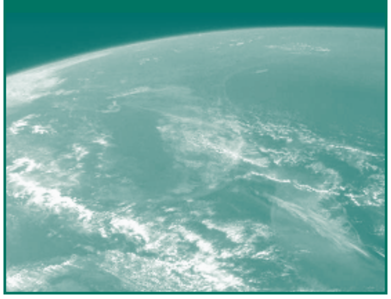
THE CANADA COUNTRY STUDY

Climate Impacts and Adaptation



VOLUME VII
NATIONAL SECTORAL VOLUME

EXECUTIVE SUMMARY

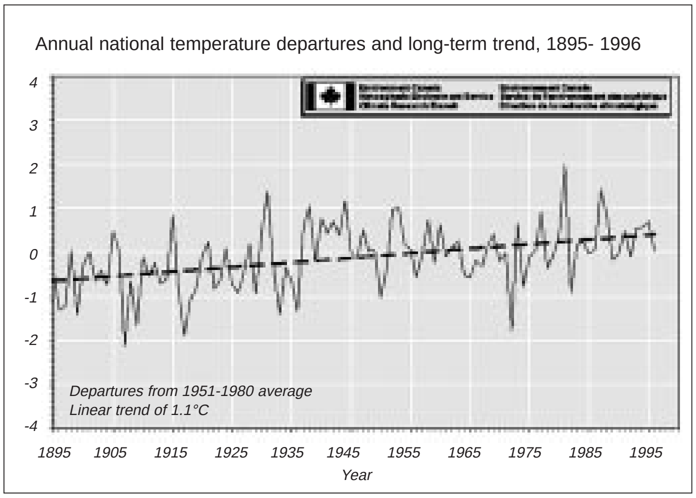
A. INTRODUCTION

The scientific and technical results of the assessment phase of the Canada Country Study (CCS) are published in eight volumes - six regional volumes (Arctic, Atlantic, Ontario, Pacific and Yukon, Prairies, and Québec), a national sectoral volume consisting of twelve papers and a cross-cutting issues volume consisting of eight papers. The current document - the Executive Summary - provides a digest of the material in the twelve sectoral papers in the national sectoral volume (agriculture, built environment, energy, fisheries, forestry, human health, insurance, recreation and tourism, transportation, unmanaged ecosystems, water resources and wetlands).

The issue of climate change

The Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report concludes that the balance of evidence suggests a discernible human influence on global climate. Human activities are increasing the atmospheric concentrations of greenhouse gases and these changes are projected to lead to regional and global changes in climate and climate-related parameters such as temperature, precipitation, soil moisture and sea level.

In order to understand how the world's climate may respond, sophisticated computer models called general circulation models (GCMs), are used to simulate the type of climate that might exist when global concentrations of greenhouse gases are doubled from pre-industrial levels. As the initial focus has been on providing a state-of-the-art assessment based on existing scientific and technical literature, the results of the CCS are not based on a single climate scenario. Instead, it includes the range of scenarios 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: 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) and; UKMO95 – UK Meteorological Office model.

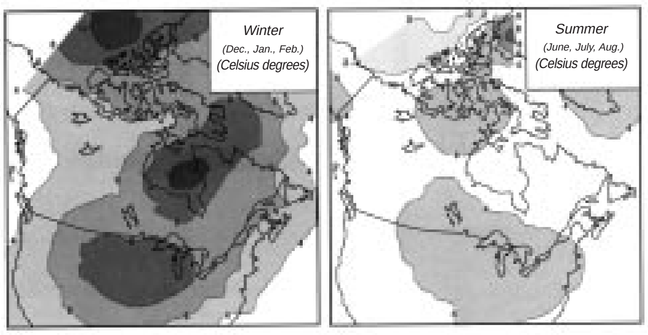


Environment Canada   Environnement Canada

Canada

CCC GCM2 2xCO_2 temperature projections for Canada for winter and summer seasons

Climate changes wil not be distributed uniformly. For a doubling of carbon dioxide concentrations, GCM2 projects an increase of 3.5C in the earth's average annual temperature but shows more substantial warming over much of Canada, particularly in winter.



Model	Winter	Summer
GFDL 91 - Geophysical Fluid Dynamics Laboratory GCM	2-6°C	2-3°C
GISS 85 - Goddard Institute for Space Studies GCM	2-14°C	1-2°C

When interpreting the results presented here, based on these scenarios, the reader should be aware that confidence is higher in the hemispheric-to-continental projections of climate change than in the regional projections, where confidence remains low. It is also worth noting that the majority of the identified changes in climate and, therefore, the identified impacts, are projected to occur over the next century, and that the average rate of warming would probably be greater than any seen in the last 10,000 years. Furthermore, although future, unexpected, large and rapid climate system changes (as have occurred in the past) are difficult to predict, future changes may also involve "surprises".

B. IMPACTS OF CLIMATE CHANGE

In structuring this executive summary, results are organized into impacts of climate change and adaptation to climate change for each of the twelve sectors individually. Virtually all sectors within Canada are vulnerable to climate change to some degree and these projected impacts are such that the status quo will not be an option. Taken individually, responses to any one of the impacts identified may be within the capacity of a particular region or sector. The fact that they are projected to occur simultaneously and in concert with changes in population, technology, economics, and other environmental and social changes, however, adds to the complexity of the impact assessment and the choice of appropriate responses. Furthermore, our climate is variable and Canadians and the economy react to it on different temporal and spatial scales. As such, all of the impacts are expected to exhibit significant regional variations which would have implications for distributional changes in social welfare and the choice of appropriate responses.

The literature of climate change impacts and adaptation shows wide disparity in the amount of research that exists relevant to any given natural system or socio-economic sector in Canada. In addition, relatively little attention has been given to a comprehensive examination of positive impacts or possible opportunities. The CCS, being based on the existing scientific and technical literature, reflects this disparity.

Water

Water is essential to many economic and societal functions in Canada including: municipalities, industries, manufacturing, recreation, navigation, and hydro-electric generation. Water is also a critical, limiting factor in the existence and distribution of our natural ecosystems. Climate change is expected to lead to an intensification of the global hydrological cycle and this will cause major impacts on regional water resources. Relatively small changes in temperature and precipitation, together with the effects on evapotranspiration and soil moisture, can result in relatively large changes in the magnitude and timing of runoff and the intensity of floods and droughts.

Hydrological impacts: Some of the generalized hydrological impacts in Canada based upon climate change scenarios include: increases in annual precipitation for most regions; increases in the intensity of local precipitation events; increases in evapotranspiration due to higher air temperatures; changes in runoff and streamflow across Canada; decreases in lake levels; decreases in groundwater levels; decreases in soil moisture in southern Canada; reductions in the ice cover season and; reductions in the extent of permafrost.

Impacts on water use: Hydrological impacts also have important implications on the natural environment and how humans use water. Rural water use conflicts may increase, as growing demands for irrigation may not be met as water supplies decrease due to increases in potential evapotranspiration. Decreased lake levels and lowered streamflows may reduce the amount of fish habitat. Increased water temperatures and reduced dissolved oxygen may impair many fish species. Lowered lake levels and flows will likely cause reductions in hydroelectric power generation capabilities, increase energy costs, and affect the cargo carrying capacity of commercial vessels. However, warmer winter temperatures may allow a longer shipping season by reducing the amount of ice cover in navigation channels. Municipal water consumption, particularly lawn watering activities, will likely increase as air temperatures rise. Changes in precipitation rates may increase the potential breeding sites for vectors which carry diseases. Floods or intense precipitation events may cause overflows of combined storm and sewage systems leading to water contamination such as outbreaks of Cryptosporidium.

Ecosystems, Biodiversity, Wildlife and Wetlands

Ecosystems contain the Earth's reservoir of genetic and species diversity. The occurrence and association of plants and animals in the natural environment depend, to a great extent, on climate. As such, projected changes in climate could have significant implications for natural ecosystems in Canada. Small variations in climate, such as a 1.0°C to 2.0°C in mean annual temperature can have significant repercussions for the characteristics and functions of natural ecosystems. The composition and geographic distribution of many ecosystems will shift as individual species respond to climate change. However, some ecosystems may remain unstable for several centuries as the changing climate continues to impose new limits and opportunities.

Terrestrial: Plant and animal species, adapted to existing climatic conditions, would be affected through projected changes in temperatures, habitat loss or degradation, changes in food abundance or availability, and changes in predation rates, competition, parasites and diseases. A real concern is the capacity for terrestrial species to be able to survive when the rate of climate change is anticipated to be both faster than the ability of terrestrial ecosystems to adapt and migrate, and faster than any experienced in the last 10,000 years.

Under climate change, the boundaries of existing plant, animal species, insects, and soil microbes can be expected to shift to higher latitudes and/or higher elevations, while the invasion of southern species into Canada is also likely. This reflects an expected northward shift in the ecoclimatic regions of Canada as well as a change in their relative size and composition. For example, the tundra area could shrink by more than a third of its current size under projected changes in climate, so that it would be confined mainly to the islands north of the mainland, and its vegetative content would likely alter to reflect snow cover and soil moisture changes. High Arctic Peary caribou and muskoxen may become extinct, while mainland caribou would come under significant stress.

With increases in air temperatures, plant growth should increase in those areas where the current climate is a limiting factor. Satellite data have provided evidence of an overall increase in terrestrial photosynthetic activity in Canada from 1981-1991 in marginal areas extending in a wide band from the Yukon and British Columbia southeastward to the Great Lakes, then northeastward to Labrador. A warmer, drier climate is also expected to substantially increase the number of wildfires and area burned in Canada, with obvious consequences for wildlife and the associated ecosystems.

Wetlands: Wetlands currently cover 14% of Canada's land mass and are a critical resource providing habitat for species (including some of Canada's rare, threatened, or endangered ones), storage for atmospheric carbon, nutrient and mineral cycling, water purification, and natural flood control. Climate change could result in the conversion of semi-permanent wetlands from open-water dominated basins to vegetated areas, and wetland salinity could increase significantly.

Hydrology is a key factor in determining wetland ecology. Lowered water levels in wetlands can alter both the quality and quantity of waterfowl habitat. A 3.0ºC increase in temperature could result in a 39% decline in the number of wet basins in Canada's parkland region, despite increased precipitation; the impact is expected to be less severe in the grassland region. There is some possibility that prairie wetlands could expand northward offsetting some of the anticipated loss in other parts of the region.

Much of Canada's peatland area is underlain by sporadic to continuous permafrost. A climatic warming of 2.0ºC would shift the boundaries of this underlying permafrost northward and increase the depth at which permafrost occurs, with the result that most of the current peatland regions would have only sporadic permafrost underlying, with major consequences for their ecology and biogeochemistry. It may also renew peat accumulation in subarctic regions of Canada although degradation of southern peatlands may be much faster than northward migration and the total area of Canada's peatlands will likely decrease.

Aquatic: Freshwater habitat for some key aquatic wildlife including salmonids could be lost in parts of Canada. Inland aquatic ecosystems will be influenced by climate change through altered water temperatures, flow regimes and water levels. Many species in inland lakes and streams, where not land locked, are likely to shift northward by about 150 km for every 1oC rise in temperature. In terms of water quality, decreased lake levels, lowered streamflow, increased water temperatures and reduced dissolved oxygen may reduce the available habitat for fish. For instance, cold-water species near their southern limits such as brook trout may be replaced by warm-water species.

Reduced sea ice thickness and extent, and sea level rise under climate change, will result in mixed impacts. Some species such as the sea otter could benefit from being able to expand into new areas while others such as seals may decline due to reduced sea-ice expanses for breeding and feeding. The polar bear is particularly of concern; it could become extinct through starvation if the Arctic Ocean becomes seasonally ice free for a long enough period. Some large breeding colonies of seabirds are at risk due to rising sea level, including colonies of Common Murre and Northern Gannets in Newfoundland.

Agriculture

In Canada, an important dimension to the relationship between climate change and agriculture is the wide range of conditions for agricultural production between different regions. There has been considerable research into the possible implications of climate change scenarios for agro-climatic conditions in all regions of Canada, except southern British Columbia. These studies have considered several climatic change scenarios and have examined the implications of altered climates for wide range agro-climatic properties, including the growing and frost free seasons, and seasonal values for temperature, growing degree days, corn heat units, precipitation and moisture deficits. The implications for thermal regimes have been investigated more thoroughly than the implications for moisture regimes.

All of the global climatic change scenarios and studies suggest warming for most of Canada. Impacts of climate change on agriculture will be most directly reflected through the response of crops, livestock, soils, weeds, and insects and diseases to the elements of climate for which they are most sensitive. Soil moisture and temperature are the climate factors likely to be most sensitive to change across large agricultural areas of Canada. Longer frost free seasons more conducive for commercial agriculture are expected under climate change. For the Prairies, Ontario and Quebec, most estimates suggest an extension of three to five weeks. Results relating to moisture regimes show estimated precipitation changes ranging from decreases of about 30% to increases of 80%. Despite favourable potential impacts in terms of longer and warmer frost free seasons and of greater precipitation, most climate change scenarios also imply important increases in potential evapotranspiration. This will lead to larger seasonal moisture deficits in all regions of Canada, with the severest situations anticipated for Ontario.

Land capability: Impacts on agricultural land potential north of 60º are generally considered to be insubstantial in nature. However, the Peace River region and northern agricultural areas in Ontario and Québec are expected to see some expansion of the land area suitable for commercial crop production. The physical potential for fruit and vegetables could expand beyond current southern locations in Québec, Ontario, and British Columbia.

Crop development: Research has focused on impacts on grain crops, including grain corn, spring and winter wheat, oats and barley. Warmer frost free seasons are expected to increase the rate of development of grain crops, reducing the time between seeding and harvesting by up to 3 weeks in most regions for spring-seeded cereals and coarse grains. In northern regions, the shorter maturation time would reduce the risk of frost-induced crop injury.

Yields: Most of the research reviewed predates the more recent generation of crop development and productivity models which take into account the potential benefits of increased CO_2 levels on crop yields. As a result, these studies probably overestimate the negative effects of climate change on crop yields. In the Prairies, spring-seeded cereal yields are expected to decrease by up to 35% in the west and increase by up to 66% in the east. Ontario and Québec would experience similarly variable results except that northern areas could anticipate increased grain production, especially for corn. In both the Atlantic region and British Columbia, increased grain yield potential is foreseen, but realization is likely to depend on increased irrigation and the availability of land. Oilseed yields may be generally reduced in Canada due to crop moisture stress, although possibly offset by northern expansion of the area capable of such production.

Agricultural trade: Canada is a major producer of agricultural products on an international scale, and therefore changes occurring abroad may have as significant an influence on Canadian agriculture as changes in domestic production prospects. Major changes, whether these be positive or negative, in Canada's agricultural production capacity will be bound to have consequences within and beyond its national borders.

Fisheries

Fisheries are important sources of food, sport and employment in Canada. In 1994, the total Canadian commercial catch was 1,070 k-tonnes primarily from the oceans with a landed value of $1.78 billion. Aquaculture is a rapidly growing sector in competition with commercial fisheries. In 1994, production reached 54 k-tonnes of fish, mainly salmon, valued at $300 million. For fish, the temperature tolerance zones for survival, growth and reproduction are species-specific characteristics. Each species exhibits a characteristic preferred temperature and preferred temperatures range from values below 10ºC to values above 25ºC. Given the importance of temperature in shaping the vital activities of fish, the responses of freshwater and marine populations to changes in water temperatures under climate change fall under two broad categories: changes in fish production in a particular area and changes in fish spatial distributions. Under a warmer, drier climate in Canada, the following impacts on Canadian fisheries are possible:

Pacific marine: Lower and more variable sustainable harvests from southern salmon populations are expected. Pacific cod abundance is also likely to be reduced. Higher, more consistent sustainable harvests are anticipated from northern salmon populations, with sockeye salmon most affected.

Atlantic marine: A decrease in overall sustainable harvests from coastal and estuarine waters is projected due to decreases in freshwater discharge and consequent declines in ecosystem productivity. Widespread changes in sustainable harvests, locations of fishing grounds, and gear efficiencies for many species could occur due to complex and likely unpredictable changes in the water current systems that shape offshore marine habitats and migration patterns.

Arctic marine: Increases in sustainable harvests for most fish populations are likely, due to increased ecosystem productivity as shrinking ice cover permits greater nutrient recycling.

Southern freshwater: There could be decreases in sustainable harvests for many fisheries due to declining water levels in lakes, declining flow rates in streams, and reductions in nutrient loading and recycling for many lakes and streams on the Canadian Shield. Of the overall sustainable harvest, the proportion comprising cold water fish will be reduced, including species such as trout, pickerel, whitefish, and grayling.

Northern freshwater: There will be increases in sustainable harvests for most fish species, due to longer, warmer growing seasons and relatively small changes in water levels. Potentially, there will also be an increase in the diversity of fish species that can be harvested sustainably due to increases in the diversity of thermal habitats available to support new species expanding their ranges from the south.

Forestry

Forests have long played an important role in Canada's economy and culturally they help define our social identity. Of Canada's 417.6 million ha of forested land (42% of the total land area), 119 million ha are managed for timber extraction while another 50 million ha are protected from harvesting through legislation. The forest ecosystem supports 1 in 15 jobs and over 200,000 wildlife species found in Canada. Forest responses to climate change can be classified as either direct changes induced by the increased concentrations of greenhouse gases, or indirect changes such as changes to temperature and precipitation.

Forest regime: Canada's forests sequester significant quantities of carbon due to the slow rate of soil organic mass decomposition. Increased temperatures would increase the rate of decomposition, as well as increases in the vegetation growth rates or net primary productivity. The fact that the climate is projected to change faster than forests can adapt or migrate suggests that our forest ecosystems will be in a state of transition in response to the changing climate, with primarily negative impacts. Furthermore, Canadian forests could experience more frequent and severe storms and wind damage in coastal areas, drought stress due to the redistribution of precipitation patterns, and an increase in frequency and severity of fire.

Shifts northward (and to higher altitudes) in the current ranges of individual forest species and species associations are expected. The boreal forest is expected to undergo an extensive reduction in size, with grasslands and temperate deciduous species expected to invade from the south. Northern expansion of the boreal forest will be curbed by poor soil, permafrost and lower solar radiation rates. Forest structure of the Pacific northwest is expected to remain similar to the present with richness in species diversity compensating for individual species migration. Wildlife habitat and natural reserves could suffer due to a lack of connectivity and the disturbance in the equilibrium between habitat and climate created by climate change.

Forest industry: With forests maladapted to the projected changes in climate, large areas of forest decline are anticipated. Salvage harvesting of these areas could increase the potential harvest for a period of time; however, at some point, there could be a timber shortage because new forested areas in the north will not be maturing fast enough to offset the losses in southern areas. As such, losses due to forest decline and modified fire and insect regimes, as well as drought stress in some areas, could challenge the adaptive capacity of the industry. This seems likely to be the case where long-run sustainable yield levels are considered. As a consequence, the overall impact on the Canadian forest industry is expected to vary by regions. For example, in the Mackenzie Basin area, yields from all stands of commercial lumber, both softwood and hardwood, are anticipated to decline by 50% as a result of the projected changes in climate.

Energy

In general, the sensitivity of the energy and transportation sectors to climate change is relatively low, compared to that of agricultural or natural ecosystems. The capacity for adaptation through management and normal replacement of capital is expected to be high. However, activities in these sectors would be susceptible to a rapid rate and sudden changes in climate, as well as changes in the frequency or intensity of extreme weather events.

Energy demand: Space conditioning demand profiles could alter to reflect lower heating needs in winter, but higher air conditioning needs in summer. An overall decline in energy needed for space conditioning is generally foreseen across the country, although in Québec, an overall increase is possible. For Ontario, overall space conditioning energy demand may decrease, but peak energy demands could rise. Changes in energy demand for other purposes are also expected. In the Prairies, for example, energy use will decrease for transportation, but increase for irrigation, grain drying, and harvesting.

Supply - hydro-electricity: Hydro-electric generation potential is sensitive to changes in water availability and river flow regimes. As such, regionally differentiated changes in hydro-electric generation potential are expected, reflecting projected regional increases (e.g., Labrador and northern Québec), and decreases (e.g., Ontario, the Prairies, and southeastern British Columbia) in water availability and flows. Transmission lines may be subject to more storm-related outages should projected changes in extreme events occur. Electricity-driven industry (for example, aluminum production) could be particularly affected as a result.

Supply - fossil fuels: Offshore oil and gas operations should benefit from reduced hazards such as sea ice and perhaps icebergs, but could be subject to more intense and frequent extreme storms. Any savings on the costs of offshore platforms would be partially offset by increased costs for coastal facilities subject to more severe wave activity. Pipeline costs in the Arctic are likely to be more expensive due to the need to address increased permafrost instability. Costs for ice-breaking tankers should be reduced. Uncertainties are still high enough, however, that the positive impacts cannot be incorporated into current design while negative impacts have to be included due to the conservative approach adopted by industry for frontier activities. As a consequence, there may be an increased cost for frontier oil and gas operations in the short term. For coal mining operations, increased erosion and landslides may be a concern in some areas, such as British Columbia.

Transportation

Land-based: It is expected that overall costs would be reduced due to shorter and/or less harsh winters (more efficient engine operation, less warm-up time, shorter snow removal seasons although with greater amounts during the winter season in some areas of the country). This is particularly applicable for the southern half of the country. In the North, however, such as in the Mackenzie Basin, winter transportation costs may be raised due to a reduced length of season for ice roads. Increased permafrost instability will likely lead to increased maintenance costs for existing all-weather roads and rail-beds.

Marine: The shipping season could lengthen for areas currently characterized by sea ice for all or part of the year, such as Hudson Bay and the western and central Arctic, and marine design needs related to sea ice may be relaxed. Sea-level rise will generally contribute to deeper drafts in harbours and channels, but will be associated with significant damage to coastal support infrastructure in Atlantic and Arctic Canada. The potential of increased storm activity has raised concerns regarding the necessity of increased navigational aid support.

Freshwater: Although longer open-water seasons will result, projected reduction of water levels will generally translate into significant, negative impacts for commercial navigation on major rivers and lakes, such as the Great Lakes - St. Lawrence River system. On the Mackenzie River, the barge season would lengthen by as much as 40%, but navigation would be more difficult with the lower water levels.

Air: The impacts on air travel have not been rigorously investigated, but decreased engine efficiency is anticipated. For smaller craft, longer seasons for the operation of float planes are likely, with conversely shorter seasons for snow and ice landing strips.

Built environment

The built environment includes homes, buildings, roads, railways and engineering structures such as dykes and pipelines. Impacts from climate change on the built environment could include changes in construction requirements, land stability (e.g., landslides and permafrost), and the frequency and intensity of floods and other extreme events.

Construction season: The length of the summer construction season is expected to increase while the length of the winter season decreases. While an advantage for southern Canada, a shortened winter season in the North will create difficulty for access (winter roads) and heavy construction since only then can heavy equipment operate safely without disturbing sensitive tundra areas.

Permafrost: Increased frost heave, thaw settlement and slope instability will negatively affect the structural integrity and design of northern construction including pipelines. Foundation conditions will change in the North as permafrost thaws, with differential settlement leading to changes in the integrity of structures, or even collapse of buildings. Utility lines and pipelines could rupture. Mining operations might become easier, but waste dumps, tailings dams, and water diversion channels would require increased and expensive maintenance.

Snow: Cost savings from projected decreased snow loadings on buildings and structures could be offset by increased wind and rain loadings and increased freeze/thaw cycles. Foundation instability may result from projections of increased winter rainfall, increased freeze/thaw cycles and drier summers.

Flooding and other extreme events: Although there remains considerable uncertainty regarding projections of changes in flooding and other extreme events, the implications, should these changes occur, warrants consideration of the impacts. The flooding of low-lying homes, docks and port facilities as well as stresses on water distribution and sewage systems caused by projected increases in sea level, extreme rain/snow fall, and spring ice jams on rivers is a major concern. Particularly vulnerable to changes in extreme events are transmission lines (e.g., wind and ice loading) and bridge piers and dams (changes in flood levels and ice jams). Increased density of population and possessions means the target of extreme events will be greater in future so that losses would be higher even without climate change. Premature structural failure due to deterioration over months and years could be accelerated where increased occurrences of such things as hours of sunshine, temperature extremes, and frequency of combined wind and rain are anticipated.

Insurance

It is anticipated that any change in the frequency or severity of such extreme events will alter demands on insurance for claim payments. This in turn affects insurance coverage and premiums under the traditional industry actuarial approach of "the past is the key to the future". Of serious concern is the possibility that abrupt climate change, resulting in more frequent claims disasters, could produce higher and more frequent claim payments before adequate reserves are built up. Thus the traditional industry approach would not have enough time to take such changes into account.

Property insurance: Property insurance is most likely to be directly affected (either restrictions in insurance coverage or steep price increases) and stronger building codes are being advocated as one means of reducing sensitivities. Among the consequences of these implications to insurance coverage may be greater public or personal responsibility to deal with natural disasters such as flood, drought, and wind storms. Also of concern is that the availability and costing of insurance will have ramifications for the viability of existing and new enterprises.

Crop insurance: Any sudden changes in the frequency or severity of extreme weather events affecting the occurrence of hail, drought, frost and excessive moisture would affect the industry. In the Prairies, it is anticipated that premiums in the agricultural sector may need to increase, with changed availability and eligibility criteria possible. Such restructuring may challenge the financial viability of agriculture and other sectors.

Marine insurance: Climate change with its possible effects on coastlines, pack ice, amount and time of ice breakup and other oceanic effects would affect the merchant fleets and the marine insurance companies that service them.

Human health

Climate change is likely to have wide-ranging and mostly adverse impacts on human health. Direct risks involve climatic factors which impinge directly on human biology. Direct health impacts of climate change include:

Heat stress: It has been suggested that an increased frequency and severity of heat waves may lead to an increase in illness and death, particularly among the young, the elderly, the frail and the ill, especially in large urban areas. A comprehensive empirical study, which examined the potential impacts of climate change on human heat-related mortality for ten cities in Canada, found that if temperatures warm as expected under $2xCO_2$ conditions, urbanized areas in southeastern Ontario and southern Quebec could be impacted. An "average" summer in the year 2050 could result in a range of 240 to 1140 additional heat-related deaths per year in Montreal, 230 to 1220 in Toronto, and 80 to 500 in Ottawa, assuming no acclimatization to increasing temperatures.

Indirect health impacts of climate change include increases in some air pollutants, pollens and mold spores, malnutrition, increases in the potential transmission of vector-borne and water-borne diseases, and impacts on public health infrastructure.

Air pollution: Respiratory disorders and allergy problems will be accentuated as heat and humidity increases, although fewer high-particulate-concentration occurrences in areas such as southern Ontario and Québec, and the Fraser Valley may reduce some smog events.

Extreme weather events: Projected increases in the frequency and severity of extreme weather events, although currently somewhat uncertain, are of concern as these changes could increase deaths, injuries, infectious diseases (e.g., contaminated runoff affecting water supplies) and stress-related disorders, as well as other adverse health effects associated with social disruption and environmentally-forced migration.

Disease vectors: It has been suggested that western equine encephalitis, eastern equine encephalitis, St. Louis encephalitis and the snowshoe hare virus would expand their ranges in Canada in response to climate change. It has also been suggested that malaria may extend northward into Canada. One study, however, noted that in temperate countries, continued and increased application of control measures, such as disease surveillance and prompt treatment of cases would probably counteract any increase in vectorial capacity. Other mosquito-borne diseases that may extend northward into Canada with climate change include dengue and yellow fever. Tick-borne diseases such as Lyme disease and Rocky Mountain Spotted Fever, may also extend their geographic distribution under climate change.

Environmental contamination: Health disorders related to environmental contamination, water contamination by bacteria *(e.g., Bacillus anthracis)*, viruses, protozoa *(e.g., Giardia lamblia, Cryptosporidium, Leptospira)* and parasites is likely to increase under climate change. Any effects of climate change on Canadian nutrition are likely to be associated with the effects on foods brought in from other countries. Food imports are likely to be associated with increases in outbreaks of some viral, parasitic and bacterial diseases, such as hepatitis A.

Public health infrastructure: There are likely to be an increased number of environmental refugees under climate change. These refugees may bring with them disease agents that are not endemic to Canada. The current Canadian public health infrastructure is also not organized to cope with changes amongst fiscal, agricultural, transportation and energy policies and how they impact health

Recreation and tourism

Tourism: Tourism destinations which rely primarily upon their natural resource base to attract visitors, such as mountains and coasts, are likely to be more at risk to climate change than those destinations which depend upon cultural or historical attractions.

Water-based recreation: Since most forms of recreation are enhanced by the presence of water, any changes in water quantity or quality due to climate change is likely to affect outdoor recreation. Sea level rise caused by climate change will affect coastal communities dependent on recreational activities. Beaches, marine wetlands, built structures and potable fresh water supplies may be affected. Fluctuating water levels can impact marinas and recreational boating activities on the Great Lakes.

Natural areas: Climate change may modify many ecosystems on which outdoor recreationalists depend on. This has implications for the amount of land devoted to parks and other natural areas the size of each individual park, park selection and designation, and boundary delineation. Climate change impacts will also affect management practices such as the content of interpretive programs, the protection of endangered species, and the determination of appropriate recreational activities.

Winter: Downhill ski areas will likely experience diminished quantities and reliability of snowcover with associated curtailments of the operating seasons of many ski areas. Ski areas may have to rely increasingly on artificial snow-making technology to retain a viable season length. Other winter activities such as cross-country skiing, snowmobiling, ice fishing and other activities dependent on snow or ice are likely to be impacted negatively.

Summer: Projections of increases in temperature may lengthen the summer sports seasons across Canada (e.g., the golfing season in Québec may be extended by up to 3 to 4 weeks). The reliable camping season in Ontario is extended under several climate change scenarios, sometimes by as much as 40 days. Hunting game and waterfowl and bird-watching are also likely to be impacted as wildlife may be displaced due to habitat loss or increased competition.

C. ADAPTATION TO CLIMATE CHANGE

There are several points that must be kept in mind when considering the extent to which adaptive strategies should be relied upon. In the first place, adaptation is not without cost and, therefore, its implementation will divert scarce natural and financial resources away from other productive activities. Canadians spend billions of dollars annually adapting to our current climate, including its variability. In addition, our climate results in a myriad of social and environmental disruptions to which we also must adapt, the "costs" of which are for the most part unknown. Adapting to changing climate will likewise "cost" Canadians, but calculating these costs will be exceptionally difficult. It is expected, however, that increases in these potential costs could be reduced if information on changes, their impacts, and viable response options was available in a timely manner (proactive opportunities) and if supportive and informative institutional and financial mechanisms were also available.

Secondly, the economic and social costs of adaptation are expected to increase the more rapidly climate change occurs. Thirdly, although many opportunities exist for technological and behavioural adaptation, uncertainties exist concerning potential barriers and limitations to their implementation. Fourthly, uncertainties exist about the efficacy and possible secondary effects of particular adaptive strategies. Fifthly, in addition to climate change, Canadians will also be dealing with major changes in technology, the economy, markets, products, and population demographics over the next century. Our adaptive responses should be integrative, not addressing simply one change but recognizing the broad spectrum of potential changes.

Finally, information on adaptation options is, in general, less often available and where it does exist, it is often subjective in nature. Interpreting a region's or sector's adaptive capacity must include rigorous research on social and cultural acceptability, as well as research on the necessary institutional and financial mechanisms to manage the change.

Water

Canadians spend close to a billion dollars in the water resources sector adapting to current climate conditions. These adaptations include the construction of dams, sewers, drainage ditches, floodways, and others. Adapting to climate change will likely increase these expenditures considerably.

Methods of adapting, in addition to increasing the capacity of the existing water infrastructure , include: the use of insurance coverage, government subsidies and disaster relief to pay for damages; bearing personal financial losses; improving public awareness concerning both the impacts of climate change and adaptation strategies; improving knowledge of water and climate linkages through further research in areas such as evapotranspiration, permafrost, groundwater, northern regions and small lakes; introducing non-structural approaches to reducing the impacts such as instituting integrated water resource management, encouraging sub-watershed planning; continuing and improving water conservation programs (e.g., behavioural change); improving zoning and building permit process; implementing water demand management (e.g., water pricing); and structural approaches such as reducing pollution; increasing municipal water supply infrastructure; making marginal changes in the construction of infrastructure (e.g. incorporate climate change scenarios); implementing more floodproofing; constructing new dams, levees, dikes, and reservoirs; continuing and improving water conservation programs (e.g. toilet dams, building code changes); and implementing natural channel design.

Ecosystems, biodiversity, wildlife and wetlands

There is considerable doubt over how specific unmanaged ecosystems will respond to climate change, especially if the amount of change is towards the high end of current projections. There is, however, no guarantee that the structure and function of future ecological communities in Canada will remain the same under the projected climate change. Humans could find it necessary to minimize the negative effects on ecosystems arising not only from climate change but also from other human-related stressors such as the acidification and long-range transport of toxic substances.

If wildlife populations decline steeply and are evidently at risk of extinction, management efforts may need to become increasingly more intrusive. Adaptation options to be considered include: creation of more and larger protected areas, connected by corridors; implementation of transplantation programs; selective breeding of parts of the population best adapted to the new climate and; off-site storage of genetic material, making up an increasingly aggressive field of "salvage ecology". Additional adaptations could include: protecting future key areas, such as areas that are likely to be flooded, and managing at a landscape level so that human activities such as forestry and agriculture can be integrated with the overall habitat considerations.

Agriculture

The assessment of adaptation strategies has mainly focused on the Prairies or the current climatic boundary of Canadian agriculture (where appropriate soils may be a limiting factor). Adaptive measures at the farm or local level that have been identified include: switching to different cultivars or introducing higher value field crops, increased use of irrigation, and diversification of farming mix to include more livestock. At the regional or national level, approaches could include: altered subsidy structures to reflect actual climate risk, crop assistance programs linked to soil conservation, and strengthened rural education programs to encourage sustainable land use practices.

Forestry

The adaptability of the forestry sector is dependent on the industry ability and willingness to adapt to whatever species do prevail as a consequence of climate change, to salvage-cut dying stands, to plant cut areas with species better adapted to the altered climate, and to move to locations where resources are more plentiful. Confidence in the industry's ability to adapt is, in part, a reflection of the expectation that future impacts will be simply extensions of the types of conditions currently dealt with - that is, same problems, different locations and extent. Adaptation, in addition to considering the social and environmental costs, will have to address such important issues as: increasing forest landscapes to reduce fragmentation, managing stands and landscapes to reduce crown and large area fires, and developing ways to maintain landscape corridors.

Fisheries

Fisheries adaptation options that would respond to climate change have, for the most part, been used previously in response to other environmental or use changes and each has limitations, typically assuming orderly change. As such, considerations in the development of adaptation options include: recognition of the possibility of an increased rate of change and the potential of surprises; need for close ties with sustainable ecosystem use objectives; need for responses at the local level to minimize negative impacts and maximize gains while aiming for a net gain overall; robust management regimes which balance long and short term views; and an ecosystem-centred "no regrets" approach wherein all stresses are reduced.

Energy

Historically, the energy industry has been able to adapt fairly successfully to changes in supply and demand, and to tackle new challenges such as the search for oil and gas under ice-covered waters through innovation. As a result, the adaptation capacity of the energy sector is considered to be high, particularly if the projected changes occur relatively slow and if the industry is not faced with surprises. Altered design criteria, energy conservation, and the use of alternatives (such as solar and wind) are among the expected adaptive responses.

Built environment

In many existing cases, the current margin of safety built into the National Building Code will likely be sufficient to maintain safe and economical structures, given good workmanship and materials. Some upgrading and/or moving of facilities and structures (such as riverine flood control systems), although costly, may be necessary. In order to limit further development in damage-prone areas, strengthening of land use planning regulations may be necessary. Where new construction is involved, altered design criteria and siting to reflect changing climate conditions should be implemented. Particular emphasis should be given to structural safety under extreme weather situations, energy conservation, and the minimization of life cycle costs of buildings and structures. For addressing coastal retreat due to sea-level change, coastal zone management that weighs the relative merits of engineering and natural should be part of adaptive strategy considerations.

Insurance

Weather modification activities such as cloud seeding in the Prairies have been funded by the industry to try to reduce hail damage and payouts by the insurance industry. Research has been funded into improving building materials, methods and lobbying for improved building codes in Canada to reduce risks. Individual insurance companies may change terms of coverage by: limiting the number of policies written and dollar coverage provided in a specific geographic area, reducing policy limits, increasing deductibles, changing payment terms, changing rules as to what risks can be covered, withdrawing from the market entirely and, spreading the risk through reinsurance.

Human health

Gradual physiological acclimatization of populations, the use of air conditioning, and an adequate hot weather warning system may reduce heat-related morbidity and mortality in the future. Although climate change may extend the range northward of various vectors such as malaria, a responsive Canadian health infrastructure may be able to prevent a large increase in number of actual disease cases.

Recreation and tourism

Recreationalists have a substantial potential to adapt to climate change since their participation is a result of choice and, although choices are not unconstrained, a great deal of flexibility is involved. Participants may be able to substitute or shift recreational activities and locations without a great deal of loss in the quality of their recreation.

The industry may be able to adapt by diversifying the types of recreational activities to ensure that investments in property and infrastructure generate incomes for much of the year. Examples include the construction of water slides that take advantage of existing ski lifts in the summer, provision of golf courses, hiking trails and swimming pools, construction of condominiums to build a reliable year-round clientele, and the addition of multi-functional facilities (e.g., combinations of recreational and conference facilities). Such strategies can reduce the seasonality of recreational enterprises and provide more reliable employment thereby strengthening surrounding communities and take advantage of possible increases in the length of summer under climate change.

Transportation

Climate is an important consideration in transportation activities. Transport industries, government agencies, and the Canadian public expend considerable effort and substantial sums of money (hundreds of millions of dollars annually) to reduce the risk of delay or incident due to inclement weather. No comprehensive inventory of these various adaptations exists, however, and the effectiveness of many of these measures is largely unknown.

Geographic Focus: Conduct studies in regions lacking attention in the necessary scientific research. Among those identified are: Eastern Arctic, British Columbia interior, the central Prairies, Northern Ontario and Labrador, and urban areas and their infrastructure.

Water: Generate more plausible scenarios of extreme events for hydrologic and river basin sensitivity analyses; use deterministic models to assess the hydrologic impacts of climate change; improve estimation of evapotranspiration rates related to vegetation changes due to climate change; conduct empirical analyses of climatological and ecological processes in high-elevation mountainous areas to improve knowledge of impacts on snow accumulation processes under climate change; assess impacts of El Niño and La Niña events on Canadian runoff/streamflow; assess impacts of climate change on water quality, small lakes, lake ice and groundwater in Canada; conduct more research on water resources uses and adaptation for agriculture, fisheries, recreation and tourism, hydrological power, commercial navigation, municipal water supply and human health and; identify methods to include climate change information into long-term water resources planning and management.

Ecosystems, biodiversity and wildlife: Continue and expand long-term multi-disciplinary monitoring and research on fundamental ecological conditions and trends in Canada; improve understanding of changes in basic physical parameters of oceans such as water temperature, salinity and ocean currents; improve life histories knowledge of fish and other marine organisms to understand impacts of climate change and variability; conduct long-term experiments on the effects of elevated CO2 on ecosystems such as grasslands, tundra and forests; continue study of plant-herbivore and other trophic-level interactions under increased CO2 conditions; improve understanding of the mechanisms regulating biogeochemical cycling and biological productivity; determine effects of soil feedbacks and biological interactions between different organisms on direct ecophysiological effects of changes in climatic variables; improve knowledge of natural patterns of genetic diversity in Canada; determine the diversity and sensitivity of soil microbes and nonvascular plants to climate change; conduct integrative studies of ecosystem-level behaviours and; improve understanding of the overall effects of climate on wildlife population dynamics.

Wetlands: There are still major gaps in our understanding of wetlands and their likely responses to climate change. Wetlands lag behind other ecosystems in being adequately modelled and are often excluded from global models of the effect of climate change. Research is needed on the hydrogeochemical processes of wetlands and on inter-relationships between water levels and wetland vegetation and areal responses. Simulations of habitat changes associated with climate change are needed to understand the potential changes in wetland numbers and quality and the impact on waterfowl production and biodiversity. Work also needs to be done in establishing the area, depths and types of peatlands as well as their carbon storage capabilities and their responses to climate change especially of methane and carbon dioxide. Climate models should be used in conjunction with other models such as those for precipitation, runoff and groundwater to assist in estimating consequences of climate change for wetlands in Canada and the functions and values they provide.

Agriculture: Standardize research utilizing a common set of climatic and crop productivity models for all regions of Canada to generate more easily comparable results in terms of climate change impacts on crop yields; further assessment of the economic impacts of climate change at various agricultural scales (*e.g., farm, regional, national)* and for different crop and livestock operations; improve the understanding of farm and agricultural adaptation by effectively integrating agro-climatic indicators which farmers identify as important in their decision-making into the climate change scenarios and; determine the implications of climate change on Canadian agriculture in the context of changing global agricultural commodity markets.

Fisheries: Conduct comparative studies of aquatic ecosystems and fish populations across latitudinal and altitudinal gradients; increase understanding of factors determining fish distributional patterns; improve life-history knowledge of salmonids which are especially vulnerable to climate change; monitor biological responses and ecological climate indicators in representative aquatic ecosystems with significant fisheries; improve understanding of linkages between climate and variations in marine productivity; improve understanding of roles of nutrient, light, thermal and mixing regimes in freshwater ecosystems in determining fish productivity; improve basic knowledge of Arctic marine and freshwater biota life histories and productivity levels; assess impacts of sea level rise and river discharge declines in estuaries; improve estimates of ecosystem and fishery carrying capacities; improve measures and valuations of subsistence and native fisheries.

Forestry: Improve knowledge of the relationship between climate and tree growth in order to better predict physiological climate thresholds for mature trees; improve knowledge on the carbon, methane, and nitrogen cycles and the interaction between the soil ecosystem's physical *(e.g. surface albedo, temperature profile)* and biological processes *(e.g. nutrient cycling, decomposition)* in order to improve current biological models; standardize and improve monitoring to include data on species composition, the rate and location of deforestation, improved measurements of hydrological interactions; forest biomass growth, mortality, and disturbance would contribute to better vegetation and carbon sequestering models; improve the interaction of climatic and biological models by establishing links through biochemical processes to better simulate carbon and nitrogen cycling; develop models which include non-climatic factors to determine the role which climate change will play in affecting future forest management practices and; develop models of ecotones and their responses to climate change to describe the transition phase of climate change, and the continual and compounded changes in atmospheric conditions and their dynamic relationship to ecological processes.

Energy: Improve knowledge of regional distribution and intensity of climate change since Canada's climatic diversity has direct impacts on how energy is produced, transmitted and used; assess the sensitivity of energy supply and demand to climate change; focus research more on adaptation measures rather than mitigation measures for the energy sector; improve cost estimates of impacts and adaptation measures; utilize a more integrated approach in research, addressing technological, social and economic issues between sectors.

Transportation: Conduct more detailed impact analyses on the implications of climate change on all dominant models of transport in Canada (automobile travel, trucking, rail, air, coastal marine); further address the issue of extreme weather events and impacts on transportation safety; determine impacts of climate-induced changes in regional economies and settlement patterns on transport demand and; inventory and evaluate the various adaptations available for the transportation sector.

Built environment: Improve collection and analyses of climate design data needed for the construction industry, especially wind-driven rain, solar radiation, snow loads and extreme weather events; assess impacts of climate change on energy efficiency (insulation) and energy use (air conditioning, space heating) of buildings; improve understanding of changes in permafrost due to climate change and impacts on building foundations, infrastructure and existing and new construction and ; improve knowledge of extreme weather events to reduce damage through more resistant building designs and avoidance of high-risk regions.

Insurance: Improve understanding of the potential effects of climate change on the property and casualty industry in Canada; improve predictions on how climate change will affect the number of catastrophic weather events, including associated landslides and snow avalanches; develop better models to determine the impacts of climate change (higher temperatures and severe weather) on mortality rates in Canada.

Human health: Improve data collection on geographic trends in the distribution and abundance of insect vectors of disease in Canada; improve surveillance and monitoring of the distribution and abundance of anopheline mosquitoes that carry malaria and the migration of deer mice that carry the hantavirus; determine the impacts of climate change on human behaviour such as the use of air conditioning, increase in aggressive actions.

Recreation and tourism: Assess the implications of climate change for natural area designation and management; assess the means by which recreational provisions can be diversified to reduce vulnerability; assess how alternative recreational opportunities are evaluated by potential participants; evaluate the role of extreme weather events in influencing recreational provision and; assess the importance of climate vs. non-climate variables on the location and types of recreational activities; assess current lengths of operating seasons, their temporal and spatial variability, and the associated economic viability of recreation businesses.