts mechanisms are typically implemented when it is accepted that impacts exceed the other coping capacities of the system, to the point where major changes are required to avoid a failure. It is recognized that implementing such changes can be very difficult given the short-term costs and, in some cases, the institutional barriers to these major changes. Two types of avoid-the-impacts mechanisms have been identified: *change-use* and *change-location.*

- *Change-use* mechanisms respond to a major impact with substantive action to adapt to the change and minimize losses. Several Southern Ontario resorts that specialize in outdoor winter recreation have already taken steps to reduce their vulnerability to climate variability and change by developing recreational opportunities in other seasons.
- *Change-location* mechanisms respond to an impact by moving the activity to a new location where vulnerability to the impacts is lower or where new opportunities can be taken advantage of. For instance, this type of response might be appropriate for certain northern communities where degradation of permafrost would render infrastructure unusable or where the rise in sea level could threaten communities.

In the long term, avoidance is often the most cost-effective means of adapting to a changing climate and can also prompt the development of new opportunities. Unfortunately, the magnitude of the investments required and the possible delays in realizing the benefits of those investments may limit the application of this strategy.

6.3 Sectoral Adaptations

In many areas of our society and economy, performance is related to the level of success in adapting to the natural environment, including the climate. Although the study of climate adaptation is relatively new, practical adaptive measures have been integral parts of the growth and development of sectors such as forestry, agriculture and construction. However, the opportunity exists to make much more strategic use of adaptation measures by maximizing opportunities and reducing vulnerability. In many areas, adaptations may already be available that could enhance industry's competitiveness within the context of the current climate and its associated variability. On the other hand, some industries may be using certain maladaptive measures that actually hinder adaptation to climate.

Tables 11 to 14 (located after Section 6.4) list adaptations found in the literature and classify them according to the categories of coping mechanisms discussed in Section 6.2. Many of the adaptations fall into more than one category. These tables are intended to present a survey of the main elements in the literature; they are not meant to be an exhaustive treatment of the subject. The reader is referred to the IPCC Working Group II report on Impacts and Adaptations of Climate Change for some detailed discussions of adaptation measures (IPCC 1996b).

Each of the four tables identifies a specific sector that could be significantly affected by a changed climate. The selected sectors are water resources, human and ecosystem health, the built environment and industry. Within each of these areas, several major themes were explored. For example, Table 11, which deals with water resources, examines water levels, water supply and water demand. Potential adaptive strategies are presented in terms of the coping mechanisms discussed in Section 6.2.

The *modify-the-events* mechanisms have not, in general, been explored here since actions that may be taken to limit greenhouse gases emissions are part of an extremely important, but distinct, area of research and policy application. The one exception is the part of Table 12 dealing with human health and regional air issues. Under either the current, or a changed climate, the most effective means of addressing the impacts of air pollution is by modifying the events through pollution prevention.

Several common themes may be traced through the four adaptation tables:

1. While many adaptation measures have been studied, a comprehensive and coordinated overarching strategy for coping with the impacts of climate change does not exist. It is important that such a strategy be developed in consultation with all affected sectors in order to avoid investment in maladaptive initiatives.
2. The amount of research on adaptation measures within each sector reflects the more general level of research conducted on climate change impacts for that particular sector.

3. The vast majority of the adaptative measures listed in the tables have been put into practice in some form. Some sectors may require only small adjustments to their operating procedures. In other areas, new and innovative approaches will be needed to realize the potential benefits and minimize the impacts of climate change.
4. Substantial efforts will need to be directed towards public education concerning the issues and impacts of climate change. Many adaptations will be dependent on some degree of behavioural change.

In addition to the common threads that run through the adaptation literature, there were a number of themes and findings that were specific to the four selected sectors. The survey of these sectors examined the amount of adaptation research that has been conducted, the primary focus of this research and the key questions for future work.

The adaptation measures found in the water resources literature (see Table 11) reflect the relatively high degree of interest and research activity in this area. Water is a critical resource and many factors, including current climate and variability, affect the quality and quantity of this resource.

As with most of the sectors, many of the water resource adaptation measures are already in force in some capacity, and could be readily applied to the conditions of a changed climate.

The primary focus for adaptation measures to date has been structural or technical. These measures are expensive but their benefits and limitations are well-known. For example, water control structures may have to be redesigned to handle the greater degree of variability of precipitation, including a possible increase in the intensity of extreme events.

It is anticipated that there will be growing demand for limited or reduced water resources under a changed climate. Potential adaptations have been identified in both the supply and demand of water resources. One avenue would be to increase the efficiency and coordination of the supply system. On the demand side, much work has been done outlining the possible means for reducing public water use. However, considerable effort will be required to bring about the behavioural changes necessary to alter current patterns of water consumption.

To date, little research has been conducted on measures to reduce the potential impact of climate change on human health (Table 12). Key areas of interest include the impacts on human health of heat stress, poor air quality and temperature dependent vectors for infectious disease. As with the water sector, significant effort will need to be directed towards public education and behavioural change.

Little work has also been done on the potential adaptive responses to the impacts of climate change on regional air issues such as smog, particulates and hazardous air pollutants. These pollutants have an impact on human health and some of these effects will be exacerbated under a warmer climate. There is also a need to move beyond single-issue management and examine ways to address the suite of regional air issues in an integrated fashion. As further research is conducted on climate change impacts over the next five years, it is anticipated that this type of integrative study will be recognized as more important.

A relatively extensive body of research has been gathered on species protection (Table 12), although this work has not often been linked to climate change. The majority of protective measures require a high level of management and intervention, the success of which is uncertain since management of natural systems is difficult. In order to develop strategies that are manageable and affordable, this sector will need to explore new and innovative approaches and exercise a substantial degree of coordination. At a minimum, efforts to restore degraded habitats and preserve existing ecosystems should allow for expected changes in climate and the associated effects on the optimum range of species. When ecosystem management areas are being designed, the feasibility of migration corridors and other adaptation mechanisms should be investigated.

Little research has been conducted to date on the specific impacts of climate change on the built environment (Table 13). However, this sector is extremely sensitive to climate, and reducing this sensitivity is a significant research priority. Most of the measures found in the literature have already been tested on actual structures. Therefore, the adjustments required to respond to a changing climate are expected to be manageable. Perhaps the best means of preparing this sector to cope with future climate change is by working to reduce the vulnerability of built structures to the current climate and climate variability by regular reviews of building codes and of the climate information used in their development.

Considerable attention has been paid to the range of adaptive measures employed by industry in responding to the current climate and its associated variability (Table 14). Less work has been done on its potential adaptations to a changed climate. In particular, a host of adaptive mechanisms have been studied for both forestry and agriculture. The adaptive capacities of these two sectors within Ontario are discussed in Section 6.4. The adaptive measures in the literature pertaining to industry have, by and large, already been put into practice. This area should be well positioned to cope with the anticipated effects of climate change.

At this point there is considerable uncertainty about the potential impacts of climate change and the appropriate measures that should be pursued to adapt to these changes. However these uncertainties do not imply that governments and industry should employ a *wait-and-see* attitude. On the contrary, there are good reasons to believe that forward-looking actions taken now will help us adapt to current climate variability and potential climate change. Prudent *no-regrets* adaptations can reduce the impacts that will be felt as the climate changes.

No-regrets adaptations are those actions which yield net benefits even in the absence of climate change. There are potentially an extremely large number of such actions extending across all sectors of the Ontario economy. For example, improvements in the efficiency of water use can reduce the size of new water supply investments, and reduce environmental impacts at the same time. There has been no systematic multi-sectoral review of adaptation options, however, and this should be undertaken without delay. The responsibility for such action rests primarily with those who own or manage the resources and economic activities at risk. Governments can encourage and promote assessments of adaptation options, and remove obstacles to such initiatives.

6.4 Provincial Adaptation Capacity

Chapter 5 of this study examined the broad range of potential impacts of a changed climate on the physical, social and economic conditions within Ontario. Less research has been conducted on climate adaptation pertaining to the province. The bulk of the Ontario-specific adaptation literature has, not surprisingly, focused on those sectors anticipated to be most affected by a changed climate. This section will examine the adaptation capacity within the province of Ontario with particular emphasis on the following: (1) water levels, supply and demand, (2) human health, (3) forestry, (4) agriculture, and (5) regional air issues.

As discussed in detail in Sub-section 5.3.1, most GCM experiments exploring the implications of a doubling of the concentrations of atmospheric carbon dioxide have projected decreases in the net supply of water within the Great Lakes basin. These simulations also predict significant drops in mean water levels for each of the Great Lakes and their connecting channels. This would have significant implications for shipping and navigation, ecosystem health, property and recreation. The primary adaptation measures found in the literature would require significant changes to structural works and improved resource management and policy measures on the part of thevarious levels and jurisdictions of government. Given the economic significance of Great Lakes water levels, the amount of existing baseline information and the fact that mechanisms for these adaptations currently exist, it is probable that successful socio-economic adaptations will be found for this sector.

In addition to changes on the Great Lakes, the combination of an anticipated decrease in water supply with the potentially greater variability in precipitation is expected to result in increased fluctuations in water levels and flows in drainage basins across the province. This would have significant economic and social implications for almost every sector of society. The primary adaptive responses include enhanced resource management, improved technological efficiency and increased physical infrastructure. The mechanisms to accomplish these adaptations are highly developed in Ontario and the potential for success in this sector is relatively high. For example, the water supply problems already experienced in some regions of the province, such as in the Grand River basin, have necessitated a coordinated approach to water management. These efforts may position water managers to respond more effectively to the potentially exacerbated water supply problems under a changed climate. However, smaller sub-basins and the natural environment will receive less attention and intervention, and therefore will be more vulnerable to potential supply changes.

The demand for water in Ontario is expected to increase in the next century, driven by climatic change, further population increases and economic expansion. This growing need for limited or reduced water resources will increase the competition for water and may lead to demand conflicts. Water resource managers will need to explore creative ways of alleviating these stresses with particular emphasis on cooperation across sectors and enhancement of water conservation practices. It is important that any research agenda addressing water supply and demand be developed in conjunction with key sectors such as municipalities and agriculture.

The impacts of a changed climate on human health are potentially significant. However, since little research has been done in this area, it is not possible to reach any definitive conclusions about the net health implications for the citizens of Ontario. It is expected that the effects that are correlated with temperature such as heat stress and smog episodes could be worsened by climate change. However, Ontario has a well-developed health care infrastructure and it is anticipated that successful adaptive strategies will be found, assuming that research and monitoring efforts are maintained.

The most significant impacts anticipated for the forestry industry include a potential increase in forest production in the southern limits of the boreal forest, the anticipated northern migration of species, and an increase in fire, disease and pest hazards. These will be long-term changes and will require long-term, comprehensive response strategies. For example, there is a need to identify trees with genetic characteristics that make them more adaptable to anticipated climatic conditions. The feasibility of transplanting shoots and seedlings to new regions in order to assist species migration should also be investigated. Given the level of sophistication that currently exists in the forestry industry in Ontario, some level of success is anticipated. However, the uncertainty associated with forest responses to climate change preclude definitive statements at this point.

The agricultural industry and its associated food distribution system are very important to the Ontario economy. As with most other sectors, the climate change impact and adaptation research to date has not produced a definitive set of conclusions. The major impacts anticipated, which present both opportunities and vulnerabilities, will vary according to the region of the province. The anticipated longer and warmer growing season, coupled with higher concentrations of carbon dioxide, should enhance production. However, these potential increases may be partially offset by reduced soil moisture. Thus, one of the keys to successful adaptation in this sector will be the ability to minimize vulnerability to a potentially reduced water supply.

In order for the agricultural industry to realize the full potential of these opportunities, it must carefully monitor the changing climate and be willing to make the necessary adjustments. Since this sector is able to adapt quickly to changing conditions by altering crop and breed choices on an annual basis, it is not expected to be affected as much as the forestry sector might be by the rate of climatic change. If a comprehensive adaptive strategy is developed, it is anticipated that this industry will successfully respond to this challenge.

As noted in the previous section, little research has been conducted to date on the potential adaptive responses to climate change in the area of integrated, regional air issues. However, because Southern Ontario is situated close to the heavily industrialized areas south of the Great Lakes, our own atmospheric emissions are augmented by a significant flow of transboundary air pollutants. This flow increases the severity of a range of air pollution concerns including smog, particulates and acid rain. It is postulated that a warmer climate could exacerbate some of these problems. These potential stresses point to the need for a more integrative approach to climate change and air issues in the Great Lakes Basin. An example of this approach is the *Toronto–Niagara Region Study on Atmospheric Change*, one segment of which will investigate how climate change and variability will affect atmospheric issues such as smog and hazardous air pollutants.

The assessment of the overall provincial capacity for adaptation should not be presumed to be merely the sum of the capacities of each sector. Ontario is a strong, healthy and diverse province with a wealth of physical, economic and social resources. If some sector or geographical area experiences problems adapting to climate change, opportunities exist for relocation or the reallocation of resources into other fields. Many other parts of the world are not so fortunate, being more restricted by their geography or economic and political conditions.

One key factor in determining how the province adapts as a whole to the changing climate will be the level of coordination of its response efforts. For example, the need for increased irrigation in the agricultural sector will require both improvements in irrigation efficiency and increased supply from water utilities. For these to be implemented most effectively, the agriculture and water supply sectors should jointly address research and policy initiatives. A coordinated multisectoral plan to deal with climate change will minimize conflicting adaptive strategies and maximize overall benefits for the province.

While Ontario is relatively well-equipped to deal with a changing climate, the adjustments required will be neither effortless nor painless. Eliminating obstacles and providing direction are the responsibility of both the government and the affected sectors themselves. Considerable research is still required to develop a detailed suite of effective adaptation measures. However, sufficient information is already available to implement measures that will enhance adaptation to current climate variability, reduce vulnerability and capitalize on opportunities for adaptation to a changing climate.

Table 11: Partial List of Adaptation Measures: Water Resources

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Provide Education & Change Behaviour	Avoid the Impacts	Application**
Great Lakes Water Levels						
• Develop joint federal policy goals for water levels; clarify current status of rights to levels and flows and to private land use.		L/R/F				A
• Develop improved information on levels and storms, related shoreline processes and hazard mapping.		L/R/F	X			A
• Review technical and policy matters related to lake-level management.		L/R/F				A
• Commit resources to the design and development of measures other than regulatory works.		L/R/F	X			P
• Establish contingency plans for extreme events.		L/R/F				A
Water Supply						
• Ensure interjurisdictional supply systems are maximized and duplication of services is reduced.		L/R/F				P
• Transfers should ensure areas susceptible to shortages have reasonable access.	X	L/R/F			X	P
• Provide comprehensive management of water resources through watershed-based land-use planning.		L/R/F		X		A
• Maintain buffer zones around significant water bodies, channels and wetlands.		L/R/F				A
• Implement incentives to promote the preservation and creation of wetlands.		L/R/F		X		A
• Upgrade existing infrastructure to include capacity for climate change.		S/T				A

* L/R/F: legislative/regulatory/financial; S/T: structural/technical; I/A: institutional/administrative; MARKET: market-based; ON-SITE: on-site operations.
** A: mechanism has been applied with success; O: mechanism based on opinion only, little or no research has been done; P: some analysis has been done.

Table 11: Partial List of Adaptation Measures: Water Resources (continued)

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Provide Education & Change Behaviour	Avoid the Impacts	Application**
• Upgrade existing water quality infrastructure.		S/T				A
• Upgrade waste water treatment facilities.		S/T				A
• Encourage new water-efficient technologies.		S/T	X			A
Water Demand						
• Develop weather-sensitive lawn-watering index.		S/T & L/R/F	X	X	X	P
• Promote research into water-efficient technology in residential, commercial, industrial and agricultural sectors.		I/A	X			A
• Increase water-pricing policies using an inclining rate, with meter rates increasing with volume used.		MARKET				A

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Table 12: Partial List of Adaptation Measures: Human and Ecosystem Health

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Provide Education & Change Behaviour	Avoid the Impacts	Application**
Human Health						
• Involve the health care sector in all bodies dealing with climate change.		I/A				P
• Coordinate regional efforts to expand epidemiological surveillance.		I/A				A
• Reinforce surveillance systems for health problems that are most likely to be influenced by climate change; particular attention should be given to populations that would be especially vulnerable to climate change.		I/A	X			P
• Expand existing research programs on the health effects of climate variability and climate change.		I/A	X			A
• Assess health care infrastructures in specific regions deemed to be at greatest risk, for their ability to deal with spread of infectious disease.		I/A	X			A
• Assess nuclear facilities, municipal and hazardous waste dumps or other waste disposal facilities in coastal areas for the potential spread of pathogens and toxic chemicals.		I/A	X			A
• Investigate building designs that will reduce impact of heat stress.		I/A	X			P
• Strengthen health-related weather advisory system.		I/A	X			A
• Develop indices like the UV Index for other climate-related health conditions.		S/T	X			A

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Table 12: Partial List of Adaptation Measures: Human and Ecosystem Health (continued)

Adaptation Measure	Bear the Loss	Modify the Events	Prevent the Effects*	Conduct Research	Education & Behaviour	Avoid the Impacts	Application **
Human Health and Regional Air Issues							
• Research interactions of air issues with climate and impacts on human and ecosystem health.			I/A	X			P
• Extend public air quality information and advisory programs such as the Air Quality Index and Air Quality Advisory programs.		X	I/A		X		P
• Prevent pollution; this is the most effective means of improving air quality. Potential approaches are numerous and often address more than one air issue. Examples include:							
∘ Negotiate international standards to reduce trans-boundary flow of air pollutants;		X	L/R/F				A
∘ Investigate emissions trading strategies;		X	MARKET	X			P
∘ Implement comprehensive national and regional control plans such as the CCME NOx/VOC Management Plan and the Ontario Smog Plan;		X	L/R/F & I/A	X		X	A
∘ Reduce emissions by applying Best Available Technology Economically Achievable;		X	S/T				A
∘ Improve vehicle emission standards;		X	I/A& S/T				A
∘ Encourage fuel switching and modify fuel composition to reduce emissions;		X	I/A& S/T	X	X		A
∘ Implement vehicle emissions inspection and maintenance programs;		X	I/A		X		
∘ Actively manage pollution episodes through source control;		X	L/R/F				A
∘ Improve urban transit management;		X	I/A				A
∘ Improve energy conservation and efficiency;		X	I/A		X		A
∘ Educate the public about consumer and lifestyle choices.		X	I/A		X		A

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Table 12: Partial List of Adaptation Measures: Human and Ecosystem Health (continued)

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Provide Education & Change Behaviour	Avoid the Impacts	Application**
Ecosystem Health						
• Protect species at bottom of food chain.	X	L/R/F				P
• Expand seed banks and gene pools in zoos and reserves.		I/A	X		X	A
• Adopt overall habitat-protection management.		L/R/F			X	A
• Expand areas of wildlife refuges to reduce vulnerability; reserves should be heterogeneous and include variations in altitude.		L/R/F				A
• Maintain corridors along altitudinal and latitudinal gradients between reserves to allow migration of species.		L/R/F				A
• Maintain flexible land-use zoning around reserves to allow movement as climate changes.	X	L/R/F				A
• Consider climate change when establishing parks or reserves.		L/R/F				P
• Consider climate change in any effort to restore or preserve habitats.		I/A	X			A
• Where invasion of exotic species is inevitable, introduce those that are most beneficial.	X	ON-SITE				P

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Table 13: Partial List of Adaptation Measures: The Built Environment

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Provide Education & Change Behaviour	Avoid the Impacts	Application**
The Built Environment						
• Review building codes on a regular basis to ensure that they reflect current information on climate variability and change.		I/A & L/R/F	X			A
• Evaluate whether current safety margins for engineering design such as probable maximum precipitation (PMP) and snow will loads be sufficient under a changed climate.			X			P
• Address gaps and deficiencies in climate design data, especially in Northern Ontario.		S/T	X			A
• Expand or reinforce riverine flood control systems.		S/T			X	A
• Strengthen land-use planning regulations to limit development in damage-prone areas.		L/R/F			X	A
• Ensure durability of building design and construction.		L/R/F				A
• Create structures that are more flexible in terms of usage and mobility.		S/T			X	A
• Explore reduction of damage from natural disasters through continued participation in the International Decade of Natural Disaster Reduction (IDNDR).		I/A	X			A
• Alter building and design to reduce cooling requirements.		S/T	X			A

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Table 14: Partial List of Adaptation Measures: Industry

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Provide Education & Change Behaviour	Avoid the Impacts	Application**
Energy						
Thermal Plants						
• Reduce water withdrawal by using closed cooling systems.		ON-SITE				A
• Use low energy, non-CFC, alternative cooling systems (dry cooling towers, wet-dry cooling systems, ammonia-based cooling systems).		ON-SITE				A
• Use municipal waste water.		ON-SITE				P
• Improve thermal efficiency.		ON-SITE	X			P
Hydroelectric Plants						
• Increase water storage.		S/T				A
• Plan for altered potentials and design factors.		S/T				A
• Market electricity at peak and off-peak rates.		MARKET				A
• Implement drought surcharges.		I/A				A
• Encourage voluntary water conservation.		MARKET		X		A
Demand						
• Increase building efficiency.		S/T & L/R/F				A
• Design communities to reduce urban heat island effect.		S/T				A
• Build more durable infrastructure.		S/T	X	X		P
Other Energy Supply						
• Increase energy generation from renewable sources.		S/T & MARKET				A
• Convert oil- and coal-burning facilities to natural gas and biomass.		S/T				A
• Improve utilizaton of waste heat energy.		S/T				A

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Table 14: Partial List of Adaptation Measures: Industry (continued)

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Provide Education & Change Behaviour	Avoid the Impacts	Application**
Transportation						
• Increase fuel efficiency.		S/T				A
• Increase dredging of channels and ports.		S/T				A
• Expand facilities at northern ports.		S/T				A
• Optimize application of anti-icing treatments and snow removal for air and road transport.		ON-SITE				A
• Increase use of telecommunications to reduce automobile use.		S/T		X		A
• Increase utility of public transit.		S/T & L/R/F		X		A
• Increase effective use of weather information for railway operations.		ON-SITE & S/T				A
• Revise maximum take-off and landing weights to account for reduced lift.		S/T				A
Tourism and Recreation						
• Apply sunscreen, install air conditioning, make artificial snow, etc.		S/T			X	A
• Reduce the exposure to climate.		ON-SITE				A
• Provide a number of recreation alternatives that have a range of climatic requirements and sensitivities.	X	ON-SITE			X	A

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Table 14: Partial List of Adaptation Measures: Industry (continued)

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Provide Education & Change Behaviour	Avoid the Impacts	Application**
Forestry						
• Plant species that are more tolerant of a variable climate.		ON-SITE	X			A
• Consider short rotation options to reduce risks during life span of stands.		ON-SITE				P
• Concentrate management efforts on sites that are less vulnerable, e.g. in southern regions, moist areas are preferable, given the possibility of more frequent and severe droughts.		ON-SITE				A
• Assess additional fibre sources or location/relocation to keep hauling distances within profitable limits.		MARKET	X			P
• Protect existing forests by:						
◦ strengthening education programs aimed at fire prevention;		I/A				P
◦ enhancing fire and pest monitoring and fighting efforts;		ON-SITE				P
◦ creating training centres for suppression of the impacts of fire, insects, diseases, frost, drought, etc.;		I/A	X			P
◦ increasing thinning to adapt to stress.		ON-SITE				P
• Introduce new species where appropriate by:						
◦ breeding disease/drought resistant traits;		S/T	X			A
◦ conserving gene pools in seed banks;		S/T	X			A
◦ diversifying species to encourage flexibility;		ON-SITE	X			O
◦ considering non-timber values in species selection;		MARKET	X			O
◦ using anticipatory planting or long-term stands;		ON-SITE				P
◦ assisting natural migration by transplanting species in other areas.		ON-SITE				O

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Table 14: Partial List of Adaptation Measures: Industry (continued)

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Provide Education & Change Behaviour	Avoid the Impacts	Application**
Forestry (continued)						
• Change or improve the use of forests		ONSITE & I/A				P
• Use shorter rotation times for commercial forests.		I/A				A
• Explore implications of climate change on harvesting and make appropriate adjustments to on-site activities such as:		I/A	X			P
◦ increasing effectiveness of sanitation and salvage harvesting to avoid losses due to pests, disease and fire;		ONSITE				A
◦ changing harvesting techniques to site-specific situations given new climates;		ONSITE				P
◦ introducing new forestry approaches to meet multipurpose and species diversity.		I/A				P
• Review nursery operations in light of potential impacts of climate change.		ONSITE	X			P
• Leave a diversity of species to enhance regrowth when harvesting.		ONSITE				P
• Explore use of plantation forests as a source of fuel and to extend natural range of boreal forest		ONSITE	X			P
• Develop alternative products.		MARKET	X			O
• Move forest industries closer to new	X	S/T	X			A

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Table 14: Partial List of Adaptation Measures: Industry (continued)

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Education & Change	Avoid the Impacts	Application **
Agriculture						
Farm Level Adaptations						
• Change dates of seeding to suit new climate.		ON-SITE				P
• Change to crops giving less variable yields.		ON-SITE				A
• Alter drainage to increase groundwater uptake.		ON-SITE				A
• Concentrate irrigation during peak growth period.		ON-SITE				P
• Periodically check well efficiency.		ON-SITE				A
• Improve irrigation efficiency.		ON-SITE				A
• Rotate fields to be irrigated.		ON-SITE				A
• Meter all water use.		L/R/F				A
• Rotate wells pumped.		ON-SITE				A
• Alter practices to conserve soil.		ON-SITE				A
• Use more efficient fertilizer and pest management.		ON-SITE				A
• Improve efficiency of energy use.		ON-SITE				A
• Plant shelter belts.		ON-SITE				A
Educational and Economic Policy						
• Reform government subsidies to reflect actual risks from climate.		L/R/F				P
• Sponsor programs such as on-farm research, market development and consumer education to encourage sustainable agricultural practices.		L/R/F	X			P
• Reassess food grading standards that may constitute a barrier or disincentive to sound environmental practice.		L/R/F				P
• Link crop-assistance programs to soil conservation.		L/R/F				A
• Harmonize agricultural institutions and policies.		L/R/F				P

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Table 14: Partial List of Adaptation Measures: Industry (continued)

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Provide Education & Change Behaviour	Avoid the Impacts	Application**
Agriculture (continued)						
Land Use						
• Discourage temporary use of marginal areas.		L/R/F				A
• Protect arable land from encroachment.		L/R/F				A
• Identify intensive control areas.		L/R/F				A
• Reform policy to encourage flexible land use.		L/R/F				A
• Identify new areas for viable agriculture and determine most suitable crops.		S/T				P
Water						
• Apportion available water equitably.		L/R/F				A
• Limit kinds of crops irrigated.		L/R/F				P
• Charge for water permits.		L/R/F				A
• Provide tax credit for irrigation fuel.		L/R/F				A
• Tax irrigated acreage.		L/R/F				A
• Offer government depletion insurance.		L/R/F				A
• Impose a severance tax on groundwater.		L/R/F				P
• Build reservoirs to store water.		S/T				A
• Build small recharge dams.		S/T				A
• Transfer water within region.		S/T				A
• Import water from other regions.		S/T				A
• Fund water law and conservation education.		L/R/F				A
• Encourage water conservation laws.		L/R/F				A
• Require tailwater reuse.		L/R/F				A
• Raise the value of crop produced per volume of water consumed.		S/T				P

* L/R/F: legislative/regulatory/financial; S/T: structural/technical; I/A: institutional/administrative; MARKET: market-based; ON-SITE: on-site operations.
** A: mechanism has been applied with success; O: mechanism based on opinion only, little or no research has been done; P: some analysis has been done.

Table 14: Partial List of Adaptation Measures: Industry (continued)

Adaptation Measure	Bear the Loss	Prevent the Effects*	Conduct Research	Provide Education & Change Behaviour	Avoid the Impacts	Application**
Agriculture (continued)						
Research						
• Pool regional resources.		L/R/F				A
• Encourage more use of good land.		L/R/F				P
• Develop food products that can be more easily stored and transported.		S/T				A
• Change policy to maintain national food security while avoiding over-supply.		L/R/F				P
• Maintain and improve input supply and export delivery infrastructure.		I/A	X			A
• Assemble, preserve and characterize plant and animal genes.		S/T	X			A
• Enhance information exchange systems.		I/A				A
Construction						
• Research more climate-tolerant practices and materials.		S/T	X			O
Finance						
• Improve research to better quantify risks posed by extreme weather.	X	N/A	X			A
• Improve knowledge of relationship between extreme events and changing climate.	X	N/A	X			O
• Increase input of insurance industry in land-use planning.		L/R/F				O

* L/R/F: legislative/regulatory/financial; S/T: structural/technical; I/A: institutional/administrative; MARKET: market-based; ON-SITE: on-site operations.

** A: mechanism has been applied with success; O: mechanism based on opinion only, little or no research has been done; P: some analysis has been done.

7.0 KNOWLEDGE GAPS AND RESEARCH OPPORTUNITIES

This fourth volume of the *Canada Country Study* has examined the impacts of, and adaptation to, the current and future climate from an Ontario perspective. The study's primary findings and conclusions may be found in the executive summary.

The assessment of the potential impacts of climate variability and change on the environment and the economy is a comparatively new area of research. The broad range of the implications of climate change for Ontario has spurred a considerable body of impacts research within the region. Most notably, the bi-national, *Great Lakes–St. Lawrence Basin Project, On Adapting to the Impacts of Climate Variability and Change*, has examined the impacts on water and land-use management and on human and ecosystem health. Recently, this project has been complemented by a number of research activities being undertaken largely by Environment Canada under the auspices of the Canada–Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA). The objective of the COA climate change target is to identify the most likely impacts of climate variability and change on the Great Lakes Basin ecosystem and to develop and promote adaptive response strategies to reduce vulnerability.

Research to date has demonstrated that the climate plays a significant role in many parts of the Ontario environment and economy. Progress has been made in exploring the implications of climate change in several sectors, including water resources and agriculture.

However, this study has also identified a large number of knowledge gaps. Detailed regional climate model scenarios are required to improve our understanding of impacts across all sectors. Climate impact assessment modelling in Northern Ontario, outside the Great Lakes Basin is notably lacking. In Ontario, and most other jurisdictions, impact and adaptation studies have typically focused on a specific sector or sub-sector; but detailed and integrative assessments are needed. Finally there has been a shortage of both research and implementation of practical measures focused on adaptation to climate variability and change.

7.1 Climate Monitoring, Processes and Modelling

- The ability to detect climatic changes will be contingent upon the performance of the climate system observational network. Reliable monitoring systems should be in place to describe the climate system and gather evidence of trends or changes.
- Under a changed climate, extreme weather events may be more frequent and intense. However, our ability to detect such changes may be limited by the lack of a thorough baseline analysis of these phenomena. A detailed climatology of extreme and severe weather events in Ontario needs to be developed.
- The quality and degree of confidence in climate impact research is dependent on the accuracy and detail provided by the driving climate models. Improved General Circulation Models (GCMs) are needed, incorporating better spatial and temporal resolution, and more realistic simulations of climatic processes and feedback mechanisms such as the roles of aerosols, cloud cover, vegetation, soil moisture and hydrology.
- Climate impact research across all sectors requires detailed, regional scale scenarios of potential climate changes. The GCMs, although valuable, are inherently limited in their resolution and ability to represent the

contribution of significant regional influences such as the Great Lakes. The use of the higher resolution, nested, limited area models (LAMs) should produce more detailed and responsive climate change scenarios for regional assessments in Ontario.

- Some evidence exists that climate change could alter the pattern of extreme events on both global and regional scales. Any such shift would be more significant than changes in mean values of quantities such as temperature and precipitation. Climate models, because of their temporal and spatial resolution, have been unable to quantitatively assess these changes. It is a priority to devise approaches to assess the frequency and intensity of extreme events under a changed climate.

7.2 Sensitivities to Current and Future Climate

- Limited work has been done on the potential impacts of climatic change on the infrastructure, economy and communities of Northern Ontario, beyond the Great Lakes Basin.
- Little is known about the extent of existing groundwater resources in Ontario. And less is known about the effect of climate variability and change on this resource. Detailed assessments of the implications of climate change for soil moisture, groundwater recharge, base flow and water quality are needed in many sectors.
- Increased mean air and lake temperatures resulting from changes in heat and water balances could have a number of direct effects but also drive secondary processes by altering buoyancy-driven turnover within the Great Lakes. More research is needed on impacts of climate variability and change on lake dynamics and the implications for water quality, air-water partitioning of hazardous air pollutants, nutrient loadings and oxygen supply.
- Municipal and agricultural water consumption are expected to increase in the Great Lakes Basin under a changed climate. Projections of water consumption need to be incorporated into evaluations of future water supply and lake levels. Potential water-use conflicts should also be investigated.
- The total surface area and distribution of wetlands around the shorelines of the Great Lakes and on smaller lakes will be altered by climate change. More research is needed on the implications of climate change for local and regional hydrology as reflected by water level changes. No detailed assessment has been made of the potential fate of Ontario’s wetland areas and any associated implications for the biological diversity of the region.
- More work needs to be done on the impacts on human health of atmospheric influences such as heat stress, air quality and temperature-dependent vectors for infectious disease. Little is known about the potential impacts of climate change and variability on these atmospheric issues and, in turn, on human health.
- Research and policy measures have traditionally investigated the various air issues individually. Little work has been done on the potential effects of climate change on regional air issues and any synergistic effects that might exist between them. *The Toronto–Niagara Region Study on Atmospheric Change* will examine regional air issues in an integrated fashion. This study will also explore the effects of climate change on urban environments and attempt to develop linkages between adaptation and mitigation strategies.
- Little work has been done to assess the potential impacts of climate change, and the rates of climate change, on the migration of ecoclimatic regions. More research is needed to assess the impacts of climate change on Ontario’s wildlife species within natural and protected areas. In addition to climate change, such research should also examine the important effects of anthropogenic changes to land and water use.

- The rate of migration of northern hardwood and boreal transition forests will be determined by a variety of competing factors, including carbon dioxide fertilization, soil composition, water-use efficiency, photosynthesis, water availability and forest fragmentation. No detailed studies incorporating this diverse range of factors have been conducted. The effects of these potential changes on the forest industry and resources communities should also be investigated.

- Laboratory studies indicate that warmer temperatures and fertilization by higher concentrations of carbon dioxide could increase crop yields and enhance their ability to adapt to stressed environments. However, this growth could be substantially limited by decreased soil moisture and potentially increased air pollution. More extensive field trials are required to evaluate the combined effects of these factors on a variety of agricultural species.

- Gaps and deficiencies exist in the climatic data required to determine climatic design values for the built environment. Geographic coverage is particularly weak in some areas of Northern Ontario that may experience increased industrial and agri-cultural activity, or undergo an expansion of the built environment under a changed climate.

- Current engineering practices, as well as many extreme-value analysis procedures for climate parameters such as precipitation rates and snow and wind loads, assume that past climatic conditions will remain steady in the future. Consequently, it is unknown whether the current safety margins for the engineering design of structures such as dams and bridges will be sufficient.

- More information is needed on the potential impacts of climate change on the hydroelectrical system. In addition to the potential implications for dam safety and design, little is known about how climate change might affect water supply for hydroelectric dams. Severe weather and extended periods of freezing rain can cause extensive damage to the transmission infrastructure. Climate models have been unable to estimate how climate change would affect the frequency and severity of these types of events.

- Solar and wind energy production are highly sensitive to weather and climatic changes. Further work is needed to determine the impact of a changing climate on the potential of these renewable energy sources.

- A detailed assessment is needed of the impacts of the current climate on the Ontario economy. Studies to date have generally focused on specific sectors. Not enough is known about the indirect effects and impacts across sectors. For example, it is unclear how agricultural yield losses due to poor or extreme weather affect the Ontario transportation sector.

7.3 Adaptation

Adaptation research is a relatively new area of study and consequently a complete list of knowledge gaps would be quite lengthy. This section will focus on the primary deficiencies that have been identified from within the most active sectors.

- Little work has been done on the potential impacts of climate change on human health and very few measures have been identified within the health care system to reduce these impacts.

- Research conducted on species protection has been fairly extensive, but this work has rarely been framed in terms of developing adaptive measures in response to climate change. When preparing to restore degraded habitats or preserve existing ecosystems, managers need to investigate the potential impacts of climate change on the target area and select species tolerant of anticipated future climatic conditions. When ecosystem management areas are being designed, the feasibility of migration corridors and other adaptation mechanisms should be investigated.

- Increased efforts should be made to identify trees that have genetic characteristics that make them more adaptable to anticipated climatic conditions. The feasibility of transplanting shoots and seedlings to new regions to assist migration should be investigated.
- Changes in climate, coupled with the anticipated growth of the Ontario population, are expected to decrease the supply of, and increase the demand for water in the next century. It is important that any research agenda addressing water supply and demand issues, be developed in conjunction with key sectors such as municipalities and agriculture. Methods should be investigated to enhance water conservation and to develop approaches to minimize potential water conflicts.
- Little research has been conducted on specific impacts of climate change on the built environment. However, this sector is sensitive to the climate, particularly climatic extremes, and reducing vulnerability is a significant research priority. Perhaps the best means of preparing this sector to cope with future climate change is by working to reduce the vulnerability of built structures to the current climate and climate variability by regular reviews of the climate information used in the development of building codes.
- The insurance industry is sensitive to climate variability and extreme events. It is important to the industry that the impacts of climate variability and change be better understood so that the associated financial implications can be assessed. At the moment, the most prudent course of action in most sectors would be to explore how they might better adapt to current climate variability and climate-related extremes.
- Over the next century, it is highly likely that society will change in ways that cannot be foreseen. Current policies, practices and regulations should be examined to determine if any of these encourage maladaptation. When exploring how best to respond to future climate change, it would seem prudent to adopt *no-regrets* strategies: ones that would be appropriate today and in the future, regardless of changes that might occur. The various sectors and communities of interest should evaluate the *no-regrets* strategies available to them.

GLOSSARY OF SELECTED TERMS

Acidic deposition The deposition of strong acids from the atmosphere in the form of rain, snow, fog or dry particles. These acids form when sulphur oxides (produced by the burning of coal and oils from smelting industries, power generation and from transportation) combine with water vapour in the atmosphere.

Aerosols Tiny atmospheric particles, composed primarily of water in combination with sea salt or pollutants such as sulphuric acid. Aerosols act as nuclei for cloud condensation, participate in chemical reactions and absorb or scatter radiation, thereby influencing the earth's radiation budget.

Biological diversity, or biodiversity The diversity of biological species within a given region. It is expressed as the variety of species, the variety within species (genetic diversity) and the variety of ecosystems in a given region or area.

Bog A type of wetland that depends primarily on precipitation for its water source, has no significant inflows or outflows, and is usually acidic and rich in plant matter with a conspicuous mat of living green moss.

Carbon dioxide fertilization The enhancement of growth, or net primary production, that could occur in natural or agricultural systems as a result of an increase in the atmospheric concentration of carbon dioxide.

Carbon dioxide sources and sinks Chief sources of carbon dioxide are the burning of fossil fuels and the combustion or oxidation of wood or other biomass. Carbon dioxide is removed from the atmosphere by the photosynthesis of green plants and through absorption into the oceans.

CCC-GCMII: Canadian Centre for Climate Modelling and Analysis Second Generation (1992) General Circulation Model.

Climate adaptation Adjustments in social and economic activities to enhance their viability and to reduce their vulnerability to climate. Adaptation represents a practical means of accommodating current climatic variability and extreme events as well as adjusting to longer-term climatic change.

Climate analogue scenarios A climate scenario that involves the use of known, historical climatic conditions as a potential model for a future, changed climate.

Climate Change A significant change, over a period of time, in the meteorological conditions and quantities generally used to describe the climate of a region. The climate is typically characterized by means and other statistics applied to meteorological elements such as temperature and precipitation, calculated over a period of a decade or more.

Climate normals Averages of meteorological variables computed over a uniform period of 30 years.

Climate scenario Description of what the future climate might be like under a carefully defined set of conditions. Two widely used scenarios are an atmosphere with doubled concentration of carbon dioxide (2xCO_2), and one based upon specific, historical climatic conditions (analogue).

Climate variability The inherent variability or fluctuation in average climatic conditions. Deviations from long-term averages in climate statistics are generally referred to as climatic anomalies.

Ecosystem A term first used to describe the interdependence of species in the living world, both with one another and with their physical environment. Ecosystem principles can be applied to definable systems of any size, from a pond to an ecozone or even to the planet as a whole.

Ecozone A large, terrestrial ecosystem that can be defined by its own distinct set of biological species and physical characteristics.

Equilibrium scenario A climate change scenario that assumes that the system is suddenly perturbed (i.e. instantaneously double the concentration of CO_2). The selected climate model is run until the system achieves a state of equilibrium.

Eutrophication The process of fertilization that causes increased productivity and biomass in an aquatic ecosystem. Eutrophication can be a natural process or one caused by a human-induced increase in nutrient loading.

Evapotranspiration The physical process by which water is transferred from the earth's surface to the atmosphere. It includes the evaporation from water, ice or land surfaces and transpiration from plants.

Fen A type of wetland that accumulates peat deposits, is less acidic than bogs and derives most of its water from groundwater rich in calcium and magnesium.

GCM, or General Circulation Model A numerical model used to describe the physical state of the atmosphere-earth-ocean system. These complex models are used to explore the consequences, for the climate system, of changes in key atmospheric conditions such as carbon dioxide concentration.

GFDL GCM The General Circulation Model developed and run by the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey.

GISS GCM The General Circulation Model developed and run by the Goddard Institute for Space Studies at Columbia University in New York City.

Greenhouse effect The phenomenon whereby certain "greenhouse" gases in the atmosphere are transparent to incoming solar radiation and yet efficiently absorb outgoing heat energy radiated from the earth. These gases retain heat within the lower levels of the atmosphere.

Greenhouse gases Gases that contribute to the "greenhouse effect" by trapping radiant heat near the surface of the earth. The most significant greenhouse gases are water vapour, carbon dioxide, tropospheric ozone, nitrous oxide and methane.

HAPs, or hazardous air pollutants Gaseous, aerosol or particulate contaminants present in the ambient air in trace amounts with characteristics (toxicity and persistence) so as to be a hazard to human health or plant and animal life. The term hazardous air pollutants is synonymous with air toxics.

IJC, or International Joint Commission A binational commission formed under the Boundary Water Treaty in 1909 to assist the governments of Canada and United States to regulate the flows and levels of boundary waters and reach agreement on issues of concern to either country.

IPCC, or Intergovernmental Panel on Climate Change An international body established in 1988 to report to the World Meteorological Organization and the United Nations Environment Program on the science, impacts and potential response strategies associated with climate change.

Lake-effect snow Snow generated by the passage of cold winds, generally from the northwest, over relatively warm lake or sea water. The areas to the east or southeast of each of the Great Lakes are referred to as the snowbelts since they are most frequently hit by heavy lake-effect snowstorms.

LAM, or Limited Area Models Climate models focused on a limited spatial domain using more sophisticated physics and at a higher resolution than the GCMs. The LAMs use the output of a GCM to set the boundary conditions for their more detailed climate scenarios.

Little Ice Age A period running from approximately 1400 to 1860 during which the climate of mid-latitudes became significantly colder. During the Little Ice Age, global temperatures dropped about one degree Celsius, glaciers advanced, sea ice filled much of the North Atlantic, and repeated famines led to cultural dislocations.

Marsh A type of wetland that does not accumulate appreciable peat deposits and is dominated by herbaceous vegetation.

Morbidity The relative incidence of disease in a given place or time.

mT (maritime tropical) airmass A large body of air characterized by warm moist conditions.

Maritime tropical or mT airmasses originate over the warm waters of the tropics and Gulf of Mexico, where heat and moisture are transferred to the overlying air from the waters below.

OSU GCM The General Circulation Model developed and run by Oregon State University.

Ozone A molecule consisting of three atoms of oxygen. Most ozone is produced naturally in the upper atmosphere (above 12 km) where it protects the biosphere by absorbing damaging ultraviolet radiation. In the lower atmosphere ozone is an irritating and harmful gas constituting the primary component of photochemical smog.

Paleoclimatology The study of the climate of periods before the regular use of meteorological instruments. This discipline uses measurements of markers such as pollen or marine plankton to develop semi-quantitative estimates of climatic conditions.

Particulates A generic term for all airborne particles including smoke, fumes, dust, fly ash and pollen. Particles range in diameter from 0.1 to 100 microns.

Photochemical smog The brownish-yellow haze of air pollutants that occurs under stagnant conditions in many industrialized regions of the world, including Southern Ontario. The main components are ground-level ozone, visibility-reducing aerosols and irritants such as PAN (peroxyacetyl nitrate).

Rainshadow The area downwind of a topographical barrier such as a hill, escarpment or mountain that is noted for less precipitation and cloud cover.

Seiche Oscillation of water back and forth along the axis of a long, shallow lake. When storm surge winds weaken and can no longer support elevated lake levels, the water flows towards the opposite end of the lake, establishing a periodic oscillation or seiche.

Soil moisture deficit The amount by which the available soil moisture fails to meet vegetative demand for water. The soil moisture deficit is the difference between potential evaporation (theoretical evapotranspiration given optimum moisture supply) and the actual water loss evaporated from the vegetation and the ground.

Storm surge Elevation of the water level at one end of a lake in response to the driving force of strong onshore winds. The effect is the most frequent and pronounced on Lake Erie, where strong winds blowing along the axis of the long, narrow and shallow lake can rapidly build a storm surge of a metre or more.

Succession The temporal evolution in the composition of plant communities at a specific location. The particular species mix responds to a variety of environmental stimuli, including climate.

Transient scenario A climate change scenario under which the system is perturbed gradually (i.e. slowly increasing CO_2 concentrations). This type of scenario is considered to be a more realistic representation of the manner in which global climate change will progress.

VOCs, or volatile organic compounds In practical use, VOCs refer to a selected set of volatile, carbon-based compounds that are precursors to the formation of ground-level ozone. There are approximately 150 common VOCs measured in Canada including propane, butane and toluene.

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